ENVIRONMENTAL SCIENCE AND ENGINEERING

UNCCD

World Meteorological Organization

Mannava V.K. Sivakumar · Ndegwa Ndiang'ui (Eds.)

Climate and Land Degradation

Springer

Environmental Science and Engineering
Subseries: Environmental Science

Series Editors: R. Allan • U. Förstner • W. Salomons

Tanzania Meteorological Agency (TMA)

United Nations Convention to Combat Desertification (UNCCD)

World Meteorological Organization (WMO)

Mannava V. K. Sivakumar · Ndegwa Ndiang'ui (Eds.)

Climate and Land Degradation

With 192 Figures and 61 Tables

Springer

Mannava V.K. Sivakumar
Agricultural Meteorology Division
World Meteorological Organization
7bis Avenue de la Paix
P.O. Box 2300
1211 Geneva 2, Switzerland
E-mail: msivakumar@wmo.int

Ndegwa Ndiang'ui
Committee on Science and Technology (CST)
United Nations Convention to Combat Desertification
Hermann - Ehlers - Str. 10
D-53113 Bonn
Germany
e-mail: nndiangui@unccd.int

ISSN 1863-5520
ISBN 10 3-540-72437-0 Springer Berlin Heidelberg New York
ISBN 13 978-3-540-72437-7 Springer Berlin Heidelberg New York

Library of Congress Control Number: 2007931628

Cover design: deblik, Berlin
Production: Agata Oelschläger
Typesetting: Satz-Druck-Service (SDS), Leimen
Printed on acid-free paper 30/2132/AO 5 4 3 2 1 0

Foreword

Desertification is one of the most alarming processes of environmental degradation. It is about land degradation: the loss of the land‘s biological productivity, caused by human-induced factors and climate change, affecting one-third of the Earth‘s surface and over a billion people. Moreover, it can have devastating consequences in terms of social and economic costs.

The impacts of land degradation on global food security and the quality of the environment are of major significance and concern when one considers that only about 11% of the global land surface can be considered as prime land, yet this must feed the 6 billion people inhabiting the World today and the 8.2 billion expected by the year 2020. Long-term food productivity is threatened by soil degradation, which is now severe enough to reduce crop yields on approximately 16% of the agricultural land, especially in Africa and Central America, as well as the African pastures. The rate of land degradation is highest in Sub-Saharan Africa, where it is estimated that losses in productivity of cropping land are in the order of 0.5-1 % annually, suggesting a cumulative loss of at least 20% over the last 40 years.

Sustainable development of countries affected by drought and desertification can only come about through concerted efforts based on a sound understanding of the different factors that contribute to land degradation around the World. Climatic variations are recognized among the major factors contributing to land degradation, as defined in the United Nations Convention to Combat Desertification (UNCCD), and it is important to understand the respective roles of the different climatic factors in land degradation. For example, development and adoption of sustainable land management practices are among the major solutions adopted to combat land degradation over drylands, but to accurately assess sustainable land management practices, the climate resources and the risk of climate-related or climate-induced natural disasters must be well known for a given region.

Only when climate resources are paired with potential management or development practices can the land degradation potential be assessed and appropriate mitigation technologies be developed. The use of climate information must be applied effectively in developing sustainable practices, since climatic variation is one of the major factors contributing to or even acting as a trigger to land degradation. There is therefore a clear need to consider carefully how climate can induce and influence land degradation.

The World Meteorological Organization (WMO) contributes to the understanding of the interactions between climate and land degradation through dedicated observations of the climate system; improvements in the application of agrometeorological methods and the proper assessment and management of water resources; advances in climate science and prediction; and promotion of capacity building in the application of meteorological and hydrological data and information in drought preparedness and management. However, much more needs to done, such as the promotion of further interest and research in this topic.

At its 58th ordinary session, the UN General Assembly declared 2006 to be the International Year of Deserts and Desertification (IYDD). In doing so, the General Assembly underlined its deep concern for the exacerbation of desertification, particularly in Africa, and noted its far-reaching implications for the implementation of the Millennium Development Goals (MDGs), which must be met by the year 2015. Accordingly, the IYDD presents a golden opportunity to get the message across, strongly and effectively, that Desertification is a global problem that we can only ignore at our own peril. It also offers an impulse to strengthen the visibility and importance of the drylands issue on the international environmental agenda, while providing a timely reminder to the international community of the immense challenges that still lie ahead.

In recognition of the importance of climatic factors in land degradation, the Seventh Session of the Conference of Parties (COP-7) to the UNCCD accorded priority to climate issues in land degradation in the future work of the Committee on Science and Technology (CST) of the Convention, inviting WMO to organize and find the necessary funding for an International Workshop on Climate and Land Degradation in 2006, in the spirit of implementation of the International Year of Deserts and Desertification (IYDD) and also asking CST to assist WMO in finding experts for this workshop.

It is with this background that WMO, the UNCCD Secretariat and the Tanzania Meteorological Agency jointly organized in Arusha (Tanzania), from 11 to 15 December 2006, the International Workshop on Climate and Land Degradation. The workshop, which was cosponsored by the Organization of the Petroleum Exporting Countries (OPEC) Fund for International Development (OFID), the United Nations Development Programme (UNDP) and the United Nations Educational, Scientific and Cultural Organization (UNESCO), focused the way that climate induces and influences land degradation and what measures need to be taken in order to enhance the applications of weather and climate information to combat land degradation.

We hope that the papers presented in this book will serve as a significant source of information to the CST as well as to all agencies and organizations involved in designing and implementing appropriate strategies for sustainable land management to arrest land degradation.

M. Jarraud
Secretay-General
World Meteorological Organization

Hama Arba Diallo
Executive Secretary
Secretariat of the Convention
to Combat Desertification

Preface

Land degradation is a threat to natural resources with consequences on food security, poverty, and environmental and political stability. The increasing occurrence of climate extremes (for example heat waves, droughts, heavy precipitation) is having an impact on land degradation processes, including floods, mass movements, soil erosion by water and wind and salinization in all parts of the globe. Climate variability, climate change and land degradation are intimately linked and are generating unexpected effects, for example, an increased occurrence of weather conditions that are suitable for a fire to start, or to propagate in the wild, in large parts of the globe. Sustainable development of countries affected by drought and desertification can only come about through concerted efforts based on a sound understanding of the different factors including climatic variations that contribute to land degradation around the world.

To address these key issues, experts from around the world were brought together at an International Workshop on Climate and Land Degradation which was held in Arusha, United Republic of Tanzania from 11 to 15 December 2006. The workshop focused on how climate induces and influences land degradation and what measures need to be taken to enhance the application of weather and climate information to combat land degradation. The workshop was organized by the World Meteorological Organization, the United Nations Convention to Combat Desertification (UNCCD) and the Tanzania Meteorological Agency and was co-sponsored by the OPEC Fund for International Development (OFID), the United Nations Development Programme (UNDP) and the United Nations Educational, Scientific and Cultural Organization (UNESCO).

Specific objectives of the Workshop were:

- To survey the status of, and summarize the information on, trends in land degradation at national and regional levels;
- To review and assess the extent to which weather and climate data and information are currently used at the national and regional levels in order to adequately monitor and assess land degradation and to develop sustainable land management practices to combat land degradation;
- To provide recommendations on appropriate strategies for reducing land degradation through more effective use of weather and climate information and applications;
- To assess the historic loss of terrestrial carbon pool due to land degradation, and estimate the potential of carbon sequestration in soil/terrestrial ecosystems through soil restoration and desertification control;

- To assess the feasibility of restoring degraded/desertified lands with a view to achieving food security in the affected developing countries;
- To document case studies of successful measures to manage land use, protect land and mitigate land degradation;
- To suggest ways and means of improving the implementation of the National Action Programmes (NAPs) through the effective use of early warning.

Sixty four participants from 30 countries and 5 UN agencies (WMO, UNCCD, FAO, UNDP, UNEP) presented state-of-the-art papers, real world applications and innovative techniques for combating land degradation, and offered recommendations for effectively using weather and climate information for sustainable land management practices.

Altogether there were 9 sessions (including the opening and closing session) in the workshop during which 34 invited papers were presented addressing the different specific objectives of the workshop. All the participants in the workshop were engaged in discussions on these papers and developed several useful recommendations for all organizations involved in promoting climate prediction and applications in agriculture, and in combating land degradation particularly in the developing countries.

This volume includes 33 invited papers presented at the workshop, the conclusions and recommendations that emerged out of the working group discussions and the final workshop statement. As editors of this volume, we would like to thank all the authors for their efforts and for their cooperation in bringing out this volume in time. We are most grateful to Mr. M. Jarraud, the Secretary-General of WMO and Mr Arba Diallo, Executive Secretary of the UNCCD for their continuous support and encouragement.

Mannava V. K. Sivakumar
Ndegwa Ndiang'ui
Editors

Contents

List of Contributors

Juliana J. Adosi
Tanzanian Meteorological Agency
P.O. Box 3056
Dar Es Salaam, United Republic of Tanzania
E-mail: julianaadosi@yahoo.com

Vesselin Alexandrov
National Institute of Meteorology
and Hydrology
66 Tsarigradsko shose
BG-1784 Sofia, Bulgaria
E-mail: vesselin.alexandrov@meteo.bg

Hossein Badripour
Forest, Range and Watershed Management
Organization
No. 31, West Zartosht St.
Tehran, Islamic Republic of Iran
E-mail: badripour@yahoo.com

Gertjan Beekman
Inter-American Institute for Cooperation
in Agriculture (IICA)
SHIS QI 23, Conj. 8, casa 10 Lago Sul
71660080 Brasilia, Brazil
E-mail: gbbeekman@yahoo.com or gertjan.
beekman@iica.int

Viorel Blujdea
Forest Research and Management Institute
Sos. Stefanesti 128
077190 Voluntari, Romania
E-mail: viorel_b@yahoo.com

John Carter
Queensland Climate Change Centre
for Excellence
Indooroopilly Queensland 4068, Australia
E-mail: john.carter@climatechange.qld.gov.
au

Reagan Chunga
Integrated Environmental Consultants
Namibia (IECN)
P.O. Box 86634
Eros, Windhoek, Namibia
E-mail: r.chunga@iecn-namibia.com

Michèle Clarke
University of Nottingham
Nottingham G7 2RD, United Kingdom
E-mail: Michele.clarke@nottingham.ac.uk

Roger Concepcion
Bureau of Soils and Water Management
(BSWM)
Department of Agriculture
BSWM Bldg., Elliptical Road
Diliman, Quezon City, Philippines 1101
E-mail: bswm@pworld.net.ph

Ken Day
Queensland Climate Change Centre
for Excellence
Indooroopilly Queensland 4068, Australia
E-mail: ken.a.day@climatechange.qld.gov.au

Paul C. Doraiswamy
United States Department of Agriculture
Agricultural Research Service
Beltsville, MD 2075, USA
E-mail: pdoraisw@asrr.arsusda.gov

Opha Pauline Dube
University of Botwana
Gaborone, Botswana
E-mail: DUBEOP@mopipi.ub.bw

M Easter
The Natural Resources Ecology Laboratory
Colorado State University
1499 Campus Delivery, Fort Collins
Colorado 80523, USA
E-mail: marke@nrel.colostate.edu

Sue Edwards
Institute for Sustainable Development
P.O. Box 171, code 1110
Addis Ababa, Ethiopia
E-mail: sustaindeveth@ethionet.et or sustainet@yahoo.co.uk

Ismail H.M. El-Bagouri
Desert Research Center (DRC)
1 El-Mathaf St Matariah
Cairo, Egypt
E-mail: bagouri38@yahoo.com

Alan Franzleubbers
United States Department of Agriculture (USDA),Agricultural Research Service
1420 Experiment Station Road
Watkinsville, Georgia 30677-2373, USA
E-mail: afranz@uga.edu

Rodrigo U. Fuentes
Environment Section
Environment and Sustainable Development Division, 5th Floor, UN Building
Rajadamnern Nok Ave
10200 Bangkok, Thailand
E-mail: fuentesrod@gmail.com

Bradwell J. Garanganga
SADC Drought Monitoring Centre
SADC Secretariat
Private Bag 0095, Gaborone, Botswana
E-mail: bjgarangan@yahoo.co.uk

Juan Jesus Torres Guevara
Nacional Agricucultural University
La Monlina, Peru
E-mail: uchuguilla1952@yahoo.com

Beverley Henry
Department of Natural Resources and Water
80 Meiers Rd, Indooroopilly
Queensland 4068, Australia
E-mail: Beverley.henry@nrw.gov.au

Ma Hong
State Laboratory for Remote Sensing and Information Techniques
Institute of Forest Resource Information Technologies
Chinese Academy of Forestry, Haidian District
Beijing, China
E-mail: lilee@sogou.com/mahong@caf.ac.cn

Moshe Inbar
University of Haifa
Haifa 31905, Israel
Email : inbar@geo.haifa.ac.il

Hongbo Ju
Asian Thematic Programme Network on Desertification Monitoring & Assessment (TPNI) Task Manager
State Laboratory for Remote Sensing and Information Techniques
Institute of Forest Resource Information Technologies
Chinese Academy of Forestry
Haidian District
Beijing, China
E-mail: ju@caf.ac.cn

K Killian
The Natural Resources Ecology Laboratory
Colorado State University
1499 Campus Delivery, Fort Collins
Colorado 80523, USA
E-mail: kendrick@nrel.colostate.edu

Cosimo Lacirignola
CIHEAM Mediterranean Agronomic Institute of Bari
Via Cegli 9, 70010 Valenzano (BA), Italy
E-mail: lacirignola@iamb.it

Nicola Lamaddalena
CIHEAM Mediterranean Agronomic Institute of Bari
Land and Water Department
Via Cegli 9, 70010 Valenzano (BA), Italy
E-mail: lamaddalena@iamb.it

Giuliana Trisorio Liuzzi
CIHEAM/University of Bari
Faculty of Agriculture
Via Amendola 165/A, 70126 Bari, Italy
E-mail: giuliana.trisorio@agr.uniba.it

Eliakim E. Matari
Tanzania Meteorological Agency
P.O. 3056
Dar Es Salaam, United Republic of Tanzania
E-mail: ematari@meteo.go.tz

Greg McKeon
Queensland Climate Change Centre
for Excellence
Indooroopilly Queensland 4068, Australia
E-mail: greg.mckeon@climatechange.qld.gov.au

Mohamed S. Mhita
Tanzania Meteorological Agency
P.O. 3056
Dar Es Salaam, United Republic of Tanzania
E-mail: mmhita@meteo.go.tz

Dora Velásquez Milla
CIZA UNALM and CCTA
Camilo Carrillo 300 A
Jesús María – Lima, Perú.
E-mail: doravelasquez@yahoo.com

Eleanor Milne
Rm 111, Department of Soil
and Crop Sciences
Colorado State University
1170 Campus Delivery
Fort Collins, Colorado 80523-1170, USA
E-mail: emilne@lamar.colostate.edu

Josephine Philip Msangi
Faculty of Agriculture and Natural Resources
University of Namibia, Private Bag 13301
Windhoek, Namibia
E-mail: jpmsangi@unam.na

Luca Montanerella
European Commission
Joint Research Center
T.P. 280, I-21020 ISPRA (VA), Italy
E-mail: luca.montanarella@jrc.it

R.S. Muyungi
Vice Presiden't Office
Division of Environment
P.O. Box 5380
Dar Es Salaam, United Republic of Tanzania
E-mail: tanzania37@hotmail.com

Ndegwa Ndiang'ui
Committee on Science and Technology (CST)
United Nations Convention
to Combat Desertification
Hermann - Ehlers - Str. 10
D-53113 Bonn, Germany
E-mail: nndiangui@unccd.int

Paul Novelly
Department of Agriculture
and Food Western Australia
Frank Wise Institute, P.O. Box 19
Kununurra WA 6743, Australia
E-mail: pnovelly@agric.wa.gov.au

K Paustian
The Natural Resources Ecology Laboratory
Colorado State University
1499 Campus Delivery, Fort Collins
Colorado 80523, USA
E-mail: keithp@nrel.colostate.edu

David Rayner
Queensland Climate Change Centre
for Excellence
Indooroopilly Queensland 4068, Australia
E-mail: david.rayner@climatechange.qld.gov.au

Helen Rendell
Loughborough University
Loughborough LE11
United Kingdom
E-mail: H.M.Rendell@lboro.ac.uk

Uriel Safriel
9920 Alta-Springs Way
Rockville, MD 20850
United States of America
E-mail: uriel36@gmail.com

Fernando Santibanez
University of Chile
Centre on Agriculture and Environment
Santa rosa 11315, Santiago, Chile
E-mail: fsantiba@uchile.cl

Paula Santibáñez
University of Chile
Doctorate on Agrarian
and Veterinarian Sciences
Santa rosa 11315, Santiago, Chile
E-mail: psvsantibanez@gmail.com

Mohamed F. Sessay
UNEP, Division of GEF Coordination
Regional Office for Africa
P.O. Box 30552
Nairobi, Kenya
E-mail: Mohamed.Sessay@unep.org

Roy C. Sidle
Geo-hazards Division
Disaster Prevention Research Institute
University of Kyoto
Gkasho, Uji
Kyoto 611-0011, Japan
E-mail: sidle@slope.dpri.kyoto-u.ac.jp

Reuben Sinange
P.O. Box 19823 - 00200
Nairobi, Kenya
E-mail: reubensinange@yahoo.com

Mannava V.K. Sivakumar
Agricultural Meteorology Division
World Meteorological Organization
7bis Avenue de la Paix
P.O. Box 2300
1211 Geneva 2, Switzerland
E-mail: msivakumar@wmo.int

Jozef Syktus
Queensland Climate Change Centre
for Excellence
Indooroopilly Queensland 4068, Australia
E-mail: jozef.syktus@climatechange.qld.gov.au

Robert Stefanski
Agricultural Meteorology Division
World Meteorological Organization
7bis Avenue de la Paix
P.O. Box 2300
1211 Geneva 2, Switzerland
E-mail: rstefanski@wmo.int

Leo Stroosnijder
Wageningen University
Soil Science Center, P.O. Box 47
6700 AA Wageningen, Netherlands
E-mail: Leo.Stroosnijder@wur.nl

Anna Tengberg
Regional Centre for Asia
and the Pacific
c/o of UNDP, GPO Box 618
Bangkok, Thailand
E-mail: Anna.Tengberg@unep.org

L. Thiombiano
Soil Resources
FAO, Regional Office for Africa
P.O Box 1628, Accra, Ghana
E-mail:Lamourdia.Thiombiano@fao.org

F. Faustine Tilya
Tanzania Meteorological Agency
Data Services, P.O. Box 3056
Dar Es Salaam, United Republic of Tanzania
E-mail: ftilya@meteo.go.tz

Svanhild-Isabelle Batta Torheim
Development Fund
Grensen 9b, 0159 Oslo, Norway
E-mail:bell@u-fondet.no

Ignacio Tourino-Soto
International Water Management Institute
Africa Regional Office
PMB 112, Cantonments, Accra, Ghana
E-mail: i.tourino@cgiar.org / nacho_tourino@yahoo.fr

IW Watson
Department of Agriculture & Food
Western Australia
Northam WA 6401, Australia
E-mail: iwatson@agric.wa.gov.au

Pandi Zdruli
Land and Water Department
CIHEAM-Mediterranean Agronomic
Institute of Bari
Via Ceglie 9, 70010 Valenzano (BA), Italy
Email: pandi@iamb.it

Julianne Zeidler
Integrated Environmental Consultants
Namibia (IECN)
P.O. Box 86634, Eros
Windhoek, Namibia
E-mail: j.zeidler@iecn-namibia.com

CHAPTER 1

The Assessment of Global Trends in Land Degradation

Uriel N. Safriel

Abstract. The motivation for quantitative assessment of land degradation at a global scale is its recognition as an environmental issue of global societal implications. Yet, due to the non-robust definition of "land degradation" and to the paucity of field data, the five global assessments carried out and presented between 1977 and 2003 differ in the selection of measurable attributes of land degradation, in the quality of the data sets, and in their spatial coverage. This resulted in a plethora of degradation estimates ranging 15% to 63% of global degradation and 4% to 74% of dryland degradation. Of these, the figure of 70% degradation (for the drylands only, comprising 41% of global land) has been cited more than the others. Though likely to be overly exaggerated (because it stands for a combination of degradation degree of a land unit and its spatial extent within the mapping unit of which it is a part), this high estimate has apparently served well the globality notion of the dryland degradation syndrome, essential to rallying support for international development assistance under the UNCCD. This thirst for development assistance aimed at "combating desertification" attracted to the UNCCD some 70 non-dryland developing countries (compared to 93 developing dryland country Parties) which experience land degradation that is not included in global assessments of desertification, since only dryland degradation qualifies as "desertification". The texts of the various assessments, including that of GLASOD as well as the UNCCD definition often trade off "desertification" with "susceptibility" to or "threat" of desertification. This suggests that an assessment of vulnerability to desertification rather than its actual occurrence are of higher credibility and utility for policy- and decision-making.

Though soil degradation featured highly in the currently available global degradation assessments, remotely-sensed vegetation attributes not only assess the most valued but threatened ecosystem service, but are also amenable for assessment at the global scale. However, caution is required when using this tool especially in drylands where productivity is tightly linked to rainfall variations. The monitoring required to meet the persistence criterion for qualifying desertification can be also used to detect current desertification trends, which are of relevance for policy-making even more than defining current desertification status. To discern changes of productivity due to state of the land from those due to rainfall features, the ratio of NPP to rainfall (RUE) could be useful were it not negatively correlated with rainfall itself. An alternative method for detecting degradation trends, the Residual NPP Trends (RESTREND) is currently under development. It is based on an analysis of the residuals of the productivity-rainfall relationship throughout a time period for each pixel in the explored region. A sta-

tistically significant negative regression of the residuals on time identifies a degradation trend, and the slope stands for its magnitude. To be reliable on a global scale such a remote-sensing approach would serve for guiding field observations required for its own verification.

1.1 Introduction

1.1.1 Land degradation – what is it and how is it assessed

It is difficult to trace the origin of the term "land degradation", a currently widely used term which assumes diverse, overarching definitions. An international legally-binding definition, that of the United Nations Convention to Combat Desertification (UNCCD) which entered into force in December 1996, describes "Land" as a *"terrestrial bio-productive system that comprises soil, vegetation, other biota, and the ecological and hydrological processes that operate within the system"*, and its "degradation" as *"reduction or loss … of the biological … productivity, … resulting from land uses, … or combination of … processes, such as… soil erosion … deterioration of … properties of soil … and long-term loss of natural vegetation"*. Applying the more recent conceptual framework of the Millennium Ecosystem Assessment (Millennium Ecosystem Assessment 2005a), the above rather cumbersome definition of "land" can be shortened to *"A terrestrial ecosystem"*, and "land degradation" – to *"reduction or loss of ecosystem services, notably the primary production service"* (Safriel and Adeel 2005). This is portrayed in Figure 1.1, featuring components of terrestrial ecosystems relevant to "land degradation" – soil, and its vegetation cover (be it grass, shrubs or trees) and "land degradation"-relevant services of such ecosystems; their linkages (e.g. the food provisioning service that is supported by the primary production service) and inter-linkages (e.g. between soil and vegetation cover) impinge on the people whose livelihood and hence well-being directly depend on the pivotal ecosystem service of primary production.

Thus, "land degradation" has validity only in the social context of human benefit derived from use of ecosystems by people (Blaikie and Brookfield 1987). It can therefore be assessed by the effect of this use on the service of primary production, which generates products of biological origin, on which much of human well-being depends. Accordingly, the degree of "ecosystem health" or its counteracting process of "land degradation" is often derived directly by assessing the soil, the vegetation cover or primary productivity itself. This is because each of these is a correlate of the other. Land degradation can be also indirectly inferred by assessing crop production (e.g. the food provisioning service), or even by using indicators of human well-being.

Earlier land degradation assessments evaluated soil parameters, whereas vegetation assessment and especially assessments of primary production have recently become more common. But since the functional relations between soil and vegetation parameters may not be linear (Prince 2002), the values for "land degradation" of a site may vary according to the variable chosen to represent it.

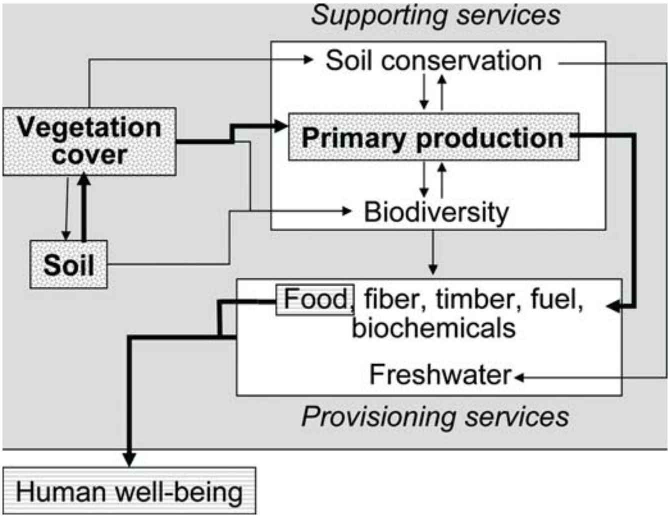


Fig. 1.1. Linkages within and between supporting and provisioning services (blank rectangles) of a terrestrial ecosystem (the grey rectangle), and between the ecosystem and human well-being. The states of vegetation cover and of soil (dotted rectangles) are direct indicators of land state (degraded or not degraded); the states of food provision and human well-being (stripped rectangles) are indirect indicators of land state. Thick arrows highlight a path linking the state of soil to state of human well-being.

1.1.2 The need for assessment at a global scale

Land degradation, expressed in soil salinization and water-logging (driven by over-cultivation and mismanagement of river courses) and soil loss (driven by overgrazing and deforestation), was implicated for the demise of ancient civilizations in both the old and the new world, and for 20th century human suffering in industrial (e.g. the US "dust bowl" of the 30s) and developing (e.g. the Sahel droughts of the 70s and the 80s) countries (Dregne 1983; Hillel 1991; Oldeman et al. 1991; Diamond 2005). Vivid qualitative descriptions of such events are common, though their extent in terms of degraded lands and affected populations have rarely been satisfactorily quantified.

The motivation for quantitative assessment of land degradation, and at a global rather than a local scale or even a regional scale, was the recognition of the environment-development interlinkages, emerging during the second half of the 20th century (WCED 1987). This realization, that intensified development reduces the potential of the environment to support it was amplified by the emergent recognition that many of the environmental as well as their coupled social problems, are of a trans-boundary nature, and therefore addressing them requires attention at regional, and often even at global, rather than just at the local scale (e.g. Agenda 21 (UN 1993)).

These realizations have apparently been instrumental in processes (e.g. the United Nations Conference on Desertification, UNCOD) leading to negotiating and adopting legally-binding global, international agreements. Most notable in this context are the three "Rio Conventions", which among other things, address land degradation, either directly (UNCCD) or indirectly (Convention on Biodiversity (CBD) and the United Nations Framework Convention on Climate Change (UNFCCC)). The pragmatic thrust of these three conventions, is the implicit and often explicit distinction they make with regard to obligations, between industrial and developing countries. Among other things, the industrial ones are expected to assist the developing ones in addressing their environmental problems, including land degradation; at least implicitly, "their" environmental problems are "ours" too, due to their global nature.

The response of three major stakeholders to this distinction was conducive for initiating assessments of land degradation and its social implications at a global, rather just a local scale. Developing country parties of UN conventions were motivated not only to define and quantify the geographical and population extent of problems within their boundaries, but also impress the developed country parties about the globality of their problems (e.g. Chasek and Corell 2002). When confronted with this claim, developed country parties required tools for reliably qualifying land degradation. A third stakeholders group is the specialized agencies and programs of the United Nations system, UN-associated entities and other international bodies involved in coordination and implementation of international development assistance. Striving to expand and invigorate their activities, these have also been instrumental in promoting the notion of land degradation as a syndrome of a global impact, thus advocating for its inclusion in their mandates.

Thus, by the 80s of the 20th century the ground was ripe for initiating efforts to assess land degradation on a *global* scale. It was implicitly assumed that a global assessment, which would of course be based on local assessments spanning over the globe, would accomplish more than just the sum of local assessment would: even if these assessments would not generate an added insight into causes of and responses to local land degradation, the added benefit would be in impressing decision- and policy-makers at all levels, from local grassroots to international ones, with the need to address land degradation (Oldeman et al. 1991; Bridges and Oldeman 1999).

1.1.3 Assessment of land degradation at the global scale

Only five attempts to carry out and present assessments of land degradation at a global scale took place during the last 30 years, either by an individual researcher (H. E. Dregne), or commissioned and/or executed by international organizations (e.g. United Nations Environment Program (UNEP), World Soil Reference and Information Center (ISRIC), and the Millennium Ecosystem Assessment (MA)). As a first attempt, the production of a "Generalized map of the status of desertification on arid lands" included in one of the official documents of UNCOD (Dregne 1977), which "was based on very little data or experience and has only historical significance" (Dregne 2002), the coverage and quality of these assessments improved. Yet, none of them can be considered a reliable source of information or a useful resource for policy making. All the five assessments differ in the reasons for their shortcomings, but they share two major causes: (a) inherent difficulties in defining and hence in measuring the attribute chosen to represent "land degradation", and (b) varying degrees of paucity of field data. These shortcomings are best expressed by the scatter of values for the overall spatial extent of global land degradation, as unfolded in this chapter.

As described in the following sections of this chapter, in-spite of past and ongoing current efforts, no satisfying assessment of land degradation at the global scale is yet available, and also not expected to be available at least until the end of the first decade of the 21st Century. Nevertheless, preliminary results of ongoing work indicate that figures attributed to the magnitude of the land degradation problem, used at the political arena and cited in grey literature might have been overly inflated (e.g. *"Desertification affects … 70 per cent of all drylands"* – Ch. 12 of Agenda 21, UN 1993). Given this, and being also motivated by the assessment reports of the Intergovernmental Panel on Climate Change (IPCC) which provide future projections, somewhat apprehensive decision-makers but also scientists suggest that the assessment of trends of land degradation is more practical and instrumental for mobilizing action, than just an assessment of the current state of global degradation (Millennium Ecosystem Assessment 2005b). As will be elaborated on in the following sections, assessment of trends of land degradation at the global scale hardly exist currently, though promising methods for their assessment are being developed.

1.2 Assessment of current degradation

1.2.1 Global land degradation and dryland desertification

The five "global" assessments greatly vary with respect to their products (Table 1.1), and their data coverage and quality (Table 1.2). GLASOD has the largest coverage and engaged the most intensive effort to date, yet it also attracts considerable criticism. GLASOD however, was preceded by assessment products of Harold Dregne, which unlike GLASOD that addressed global "land degradation" ("*Global* Assessment of Human-induced *Land Degradation*"), addressed "desertification" in "arid lands", i.e. in drylands only, as the name of this product signifies ("*Desertification of Arid Lands*").

Since desertification is defined by the UNCCD as *"…land degradation in arid, semi-arid and dry sub-humid areas …"* (UNEP May 1995) and since these three climatic zones (together with the hyper-arid zone) are "drylands" – lands where water input via precipitation relative to output in all forms, aggregated to "potential evapotranspiration" (i.e., the "aridity index") ranges between 0.05 to 0.65 (Middleton and Thomas 1997), the first three "global" assessments of Table 1.1and Table 1.2 are not really global. Furthermore, for the preparation of the World Atlas of

Table 1.1. Assessments and their products

Assessment's identification					
Name used in this chapter	UNCOD[1] map	Dregne book	Dregne & Chou book chapter	GLASOD	MA Desk Study
Full title	Generalized Map of the Status of Desertification in Arid Lands	Desertification of Arid Lands	Global Desertification Dimensions and Costs	Global Assessment of Human-induced Land Degradation	Synthesis on the Main Areas of Land-Covern and Land-Use Change
Organizations or institutions involved	UNEP[2]	Texas Tech University	Texas Tech University	ISRIC[3], commissioned by UNEP	IGBP/IHDP[4] LUCC[5], GTOS[6], commissioned by the MA[7]
Products					
Data bases	None	None	None	Geo-referenced digital version of original data base, performed by and available at GRID[8] (GRID 1991)	Secondary data, reference to data sources and summary of Synthesis available on a website
Maps	Map, in UNCOD A/CONF 74/31, (Dregne, 1977)	Global and continental maps, in figures of a book	None	1:10 million scale wall chart produced and published by ISRIC in 1990. Mapping of degradation by types in WAD9, and by countries (FAO no date b.)	Map of 10x10 km spatial resolution, in a Report at the LUCC website (Lepers 2003), and in a journal publication (Lepers et al. 2005)
Publications	none	Book, with figures of maps (Dregne 1983)	Chapter in a book (Dregne and Chou 1992)	Website downloadable file, (Oldeman et al. 1990, 1991; UNEP 1992; Oldeman 1994)	A report at LUCC website (Lepers 3003), and in a journal publication (Lepers et al. 2005)

[1] United Nations Conference on Desertification; [2] United Nations Environment Programme; [3] ISRIC – World Soil Information; [4] International Geosphere-Biosphere Programme/International Human Dimension Programme on Global Environmental Change; [5] Land Use and Land Cover Change; [6] Global Terrestrial Observing System; [7] Millennium Ecosystem Assessment; [8] Global Resource Information Database; [9] World Atlas of Desertification

Desertification (WAD, Middleton and Thomas 1997) the land degradation data in the three dryland type of the UNCCD only, were extracted from the GLASOD data base for drawing maps and calculating statistics of *global* desertification. This is in-spite the fact that by its own definition GLASOD is engaged with "human-induced" land degradation only, whereas the UNCCD defines the drivers of desertification as *"climatic variations and human activities"* (UNEP May 1995). In addition, the MA Desk Study too focused on "desertification", i.e. dryland degradation (though it included the hyper-arid dryland zone too). Thus, the major thrust of assessing *global* land degradation is for all practical purposes limited to only 41% of the global land, which comprises the four dryland zones (Safriel and Adeel 2005).

1.2.2
Is land degradation in drylands different than that in the non-drylands?

The relevant literature is not explicit regarding why an aridity index value of 0.65 has been selected for demarcating drylands from non-drylands. The dry-subhumid zone that is delimited by that value is characterized by highly seasonal rainfall with less than 25% inter-annual rainfall variability. UNESCO (1977) included this zone in the dryland realm due to its being *"very susceptible to degradation, probably enhanced by the seasonality of rainfall, drought periods and the increasing intensity of human use"* (Middleton and Thomas 1997). Once the drylands' aridity extent has been defined in that way, one can only explore ways in which the drylands differ from non-drylands in features relevant to land degradation.

The Millennium Ecosystem Assessment demonstrated that the drylands, as defined by UNESCO (1977) and the WAD (Middleton and Thomas 1997) are of very low net primary productivity and at the same time are of the highest population growth rate (during the last two decades of the 20th Century), as compared with all other terrestrial major ecosystem types (Fig. 1.2). This combination may indeed account for high human pressure on scarce natural productivity, one that makes the drylands susceptible to land degradation more than non-drylands. Indeed, using GLASOD data, land degradation in the "susceptible drylands" (following UNCCD usage hyperarid drylands are not susceptible to desertification, hence all other three dryland zones are termed "susceptible" [to desertification]) is significantly higher (20% of their global areas) as compared with that of "other" areas – mostly the "humid" areas (39.2% of global land) but also the hyperarid ones (7.5% of global land, Middleton and Thomas 1997), which is only 12% (Table 1.3).

A shortcoming of the GLASOD data analysis is its lumping together the most and the least arid global lands into the category of "non-drylands". But even if indeed land degradation in drylands is more prevalent than in non-drylands, the fact that all the available assessments of current land degradation (Tables 1.1 and 1.2) focus on "desertification", i.e., on degradation in drylands only, can be attributed to political rather than to biophysical considerations. Chapter 12 ("Managing fragile ecosystems: combating desertification and drought") of Agenda 21 (UN 1993) and the subsequent negotiations on a third Rio agreement – the UNCCD- that would specifically and explicitly target Africa ("United Nations Convention to Combat Desertification in those Countries Experiencing… Desertification, *par-*

Table 1.2. Assessments' features – coverage and quality

	UNCOD map	Dregne book	Dregne and Chou book chapter	GLASOD	MA Desk Study
Years of data collection	1977 and earlier	1983 and earlier	1992 and earlier	~1995-1990, possibly 1980 – 1990 (Oldeman et al. 1991)	1960-2001, but mostly 1980-2000
Source of data	Not specified	Secondary data from 100 countries in six continental regions	Source of land use figures -FAO 1986. Secondary data from 100 countries aggregated by 6 continental regions. Additional field experiments and better literature search than the 1983 "Desertification of Arid Lands" assessment	FAO 1:5 M soil map of the world. ~300 national collaborators, moderated by 21 regional "correlators", depending on local knowledge more than on field surveys, data aggregated by 8 geographical regions (Oldeman et al.1991)	30 experts identified 18 data sets, most of CCD[1] national reports and national focal points contacted for identifying recent desertification data sets
Degradation attributes	Not specified	(1) Vegetation cover and composition (range quality criteria) in rangelands; (2) Soil salinity mainly in irrigated land, and resulting crop yield reduction; (3) Soil erosion in rangeland, irrigated and rainfed croplands	Attributes impacting economic plant yield, similar to those used for the 1983 assessment	(1) Soil erosion by wind; Soil erosion by water; (2) Chemical soil deterioration (salinization, nutrient depletion), (3) Physical soil deterioration (compaction, sodification, waterlogging)	Secondary data include: NPP[2] expressed by NDVI[3]; Soil erosion derived from soil erosion models driven by measured climatic and soil variables

Table 1.2. *Continued*

	UNCOD map	Dregne book	Dregne and Chou book chapter	GLASOD	MA Desk Study
Authors' comment on value	"… based on very little data or experience and has only historical significance, if any" (Dregne 2002)	"… data base was poor… Informed opinion, anecdotal evidence, observations by travelers, and published and unpublished reports formed the basis for the numerical estimates" (Dregne 2002).	"The information base upon which the estimates were made is poor. Anecdotal accounts, research reports, travelers' descriptions, personal opinions, and local experience provided most of the evidence for the estimates" (Dregne and Chou 1992); "considerably better than the 1983 estimates, due to additional field experiments and better literature searches. Its accuracy was still low" (Dregne 2002)	" … to a degree subjective, and open to the criticism that local experts may have allowed perceived correlations with other factors, or even the vested interests of conservation institutions, to influence their judgment." (FAO no date a); "… qualitative, subjective judgment" (Bridge and Oldeman 1999). "Although GLASOD was … a somewhat subjective assessment, it was extremely carefully prepared by leading experts in the field" WAD, p. V).	"The reported percentages should not be considered as absolute but as an indication of the relative importance of degradation" (Lepers 2003); "If all continents were evenly studied, the geographic distribution of most degraded lands could be very different" (Lepers et al. 2005).

[1]Convention to Combat Desertification:

[2] Net Primary Productivity;

[3] Normalized Difference Vegetation Index

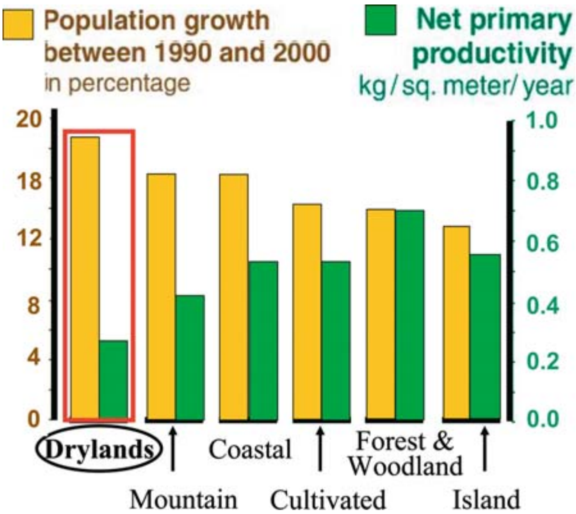


Fig. 1.2. Drylands' Net Primary Production (NPP) and population growth rate compared to other Millennium Ecosystem Assessment's global terrestrial systems (Millennium Ecosystem Assessment 2005a)

ticularly in Africa") were triggered by the public and political impact generated by the Sahelian droughts of the 70s and 80s of the 20th Century. These political processes culminating in the emergence of a legally-binding instrument addressing "desertification", required assessment of land degradation where according to this agreement it may occur – specifically in the "susceptible" drylands, rather than in the world over.

As implied by Article 2 ("Objectives") of the UNCCD, the objective *"to combat desertification …in countries experiencing … desertification, particularly in Africa … through effective action … supported by international cooperation and partnership arrangements …"* means an effective orchestration of the support of industrial countries to dryland developing countries in effectively addressing their land degradation problems. Indeed, as of its opening for signature on October 1994 developing "affected" countries (countries with lands *"affected or threatened by desertification"* – UNCCD) rushed to ratify the Convention, but also joined the Convention a few "non-affected" developing countries, i.e. countries that simply do not have drylands, hence by definition can not be "affected". Since the Convention opened to accession the number of Parties steadily increased but as of 1997, some 3-4 years after being opened for signatures and about one year after the convention entered into force, the rate of increase in number of joining "affected" countries slowed down. At the same time the number of non-affected developing countries joining the Convention was still on a steep increase (Fig. 1.3), slowing down only in the mid 1999, yet more countries of this category joined until 2004 in a rate faster than that of affected countries. This interest of developing non-dryland countries in the UNCCD culminated in adding a new, fifth implementation annex to the UNCCD, one for Central and Eastern European Countries which includes 17 developing countries, 11 of which do not have drylands within their boundaries, hence they have no desertification to combat. Currently, of the 191 Country

Table 1.3. GLASOD soil degradation – drylands vs. non-drylands[1]

	Susceptible drylands[2]	Other areas[3]	Total land
	Million ha (% degraded of aridity class)		
Degraded	1,035.2 (20.0)	929.2 (11.8)	1,964.4
Nondegraded	4,134.0 (39.7)	6,914.3 (60.3)	11,048.3
Total land	5,169.2	7,843.5	13,012.7
	$\chi^2 = 163.3$, $P<0.001$		

[1] Data from WAD, p. 18, Table 1.4
[2] Semiarid, Arid & Dry subhumid lands
[3] Mostly Humid, but also Hyperarid lands

Parties to the UNCCD 93 are developing dryland ("affected") countries, and 69 are non-dryland developing ones; the ratio of non-dryland to dryland developing countries rose from 0.33 in 1995 to 0.74 in 2004 (Fig. 1.3). It should be noted also that a large proportion of the developing dryland countries, mostly those that joined the UNCCD late, have within their boundaries only the least dry drylands, namely dry-subhumid areas; or altogether the amount of drylands within their territory is very small.

Most of the non-dryland developing countries and those with a very small proportion of drylands in their territory that joined the UNCCD are affected by or prone to land degradation. Their motivation to join the UNCCD is the aspired benefit from the tendency of donor countries and international funding agencies like the Global Environment Facility (GEF) to support projects that address the problem of "land degradation" anywhere in the developing world, rather than focus on "desertification", which occurs only in drylands. Furthermore, there are some salient cases in which land degradation in a non-dryland country is far more severe than in any dryland country (e.g. Iceland, Arnalds et al. 2001). Thus, for all practical purposes the UNCCD has evolved into an instrument for addressing global land degradation, not necessarily limited to drylands and to "desertification". This is the rationale for attributing globality to assessments of desertification at the global scale, provided it is qualified when an assessment addresses land degradation just in the drylands (i.e., desertification) or also in non-drylands.

1.2.3
Degradation degree and degradation severity

Assessment of degradation, especially on a global scale, involves three stages – (a) generating numerical data based on ground observations and measurements; (b) transforming the numerical data to map units; and (c) extracting statistics by subjecting map units to various analyses. Regarding the first stage, the two major as-

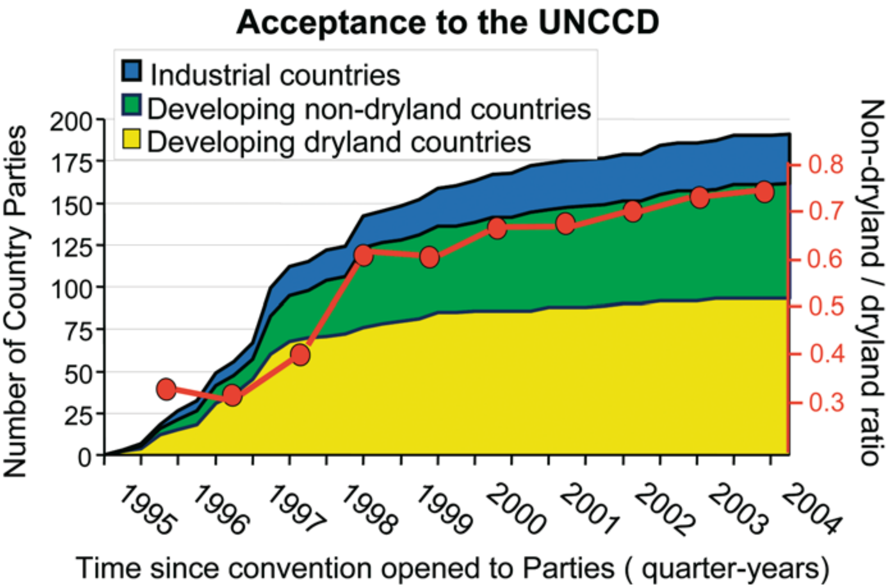


Fig. 1.3. Cumulative number of country parties to the UNCCD (following their ratification of the convention) in each quarter-year since the convention was opened for accession (areas under curves), and the ratio of developing *non-dryland* countries to developing *dryland* countries at the end of each year (red curve). List of countries and the dates of their acceptance are from the UNCCD website (www.unccd.int). A developing Country Party was defined as "dryland country" when UNEP's map (downloaded from the Millennium Ecosystems Assessment core database) of the global drylands (also used by the WAD) shows drylands within its boundaries, irrespective of the proportion of these drylands of the total country's area.

sessments (see Table 1.1 and Table 1.2 for information) were based on observations of several land (mostly soil) attributes, which were more often qualified than quantified, and then aggregated into a few classification units ranging from "low" to "high" degradation "degrees"(Table 1.4).

Regarding the second stage, the transformation of these classified degradation degrees into map units often has to grapple with a mismatch between the ground sampling scale and the map unit's scale. Thus, only one part of each mapping unit may be affected by degradation and it is not known which part of the unit is degraded and which is not. Hence, when deriving cartographic output, shading the entire polygon is the only option, although this gives an exaggerated impression of the extent of degradation.

Therefore, regarding the third stage of generating land degradation statistics, two different statistics may apply. The first takes into account only the actual degraded area, i.e. aggregating land units according to their degradation degrees. The second is to use a composite estimate of "degradation severity" – a combination of degradation degree and its spatial extent within mapping units (Table 1.5). It is claimed that while the latter results in an inflated figure of degradation, the former

Table 1.4. Assessment of Degradation Degrees

Assessment's identification				
Degradation types	Assessed degration attributes		Range of values (from low to high degree)	
			Desertification of Arid Lands – 1983 & 1992[1]	Global Assessment of Land Degradation (GLASOD) – 1990[2]
Soil erosion	Lost soil	Topsoil	Little to all	Little to all
		Subsoil		None to some
	Gullying		Low to servere	
	Space between rills (water erosion)			>50m – <20m
	Area coverage by holes (wind erosion)			10% – >70%
	Sheet erosion		Moderate to servere	
	Blow out areas, hummocks		Few to numerous	
	Vegetation cover			<30% – >70% of area
Soil salinity[3]	Observed salinity (in ECe)		ECe x 10^3 <4 – ECe x 10^3 15 mmhos	
	Salinity change during last 50 years (in EC, and ESP<15%, pH<8.5, 3 range classes within the range 5mS/cm - >16 mS/cm)			Slightly to severely saline, depending on the number of range classes added to salinity prior to degredation
Nutrient depletion	Cultivation of cleared range or forrest			
	Cultivated crop			Perennial/annual crop
	Potential of fertilizer to offset lost productivity			Moderate to non-existent
	Quality of soil parent material			Rich to poor
Vegetation	Representation of climax species		50% – <10%	
	Loss in range productivity		>25% – >75%	
	Range quality estimate		Fair-poor	
crop yield			<10% – >90%[4]	

[1]based an Dregne 1983, pp.17,171–173, and most criteria are the saure as in Dregne and Chou 1992 assessment,

[2]based an WAD, boxe 1 p. 26, box 2 p. 27 and boxes 3, 4, p. 26

[3]EC – Electric conductivity of a saturated soll extract ESP– Exchangeable sodium percentage, mS – millisiemens mmhos – millimhos, whereby mho is a reciprocal of an Ohm

[4]In Dregne and Chou 1992 assessment the highest degradation degree is >50% loss of crop yield

Table 1.5. Assessment of Degradation Severity (combination of degradation degree and its spatial extent)

Desertification of Arid Lands – 1983[1]					
Severity / Degree	Percentage of area of a mapping unit affected by each degradation degree				
	Slight	Moderate	Severe	Very severe	
Slight	0–50	0–50			
Moderate					
Severe	0–20	0–30	30–100		
Very servere	0–10	0–30	0–30	30–100	
Global Assessment of Land Degradation (GLASOD) – 1990[2]					
Severity[3] / Degree	Low	Medium	High	very High	
Light	0–10	11–50	51–100	0	
Moderate	0–5	6–10	11–50	51–100	
Strong	0	0–5	6–10	26–100	
Extreme	0	0–5	6–10	10–100	
Frequency classes (% of mapping unit actually degraded)	>5	6–10	11–25	26–50	>50
Frequency definitions	Infrequent	Common	Frequent	Very frequent	Dominant

[1] based on Dregne 1983, pp. 17, 171-173

[2] based on Oldeman et al. 1991 Fig 5 p. 15 and FAO no date a Fig. 13.

[3] A low severity class in either 0-10% of area of the mapping unit covered by light degree or 0–5% cover by moderate degree. If the light degree covers more than 10% of the area the severity willbe medium if the cover is up to 50% and very high if it is up to 100%; Each map unit of GLASOD has at most two types of degradation, and the severity class of the units will be elevated, depending on their relativ degree and extent; Maps and statistics for each country, derived from GLASOD data base are available in FAO website (FAO no data b): on each map each map unit is colored denoting one of the four severity classes (see also Fig. 8c), and the areas in each of the five frequency classes (for each severity class) are provided in an adjoining table.

may be an underestimate of the overall phenomenon. This is because it does not take into account (a) the effect of the degraded site on the use of the land surrounding it, (b) off-site effects, such as sedimentation and others, and (c) the adverse effects upon the economy as a whole, whether at village, regional or national levels. For these reasons FAO for example chose to use "degradation severity" when presenting the GLASOD database applied to individual countries on its website, as "an indicator of the overall seriousness of degradation, within a mapping unit, country

Table 1.6. Global land degradation

Assesment	Global Assesment of Soil Degradation (GLASOD) 1991							
Sources	Oldeman et al 1991[1]		GLASOD digital database[2]					
Area assessed (1000 sq.km)	130,127[3]		?		124,791[4]			130,013[5]
% degraded by categories[6]	"Degrees" [7]		"Severity" [8]		"Severity" [9]			"Severity" [10]
	Light	6	Light	18	Light	18	18	
	Moderate	7	Moderate	21	Moderate	20	21	
	Strong	2	Servere	20	Servere	20	21	
	Extreme	0.1	Very servere	6	very servere	6	6	
Total degraded (1000 sq.km)	19,640		?		86,688			79,690
% degraded of assessed area	15		65		63		63	61

[1] This is the "Explanatory Note" of the GLASOD map, providing global assessment and not addressing drylands specifically. Later publications provide more analysis of this data base, e.g. Oldeman 1994 and Bridge and Oldeman 1999

[2] Used for generating "Severity" category values, which combine "degrees" of degradation with their spatial extent within mapping units (e.g. map 1.11 p.20 in WAD 1997).

[3] Based an WAD Table 1.4 p.18

[4] Based an WAD Table 1.1 p. 5

[5] From Oldeman et al. 1991, Table 1 p.28

[6] Terminology for each category used by the different assessments is preserved

[7] Based an WAD Table 1.4 p.18, Bridge and oldeman 1999 Table 1 p. 323, Oldeman et al. 1991 Table 9 p. 32

[8] From FAO 2002, a file from a CD, an the FAO web, Table 11

[9] First value – data copied from FAO no date a; second value – based an values of degraded areas provided by this source, but percenages recalculated

[10] Based on Oldeman et al. 1991 p. 27 – all land which is not "stable", grey-colored on the GLASOD map, relative to total global land assessed

or region" (FAO no date b). Nevertheless, though "The global maps (in WAD) are designed to give an overall, if exaggerated, impression of the scale of soil degradation" (Middleton and Thomas 1997), one needs to remember that "only a part of each mapping unit is actually affected by degradation" (GRID 1991).

Table 1.7. Dryland Degradation

Assessment	Desertification of Arid Lands (Dregne, 1983, 1992)								Global Assessment of Soil Degradation (GLASOD) 1991			
Sources	Dregne 1983				Dregne and Chou 1992				WAD[1]		WAD[2]	
Dryland zones assessed[4]	HA / A / SA / DSH				HA / A / SA / DSH				HA / A / SA / DSH		HA / A / SA / DSH	
Area assessed (1000 sq.km)	47,063[5]				51,597[6]				51,692[7]		61,473[8]	
% degraded by categories[10]	“Classes” [5]		Land uses[11]		“Classes” [12]		Land uses[13]		“Degrees” [14]		“Degrees” [15]	
	Slight[17]	52	Irrigated	0.6	Slight	30	Irrigated	0.8	Light	8	Water	8
	Moderate	29	Rainfed	5	Moderate	29	Rainfed	4	Moderate	9	Wind	8
	Severe	18	Range	65	Severe	39	Range	65	Strong	3	Chemical	2
	Very severe	0.2			Very severe	2			Extreme	0,1	Physical	0,16
Total degraded (1000 sq.km)	22,543[18]		32,718		35,922				11,370		11,370	
% degraded of assessed area[20]	48		70		70				20		19	

[1] World Atlas of Desertification, Middleton and Thoams 1997; values based on tables in the WAD using GLASOD database and a delineation of the drylands from maps of the dryland zones commissioned by UNEP to the Climatic Research Unit (CRU) of the University of East Anglia (UEA) using their data sets to derive global Aridity Index values. This dryland types data set was downloaded from the MA core database.

[2] Data from Oldeman 1994, based on GLASOD data base and the global aridity zones delineation by the CRU/UEA (see[1])

[3] Used for the “Severity“ category values, which combine “degrees“ of degradation with their spatial extent within mapping units (e.g. map 1.11 p. 20 in WAD 1997)

[4] Aridity zones: HA – Hyperarid; A – Arid; SA – Semiarid; DSH – Dry subhumid, following UNEP/WAD classification. Grey zones only are covered by the assessment

[5] Based on Dregne 1983 Table 6.2 p. 174

[6] Based on Dregne and Chou 1992 Table 1

[7] Based on WAD Table 1.1 p. 5 and Table 1.4 p. 18

[8] Based on WAD Table 1.1 p. 5

[9] From GLASOD digitized database downloaded from ISRIC website to the Millennium Ecosystem Assessment (MA) “core data“ (e.g. Safriel and Adeel 2005, Fig. 22.9 p. 640)

[10] Terminology for each category used by the different assessments is preserved. The bottom category (bolded figures in a highlighted grey cell) are regarded by the authors of the assessments as a practically irreversible state, which by some it means, in the drylands -“desertification“

				Land-Cover Land-Use Change – Drylands (LUCC) – 2003			
GLASOD database[3]				Lepers 2003, Lepers et al 2005			
HA A SA DSH		HA A SA DSH		HA A SA DSH		HA A SA DSH	
51,125[9]		60,902[9]		51,692[7,16]		61,473[8,16]	
"Severity" [9]				"Main areas of degraded land" [16]			
Low	15	Low	15				
Medium	26	Medium	23				
High	24	High	22				
Very high	8	Very high	8	Very severely degraded	4	Very severely degraded	10
37,588		41,221		1,959		6,147	
74		68		4[19]		10[19]	

[11] Based on Dregne 1983 Table 1.3 p. 19; These land uses occupy 41,018,000 sq.km of the assessed "used" dryland, of 47,063 thousands sq.km

[12] Based on Dregne and Chou 1992 Table 8

[13] Based on Dregne and Chou 1992 Tables 3,5,7

[14] Based on WAD Table 1.4 p. 18

[15] Based on Oldeman 1994 Tables 7.1–7.4 pp 108-111, assessing degradation types (water and wind soil erosion, chemical and physical soil deterioration)

[16] From Lepers 2003 – degradation is the highest degree (of 3-4 degrees in 5 of the data sets used, or values above a high threshold in all other data bases). Note also that only 62% of the drylands (including the Hyperarid) are covered by data accepted by this assessment, what makes the total assessed global area smaller than presented in the row above

[17] This class also includes non-degraded areas, mostly occurring in the hyperarid zone

[18] "Moderate" to "Very severe", i.e. "Slight" excluded

[19] Note that this percentage is close to the GLASOD "High severity" degradation, since in both assessments the mapping scale results in an exxaggeration – mapping units defined as degraded are only degraded in part of their area

[20] These values, though each is a percentage of a different definition of the term "dryland", are often used to denote "dryland degradation", or "desertification"

1.2.4
The Spatial extent of global land degradation

GLASOD is the only assessment of current land degradation at the global, rather than just the dryland scale. Its products provide several values for the global spatial extent of land degradation, ranging from 15% to 65% of global land (Table 1.6). The lowest value represents ground data of the four "degree" degradation values, whereas the highest value represents the apparently exaggerated degradation "severity" as presented on maps. The severity of the degradation is characterized by the degree to which the soil is degraded and by the relative extent of the degraded land within the delineated map units, within each of which only a portion of the delineated unit is degraded.

These high values range 61% to 65%, depending on the area estimates of global land, used for calculating the percent degraded. The highest degradation is of the intermediate categories, and the spatial extent of areas of the highest degradation degree is the smallest – just 6% of global land. To reiterate, these values include drylands and non-drylands, for example – using GLASOD database, the overall degradation severity of Niger, a Sahelian dryland country is 27.7%, whereas that of Iceland, a typical country of the humid, non-dryland zone – is 35.7% (FAO no date b).

1.2.5
The spatial extent of dryland degradation

The relevant information on dryland degradation provided by the three major assessments is summarized in Table 1.7. Depending on within- and between-assessment differences in methodology (using degree- or severity-degradation, distinguishing between erosion processes or between land uses, excluding or including "slight" degradation) and spatial coverage (47 million km^2 of arid and semiarid dryland only, to 61.5 million km^2 of all four dryland types combined), there are great differences in the "bottom line" of Table 1.7, the one that is often cited in public media and in grey literature, i.e. – the overall extent of dryland desertification. The estimates vary between 4% to 74% (!) of drylands being desertified. The highest estimate, derived by GLASOD, is of "severity" degradation when the hyperarid areas are excluded. The lowest estimate, derived by the MA desk study and excluding the hyperarid too, results of attributing "desertification" status only to the "very severely degraded" state. Thus, for meaningful comparison of the MA desk study with the two other assessments, it is necessary to assesses the global spatial extent of highest (fourth) degradation classification. This ranges between 0.1% and 0.6% of GLASOD, to 4% and 10% of the MA desk study, when the hyperarid zone is excluded or included, respectively. It should be noted that the MA desk study exercised data quality control claimed to be stricter than that of GLASOD. This may give higher credibility to the MA desk study estimates. But this stricter data control reduced the overall global dryland area covered by the MA desk study to only 62%, which may cloud its image as a global assessment, as compared to the full coverage

Table 1.8. Estimates of desertification extent (% of global dryland area)[1]

The dryland domain \ Degradation assessment methos	Degrees[2]	Severity[3]
	All degradation categories combined	
Hyperarid excluded	20	70 –74
Hyperarid included	19	68
	Highest degradation category only	
Hyperarid excluded	0.1	4–8
Hyperarid included	0.6	8–10

[1] For sources see Table 7
[2] Measured degradation area
[3] Combination of degree degradation with its spatial extent on map units

claimed by GLASOD. Summary of the qualified status of current dryland degradation is provided in Table 1.8.

1.2.6
Degradation and degradation vulnerability

The title of the GLASOD ("Global Assessment of … Land Degradation") project explicitly addresses an assessment of land degradation, literally meaning an assessment of the spatial extent and severity of tangible land degradation. Yet, the most publicized secondary source of GLASOD focusing on desertification, the World Atlas of Desertification (Middleton and Thomas 1997), presents a map entitled "Soil degradation severity in susceptible drylands" (WAD, map 1.11, p. 20) which is qualified in the text of its chapter "Soil Degradation in Drylands" as a map which "concentrates on areas where natural dryland soil properties are *susceptible* to degradation and where land use activities *may* cause desertification". The WAD text actually follows the first World Map of Desertification produced for UNCOD by FAO, UNESCO and WMO, where many areas falling under the desertification label qualified as such due to local conditions that signified only a potential or a hazard for becoming desertified.

Indeed, the UNCCD defines "affected areas" (i.e., by desertification) as "arid, semi-arid and /or dry sub-humid areas affected or *threatened* by desertification" (UNEP May 1995, Article 1h). Since by definition all these three dryland areas are of a potential to become desertified, the UNCCD Secretariat produced a brochure for publicizing the Convention's 10-year anniversary which presents a map of the global drylands, under a subtitle *"Desertification in the World"* (UNCCD 2004).

Finally, even the definition of “degradation” (rather than just “desertification”) by the Global Environment Facility (GEF) is “any form of deterioration of the natural *potential* of land …” (GEF 1999). It seems therefore, that due to low robustness of the definitions of both “degradation” and “desertification” the literature on degradation assessment is often not easily amenable for elucidating the current state or the currently prevailing trends of land degradation. On the other hand, it is the trend rather than the current state that is important and relevant to most decision- and policy-makers. Hence vulnerability, which may provide an early warning for an upcoming trend requires a robust treatment.

1.2.7 Degradation vulnerability and degradation risk

The “Global Desertification Vulnerability and Risk”, a global assessment of desertification vulnerability, was carried out by the Natural Resource Conservation Service (NRCS) of the United States Department of Agriculture (USDA). It was first publicized in conference proceedings (Eswaran and Reich 1998), later succeeded by several products: maps in scale 1:5,000,000; websites of NRCS (for vulnerability http://soils.usda.gov/use/worldsoils/mapindex/desert.html, for Risk – http://soils.usda.gov/use/worldsoils/mapindex/dsrtrisk.html); and publications (Eswaran et al. 2001a; Eswaran et al. 2001b).

In this assessment the vulnerability of each land unit within the drylands is evaluated by its soil properties and their response to climatic properties to which this land unit is habitually exposed. The range of soils-climate linkages within the global drylands was classified into four vulnerability degrees (Table 1.9). These vulnerability values are transformed to four risk categories based on the soil-climate

Table 1.9. Assessment of Degradation Vulnerability and Risk[1]

<table>
<tr><th>Determinants of Vulnerability and Risks</th><th>Method of assessment</th><th>Vulnerability</th><th>Risk</th></tr>
<tr><td>Soil potentials and constraints for sustainable agriculture</td><td>9 Land quality classes (LQCs)</td><td rowspan="2">4 Vulnerability classes</td><td rowspan="3">4 Risk classes</td></tr>
<tr><td>Climatic properties</td><td>Impact of climatic variables (e.g. reinfall, temperature) on soil mositure and soil temperature regimes</td></tr>
<tr><td>Population destiny[2]</td><td>Population estimates for each LQC class used to assign risk classes by reclassifying the vulnerability class</td><td></td></tr>
</table>

[1] Sources – Eswaran et al. 2001a b; NRCS no date

[2] 1994 global population, from Tobler et al. 1995

system of each land unit which is exposed to human impact, expressed by the density of the population that uses or depends on this land unit (Table 1.9). The rules for this transformation from vulnerability to risk classes are determined by human density ranges classified into three classes, each interacting differently with each of the four vulnerability classes (Table 1.10). Thus, for example, a high population density in a highly vulnerable area poses a very high risk of land degradation, just as a low population density in an area of low vulnerability poses a very low risk.

The sources for the assessments of vulnerability and the flow chart leading from data sources to the determination and mapping of vulnerability, following by the determination and mapping of risk are summarized in Figure 1.4.

The NRCS Degradation Vulnerability and Risk assessment covered the global drylands, except the hyperarid areas, concluding that the 84% of this domain is vulnerable to and at risk of desertification (Table 1.11). As expected, this figure is higher than the highest value of GLASOD, being 74% (Table 1.7), since GLASOD is supposed to provide values of actual desertification, whereas the NRCS assessment adds to that also areas that are not desertified, but of high risk of becoming deserti-

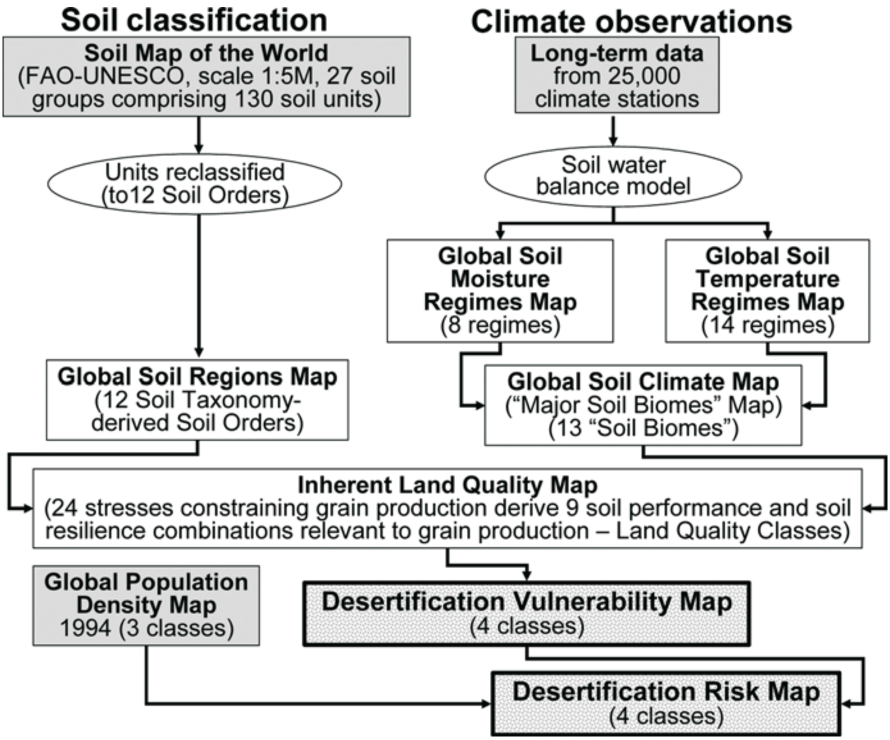


Fig. 1.4. A flow-chart connecting input data of a global soil classification map, long-term climatic observation at a global scale and global population density map (dark grey boxes), to outputs of desertification vulnerability and risk assessment maps (light grey boxes). Sources: Eswaran et al. 2001b

Table 1.10. Degrees of risk as combinations of vulnerability and population density classes[1]

Vulnerability & density / Risk	Combinations of vulnerability and population density classes (number of persons/sq.km)					
	Combination (a)		or combination (b)		or combination (c)	
	Vulnerability	Density	Vulnerability	Desity	Vulnerability	Density
Low	Low	<10				
Moderate	Moderate	<10	Low	11-40		
High	High	<10	Moderate	11-40	Low	>41
Very high	Very high	>10	Moderate	>41	High	>41

[1] Based on Table 1 of Eswaran et al. 2001a

Table 1.11. Dryland degradation vulnerability[1]

Assessment	Desertification Vulnerability and risk 1998			
Dryland zones assessed[2]	HA	A	SA	DSH
Area assessed (1000 sq.km)	51,692[3]			
% vulnerable/at risk by categories[4]	Vulnerability classes[5]		Risk classes[6]	
	Low	28	Low	14
	Moderate	26	Moderate	17
	High	14	High	30
	Very High	15	Very High	23
Total vulnerable/at risk (1000 sq.km)	43,319[7]			
% vulnerable/at risk of assessed area	84			

[1] Based on Eswaran and Reich 1998, cited by Eswaran et al. 2001a, b
[2] HA – Hyperarid; A – Arid; SA – Semiarid; DSH – Dry subhumid, following UNEP/WAD classification. Grey zones only are covered by the assessment
[3] Based on Eswaran et al 2001 1.1 p. 5 and Table 1.4 p.18
[4] Terminology used by the assessment is preserved. The bottom category (bolded figure in a highlighted grey cell is regarded by the authors of the assessment as representing "desertification tension zone" (see text)
[5] Based on Eswaran et al 2001a Table 3 and Eswaran et al. 2001 b Table 3
[6] Based on Table 3 in Eswaran et al. 2001b: "risk" dass is derived by weighing the vulnerability classes by population density classes: vulneraiblity classes are reclassified into risk classes, depending on population density, Eswaran et al 2001a
[7] Value of Eswaran et al. 2001 a. In 2001 b it is 43,240 or 43,221 1000 sq.km

fied. That the difference between the two assessments is not much higher is also expected, since apparently GLASOD might have not always explicitly discerned tangible desertification from vulnerability to and risk of desertification.

It is to be noted that though the overall global vulnerability and risk for the drylands are of identical value, the difference between vulnerability and risk is evident when examining the individual classes in Table 1.11. It is evident that most of the 84% of the drylands which are vulnerable and at risk are within the low and moderate vulnerability classes (54% of total drylands), but at the same time most these 84% are of the high and very high risk classes (53% of total drylands). Thus, whereas 15% of the drylands are of very high vulnerability to desertification, 23% are of very high risk that the vulnerability will be materialized when human pressure is considered (Table 1.11, central cells). The difference between the vulnerability values and the risk values is that being inherent feature vulnerability is temporally stable, whereas the risk, depending on population impact, can vary with temporal changes in population size.

The authors of this assessment attribute much significance to "very high" classes of vulnerability and risk, labeling them as "desertification tension zones" – those "*in which the potential decline in land quality is so severe as to trigger a whole range of negative socioeconomic conditions that could threaten political stability, sustainability and general quality of life*" (Eswaran and Reich 2001b). Accordingly, 23% of the drylands (the hyperarid excluded) are of very high risk of becoming desertified (if not already desertified).

1.3 Remote-sensing of productivity for assessing global degradation

1.3.1 Soil or vegetation assessment?

Though the "Desertification of Arid Lands" (Dregne and Chou 1992) and the MA desk study assessments addressed vegetation status as an attribute or an expression of land degradation, soil degradation is emphasized by all assessment of global degradation, and is the sole feature assessed by GLASOD (Table 1.2) and by the NCRS vulnerability and risk assessments (Fig. 1.4). Indeed, soil is interlinked with vegetation cover and the ecosystem service of primary productivity which so much matters for human well-being (Fig. 1.1). Thus, soil degradation would not have been of concern were it not leading to reduced productivity, which is the ultimate expression of desertification. The weight given by land degradation assessments to soil rather than to vegetation and productivity degradation may attest to the significance attributed to soil by the assessors, or it indicates that soil properties are more amenable for quantifying than vegetation and productivity attributes. As to the first option, it is interesting to note that a social survey in Zimbabwe found that dryland farmers regarded soil erosion as a minor problem only compared to other issues related to farming (Grohs 1994). As to the second option, the advances in remote-sensing technologies since these global land degradation assessments have been conceived made vegetation assessment, especially at a global scale, an attractive option for addressing land degradation.

Indeed, already the WAD (Middleton and Thomas 1997) attempted to link remote sensing of vegetation with the GLASOD data. The Normalized Difference Vegetation Index (NDVI) is a qualitative measure of vegetation phenology, derived from remotely sensed reflectance from live vegetation in specific spectral bands. The WAD team used the Global Vegetation Index (GVI), which is the highest daily NDVI value (calculated from data of 16 km X 16 km spatial resolution images taken by the Advanced Very High Resolution Radiometer [AVHRR] satellite) occurring within a week, averaged over a given period (1983-1990 for the WAD study). This index relates to the capacity of plants to photosynthesize, and under a range of environmental conditions it is indicative of vegetation biomass (Middleton and Thomas 1997). The WAD generated a map of global coverage of GVI values, represented as a five-grade scale from low to high indicating biomass differences, and overlaid this map on the GLASOD four-degree scaled degradation severity map. Thus, the WAD team created a map with a 20-color grid, each color standing for an implied interaction between land degradation severity degree and the state of the above-ground vegetation. This map, however, does not explicitly address land degradation, but may discern tangible degradation from degradation risk. For example, areas of only low degradation severity but low GVI, imply a degradation risk due to low vegetation cover, even though the soil has not apparently responded to this loss. On the other hand areas with high degradation severity and low GVI are more likely to indeed be already degraded. Finally, areas with high degradation severity but high GVI may indicate bush encroachment into an impacted area. This exercise of WAD is useful for drawing attention to the potential of satellite imagery to degradation assessment, but rightly the WAD did not find it useful for attempting statistical analyses of the database used to derive this product.

The MA desk study, the only assessment at a global scale that added vegetation-detection by satellite imagery data to the information contributing to the overall assessment of dryland degradation, noted the shortcoming of such an approach due to difficulties in determining whether spatial variability in NDVI values is due to spatial changes in human impact or to temporal, inter-annual climate variability. This shortcoming was overcome by the WAD team through their long-term averaging of the GVI values. But even this approach could not distinguish between two identically low long-term averaged vegetation signals in which one of them is produced by a non-degraded state of an inherently low productivity land, and the other is produced by land of an inherently high productivity but exposed to long-term human impact. However, since in drylands the vegetation and its productivity directly respond to variations in rainfall, the distinction between the two sites that produced an identical signal can be made if they differ in their rainfall regime – the site with the higher rainfall is likely to be the degraded one. Alternatively, two sites affected by the same rainfall will respond differently if they differ in the degree of human-induced impact, i.e., in their degradation.

A test for this assumption is provided by monitoring and comparing two different areas with regard to their responses in net primary productivity (NPP) as detected by satellite imagery and expressed by NDVI summed over the growing season (sumNDVI), to an identical 16-year inter-annual variation in rainfall. These

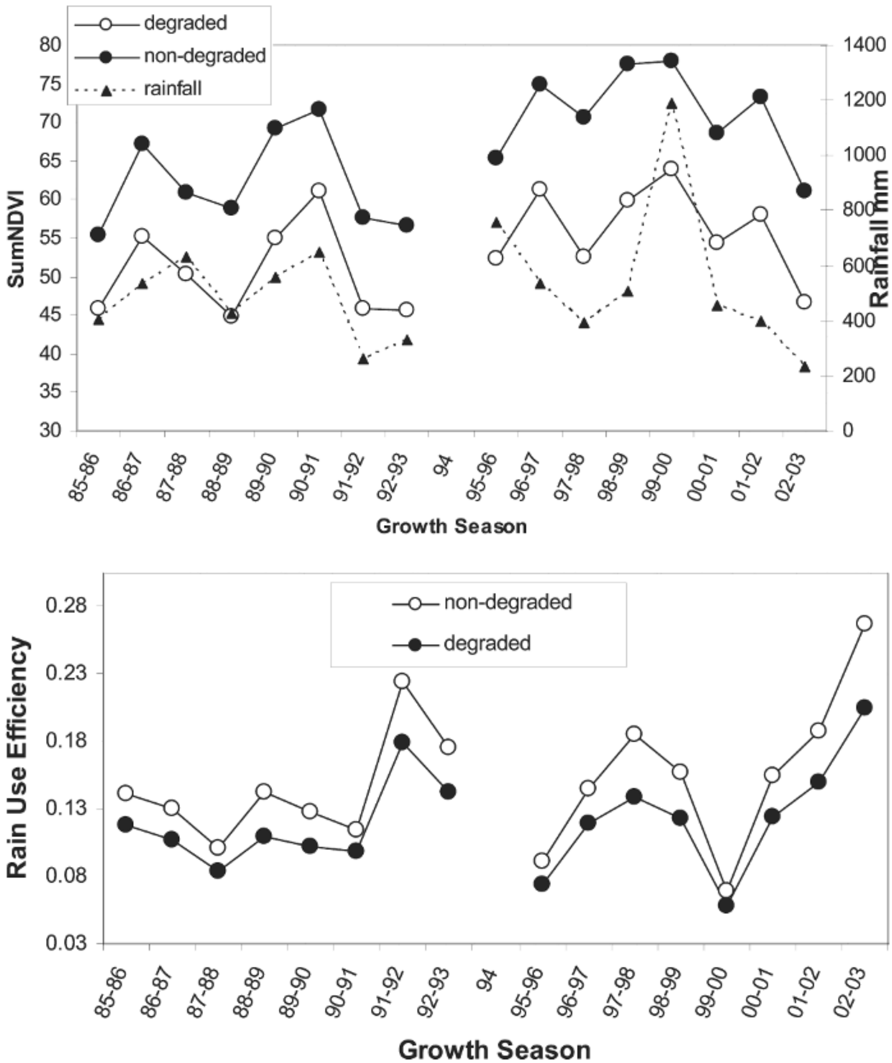


Fig. 1.5. (**a**) SumNDVI (indicative of NPP) of degraded and non-degraded sites in two areas in north-eastern South Africa, both exposed to identical rainfall regime and monitored along 16 growth seasons. Note that in wetter years the sumNDVI in degraded sites exceeded that of non-degraded sites in dry years (Wessels et al. 2004, adapted from Safriel and Adeel 2005). (**b**) Rain Use Efficiency (RUE – sumNDVI divided by rainfall) of the two areas. Note that RUE of the degraded area is always lower than that of the non-degraded one but in each area RUE values, i.e. biomass production per unit of rainfall may greatly vary between years.

two areas in north-eastern South Africa are known from ground observation to differ in their degradation severity due to difference in human impact. It was found (Fig 1.5a) that the NDVI in the degraded area relative to the non-degraded one was reduced by an almost constant proportion throughout the monitoring period (Wessels et al. 2004).

The increase in productivity driven by increase in rainfall evident in Fig 1.5a is always smaller in the degraded than in the non-degraded area. The different response to rainfall increase between the two areas can be attributed to the lower rainfall use efficiency of the two areas (Fig. 1.5b). Furthermore, it is also possible to use the data presented in Fig. 5b for calculating the ratio of NDVI (standing for NPP) to the annual precipitation, thus signifying the efficiency of using rainwater for primary productivity and hence termed "Rainfall Use Efficiency" (RUE). Indeed, the RUE of degraded areas too is always lower than that of the non-degraded area. However, the values of RUE fluctuate between seasons (for example the similarly low rainfall in 92-93 and in 02-03 growing seasons produced a very different RUE response, that of 02-03 being much higher than that of 92-93), signifying that other factor beside rainfall affect the efficiency of using soil moisture for primary productivity (Le Houerou 1984, Prince et al. 1998).

1.3.2
Degradation as a persistent reduction in land productivity

The clear-cut relations between ground-verified degradation and its expression in remotely-sensed productivity attributes make one wonder what the reason is for the wide range of values of the global extent of land degradation generated by the various assessments (Tables 1.7 and 1.8). One suggestion is that this is at least partly due to the rather loose definition of "land degradation", and especially "desertification", definition which does not provide a clear choices of variables to be measured (i.e., soil erosion or vegetation cover, etc.) and is vague regarding the criteria for classifying observations into the "degraded" or "non-degraded" classes.

The data set presented in Figure 1.5 simply suggests that land degradation can be best described and assessed as a *persistent* reduction in land productivity (Prince 2002; Millenium Ecosystem Assessment 2005b). This definition has two elements. The first one is the focus on primary productivity. This variable is habitually measured on the ground since it is the economically most important feature of the land, and it integrates all other biophysical variables that drive it and interact with it. Also, its local ground assessment can be upscaled with the use of sensors on airborne or space born crafts that detect radiation bands reflected from vegetation. The second element is that detecting reduction in productivity alone is insufficient and can also be misleading; it must be *persistent* for it to qualify as degradation. Namely, the critical issue in defining degradation is not to what level productivity was reduced, but for how long it remained low, as compared to a matched baseline. Thus, the reduced productivity should be observed long enough to be defined as persistent reduction below that baseline.

1.3.3
Assessing degradation as deviation of productivity from its potential

In the example portrayed in Figure 1.5, the degradation and its drivers at a local scale, were verified on the ground (Wessels et al. 2004). The question remains as to how degradation can be detected and defined at a regional scale, thus leading to a global assessment of land degradation of large areas for attaining the spatial extent of global degradation. Surely, for establishing persistence of degradation a time series of airborne or satellite images is required. Next, the major issue is how to relate a persistent productivity state to a baseline or a reference value, for establishing whether or not the persistent state is one of degradation.

One way is to use the same NPP-related NDVI map (like the one employed by the WAD team, for example) for both extracting the required baseline and for qualifying all other observed NPP values as to their status with regard to degradation, in relation to the reference value (Prince 2004). A large region can be classified into homogeneous areas that consist of grid cells (pixels) having the same climate, soils and plant community structure, but not necessarily the same human impact. This can be done by employing vegetation, soil, and rainfall maps, as well as landscape maps of slopes and aspects. The NPP of these pixels extracted

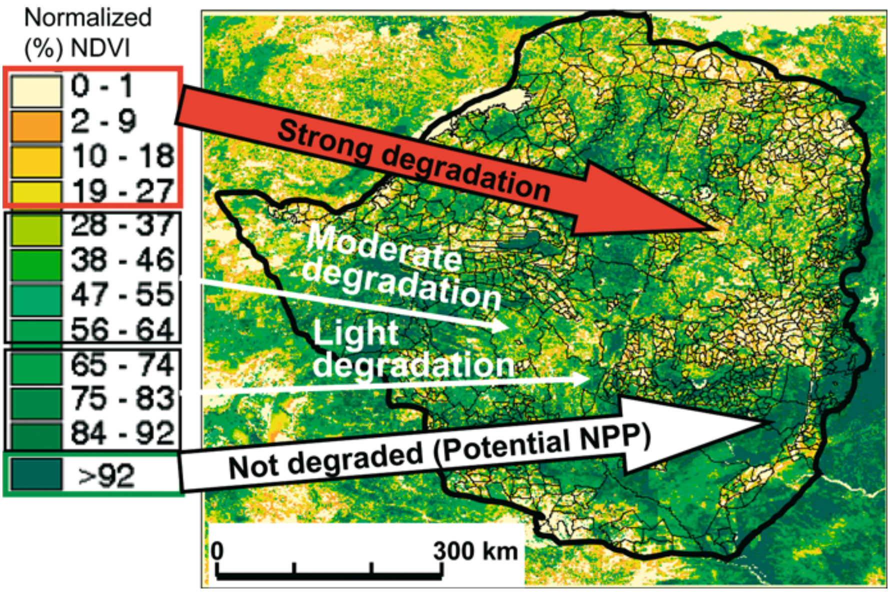


Fig. 1.6. Zimbabwe, map of Local NPP Scaling (LNS) based on mean NDVI of 5 years (1998-2002) using SPOT-VEGETATION, 1 km^2 resolution images. Intensity of color does not stand for intensity of NPP, but for normalized NPP values relative to the "Potential NPP" percent class (bottom value at the legend column), whose absolute value varies depending on the vegetation type/rainfall regime class of each of the homogenous regions, typically of 1,000-10,000 km^2 each (adapted from Safriel and Adeel 2005, based on Reshef 2003)

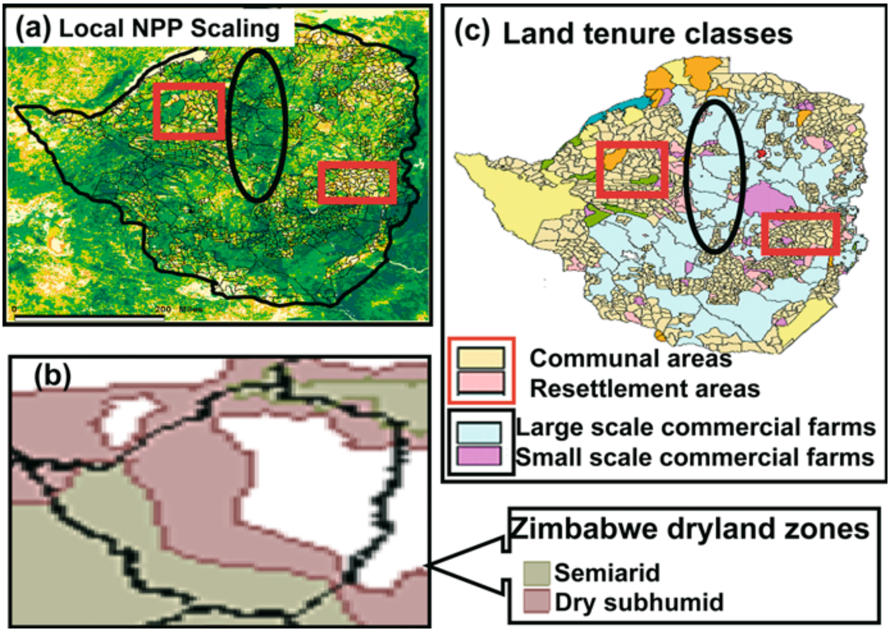


Fig. 1.7. Drivers of degradation in Zimbabwe. The 4th level administrative boundaries of Zimbabwe (**c**) can be compared with (**a**): the most degraded areas in (**a**) are the communal and resettlement areas, and the least degraded – the commercial farm lands in (**c**). (**b**) provides the spatial Extent of Zimbabwe drylands zones (UNEP commissioned database, extracted from the MA core database). Note that degradation occurred also in the non-dryland (white areas) parts of the country. Comparison of the drylands map (**c**) with the LNS map (**a**) shows that there is more degraded land in the dry-subhumid than in the semiarid zones. Both dryland zones are similarly "green" in the LNS map, which does not mean they have similar productivity; rather, the color signifies deviations from a potential of each zone, not actual NPP. Also note that degradation occurred also in the non-drylands of Zimbabwe.

from the signals detected by the satellite sensor are then normalized (i.e. the highest NDVI value takes the 100% value). This highest NPP value for each of the land classes is used as an estimate of the baseline or reference value, representing the potential NPP for that land class, all pixels of which have a homogenous vegetation type, soil type and rainfall regime. This value can thus be regarded as the potential value for that land class, serving as its baseline or reference. To this value of the class potential all other normalized NPP values in that land class can be compared and scaled as a percentage of it.

An application of this methodology, called Local NPP Scaling (LNS) is an assessment of land degradation of Zimbabwe (Fig. 1.6), which can be upscaled for deriving an estimate of the spatial extent of global land degradation. Based on maps of Zimbabwe‘s land cover and rainfall the whole land surface of Zimbabwe was stratified into land classes with respect to their vegetation type and rainfall. The

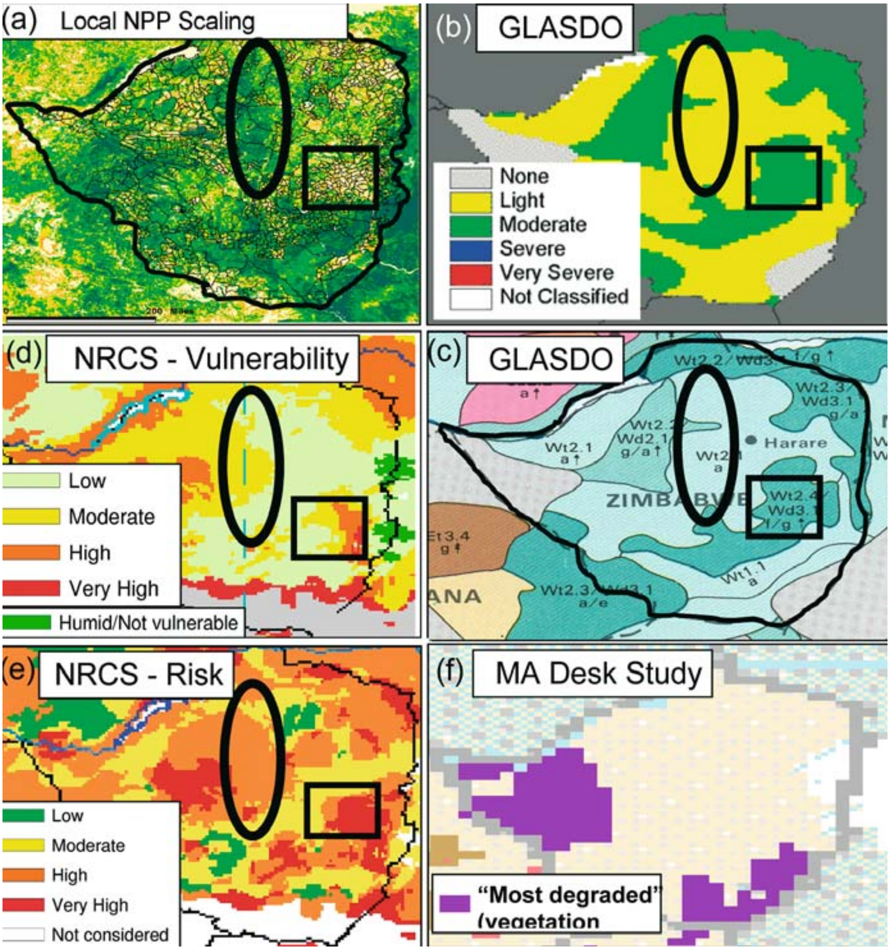


Fig. 1.8. Global degradation assessments applied to Zimbabwe (**b**)-(**f**), compared with the Local NPP scaling based on remotely-sensed NPP of Zimbabwe (**a**); Rectangles and ellipses inserted to facilitate comparisons of sampled areas. (**b**) GLASOD, downloaded from FAO website (FAO no date b); The GLASOD data base (**c**) is collapsed to four degradation severity classes, of which large areas of the country are affected by light and moderate degradation severity only; (**c**) GLASOD digitized GIS data base, downloaded from ISRIC website (ISRIC no date). Acronyms on this map signify that the green areas on (**b**) are of moderate topsoil loss extending over >50% of the areas and of strong terrain deformation and soil mass movement in <5% of the area; both types of degradation are due to water erosion and are driven by deforestation and a medium rate of overgrazing; The yellow areas of (**b**) are of moderate topsoil loss due to water erosion, extending over <5% of the area. (**d**) and (**e**) have been downloaded from NRCS website (NRCS no date) and assess "desertification vulnerability" determined by soil classes and climate features (**d**), and its derived "risk" when population impact is addressed too; (**f**) is the MA desk study map for Zimbabwe, downloaded from LUCC website (LUCC no date). Only "hotspots", or "most degraded areas" are provided, and in Zimbabwe all these are expressed by reduced vegetation cover. The whole area of Zimbabwe is covered by data regarded as reliable by the MA desk study assessment.

percentage reduction from the *potential* NPP was then calculated for each pixel. Note that in the resulting map (Fig. 1.6) areas of identical color do not mean they are of identical NPP. Rather, they are of identical potential NPP, which may differ in absolute value depending on the vegetation type/rainfall regime of the land class to which the pixels within these areas belong.

Though the drivers of degradation have not been studied on the ground, the majority of degraded areas belonging to the LNS degradation classes of Zimbabwe (most yellow areas in Fig. 1.6) are the overcrowded communal lands, known to be seriously degraded. The least degraded ones are the privately owned farms, areas with low human density and apparently well managed rangeland (Fig. 1.7).

Though the LNS method of assessing degradation has not yet been used for assessing land degradation at the global scale, it is instructing to reflect on its potential by comparing it with the performances of the available global assessments when applied to Zimbabwe (Fig. 1.8). It is then evident that despite its apparent shortcomings GLASOD assessment based on ground observations of soil state is quite compatible with the LNS assessment of NPP detected from space. Also, areas that GLASOD classified as of "slight" and "moderate" degradation are classified as of "moderate" and "high" vulnerability by the NRCS vulnerability assessment, respectively. It is indeed expected that the extent of vulnerable areas will have a larger extent than areas where degradation already occurs. Furthermore, these areas are of "high" and "very high" desertification risk, when population impact is incorporated, which is expected too. On the other hand the MA desk study assessment results, at least for Zimbabwe, differ from those of all other assessments, including the LNS, even though the MA desk study is the only global assessment that used also remote-sensing vegetation data for its work.

1.4 Assessment of degradation trends

The initiators of the global assessment projects were aware of the need to detect trends rather than just engage in the current state of land degradation. The detection of trends was indeed a component of the GLASOD protocol, recommending assessment of degradation trends during the 5-10 years within the 1980-1990 decade. This, however, did not materialize due to paucity of manageable data and the short time allotted for this project ("Politically it is important to have an assessment of good quality *now* instead of having an assessment of very good quality in 15 or 20 years", Oldeman et al. 1991). Similarly, the MA Desk Study too aimed at assessing trends. The title of this study was "Synthesis of the main areas of land-cover and land-use *change*" (Lepers 2003), and it attempted to detect areas with trend of environmental degradation during the two decades of 1981–2000 (Lepers et al. 2005). This worked well for detecting global deforestation and global cropland extent trends, but not for desertification trends. This is because none of the data sets available for the desk study covered the whole 1981-2000 period, and hence the final product of the study does not include information on the time during which the land was degraded, within that period or even prior to it (Lepers et al. 2005).

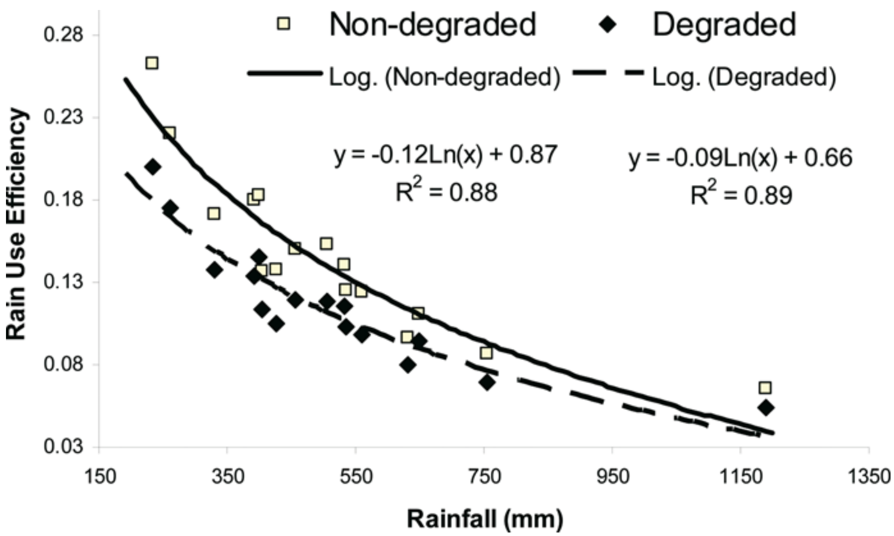


Fig. 1.9. Rain Use Efficiency (RUE) as a function of annual rainfall of degraded and non-degraded sites in two areas in northern South Africa, both exposed to identical rainfall regime and monitored along 16 growth seasons (see Fig. 1.5, data of Wessels et al. 2004, adapted from Safriel and Adeel 2005).

To conclude, there are no quantitative-oriented assessments of land degradation *trends* at a global scale.

1.4.1 Rain Use Efficiency methodology

Though land degradation trends for the global land have not been assessed, relevant methodologies have recently been, and are being currently developed for this purpose, with already available applications at the local scale. The major obstacle for detecting a trend in land productivity, especially in drylands, is the strong dependence of dryland NPP on rainfall, coupled with the drylands‘ strong inter-annual rainfall variability (e.g. Fig. 1.5). In combination, they prevent discerning human-induced from rainfall-induced changes in NPP. A simple way to control for the effect of rainfall is using the Rainfall Use Efficiency (RUE) ratio, and following its behavior through a period during which an existence of trend is explored.

Using the RUE method it was found, for example, that during the period 1982-1990 which included the severe 1984 Sahel drought, a trend of RUE *increase* (though of small magnitude) rather than of a decrease took place in most Sahelian areas (Prince et al. 1998). This led to the conclusion that the reduced productivity of the Sahel was not “desertification” (in the sense depicted by GLASOD). Namely, it is a

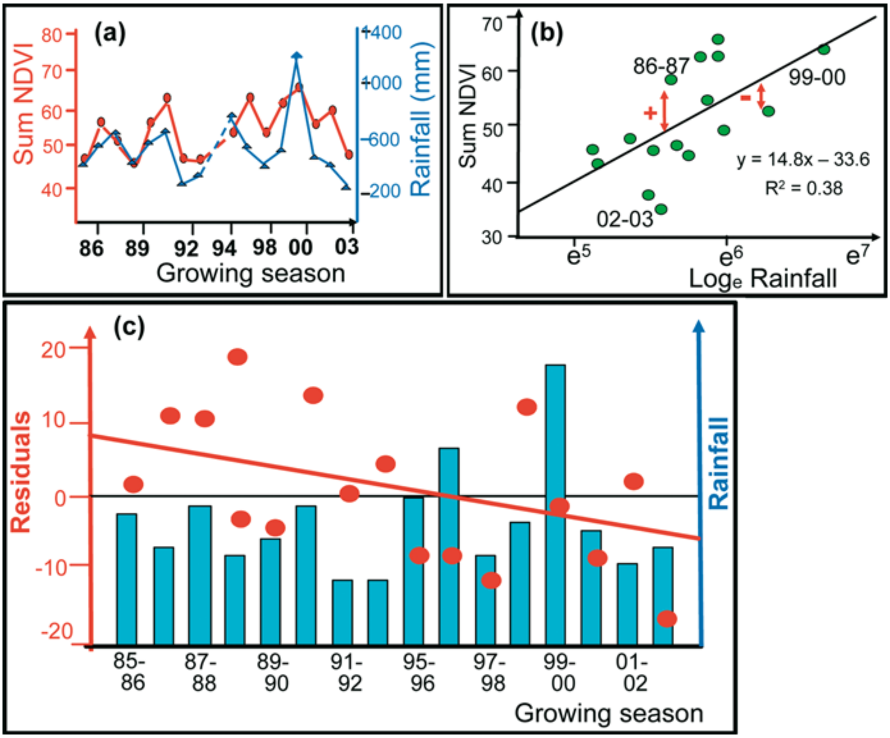


Fig. 1.10. The RESTREND methodology applied to area in north-eastern South Africa (adapted from Wessels et al. 2007). (**a**) SumNDVI of the degraded areas (red curve) and the rainfall (blue curve) in each of the 16 growing seasons (as in Fig. 1.5). (**b**) Based on (**a**), sumNDVI is plotted as a dependent variable against ($\log_e$) of rainfall as an independent variable; each point stands for one year of the studied period, and log scale is employed to generate a linear regression of productivity on rainfall. The vertical distance between each point and the regression line is the residual, or deviation from the mean relationships between productivity and rainfall. Residuals above the regression line are positive deviations and those below the line are negative ones (vertical red lines), whereas the residual value for those on the line is zero. (**c**) All residuals measured in (**b**) are plotted against the time-series of growing seasons [abscissa same as in (**a**)]; a regression line is then calculated and evaluated. The regression in this case study is negative, indicating a negative (i.e. increasing) trend of degradation during the period 1985 to 2003.

response to reduced precipitation, and not a response to human impact. The Sahel "desertification" seems to be only a temporary rather than a *persistent* reduction in land productivity. This claim was further corroborated by a remote-sensing based study of a longer period (1982-2000, Nielsen and Adriansen 2005), suggesting that the Sahelian NPP is resilient to the rather infrequent severe droughts and currently it is slowly recovering from their 20th Century Sahelian onslaught. The RUE methodology has also been incorporated into a land degradation monitoring system for sub-Saharan Africa, which also monitors soil erosion as an output of a surface runoff model driven by rainfall data. This system is claimed to be of a potential for

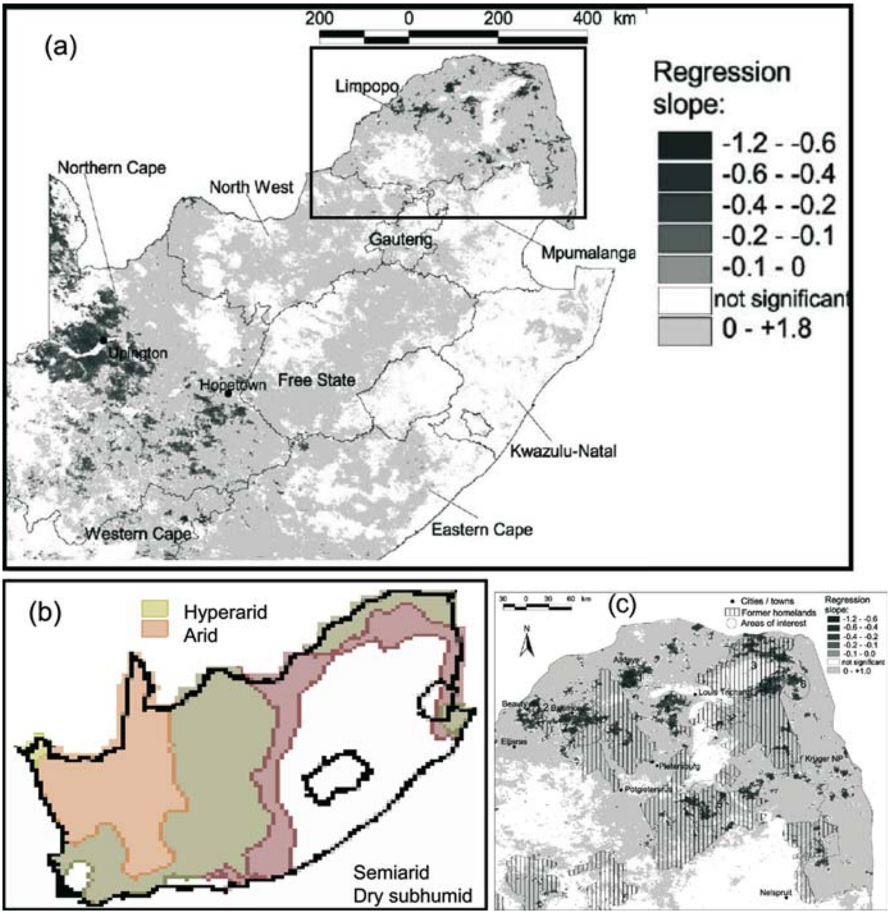


Fig. 1.11. South Africa – RESTREND of 1985 – 2003. (**a**) Expressed in classes of regression slopes (**a**) (from Wessels et al. 2007); (**b**) The country's dryland types (from MA core data base). Note that the strong trend of degradation during this period [seen at (**a**)] is in arid drylands of the south-west and in the semiarid drylands in the north-east. On the other hand there is no degradation trend and/or an improvement trend in the non-drylands (but also in other areas); (**c**) North-east region of the country [rectangle in (**a**)], with location of the former homelands, where human impact has been severe. Note that most sites with accelerated trend of degradation during the studied period are in these areas, which are semiarid and dry subhumid ones.

detecting and monitoring land degradation trends (Symeonakis and Drake 2004). Yet, in-spite of its apparent power of discerning the RUE methodology`s reliability has been doubted by the finding of a strong negative correlation of RUE with rainfall (Fig. 1.9) e.g. for South Africa r = -0.82 (Wessels 2007). Thus RUE may not remove the effect of rainfall variability on primary production of individual years, and hence in spite of its utility for detecting degradation it may not be useful for detecting degradation trends.

1.4.2 The Residual Trends methodology

The Residual Trend (RESTREND) methodology for detecting trends uses rainfall but is not rainfall-dependent and is based on an analysis of the residuals of the productivity-rainfall relationship throughout a time period, for each pixel in the area explored for detecting degradation trends (Evans and Geerken 2004). This methodology was successfully applied to a region in northern South Africa (Wessels et al. 2007). It is applied here to the same data presented in figures 1.5 and 1.9, and its procedure is explained in the legend for Figure 1.10.

Thus, the inputs for the RESTREND method are NDVI and rainfall values for a time-series under consideration. These are used to obtain a regression line of the relations between sumNDVIs and rainfall. If this regression is significant, then the residuals from the regression line are calculated and plotted against the time-series.

Significant regression indicates a degradation trend, its sign indicates whether the trend is positive (i.e. successful rehabilitation of degraded areas) or negative, and the slope of the regression line (i.e. the size of the regression coefficient) denotes the magnitude of the trend. Thus, whereas the current state of the land and the severity of its degradation are expressed by the percentage deviation of the productivity from the potential productivity (e.g. Fig. 1.6), degradation trend is expressed by the sign and the size of the coefficient of the regression of the NPP-rainfall residuals, on the time-series for which the trend is established (which stand for the direction and slope of the regression line, respectively).

This methodology was used for detecting and quantifying degradation trends for South Africa, where they can be associated with the inherent degrees of aridity in the different regions of the country and with areas of human impact typical to the former homelands during the studied period (Fig. 1.11). Indeed, results of a country-wide rangeland monitoring program, the South African National Report on Land Degradation's data on rate of change in rangeland condition of magisterial districts over the period of 1989-1999, were compatible with the RESTREND results. This is so in spite of differences in spatial scales between the two assessments (Wessels et al. 2007).

Given the encouraging results from the South African study, it seems that the RESTREND method can indeed detect degradation trends. Yet, in-spite the observed relations with dryland type and with human impact (Fig. 1.11), the precise causes of negative trends can not be fully understood when using this method alone. Field surveys for elucidating features and processes that are not always detectable using satellite data only are required (Wessels et al. 2007). This RESTREND method, however, already produced several provisional versions of maps of global land degradation trends, which are under testing and improvement efforts (S. D. Prince, personal communication).

1.5 Conclusions

Land is a component of Mother Nature serving as infrastructure for much of life on earth, yet its functioning is in the hands of mankind. Monitoring and assessment of states and trends of the services provided by the land when used by people are therefore essential. Especially when burgeoning populations and expanding human footprint on the surface of the earth drive globalization, there is an increasing need, awareness and demand to assess the state of the global degradation, rather than just that of the national or local lands. But the commendable efforts so far made to assess where and when on earth land cooperates with people, and where, when and why it is misused and therefore betrays them have been fraught with difficulties. Thus, we even don‘t have a satisfactory answer to the question of how much of the global land is degraded; let alone what the trends of degradation have been in the past and evident at present.

One important step forward is conceptual, and this is the definition of land degradation as a persistent reduction in the provision of the major land service – primary productivity. The other step forward is harnessing remote-sensing sciences for assessing states and trends of land degradation, especially those through the remotely-sensed assessment of vegetation functions. Thus, the best promise for future assessments at global scale is the use of remote-sensing for addressing the persistence of reduction in land productivity. Methods such as LNS and RESTREND which discern productivity from rainfall effect and therefore, by default, implicate human impact, need to be verified by field studies (e.g. as shown in Fig. 1.5 and the other evidence provided in this chapter) and upscaled to support not only local but also global insights.

It should be stressed however, that *persistence* does not imply *irreversibility* i.e. it is not known whether the productivity of land that is properly identified as degraded, and explicitly so due to human impact, can recover once the impact is removed or actions to rehabilitate it are taken. This would only be elucidated by assessing *trends* both at a local and a global scale using methodologies like RESTREND and others yet to be developed (e.g., by the LADA [Land Degradation Assessment in Drylands] project, Lantieri no date). Since methods like the RESTREND can detect both degradation trends and rehabilitation trends, assessing trends of land degradation will be instrumental in detecting the effectiveness of measures for "combating desertification" in the drylands and addressing land degradation in the non-drylands. Further developing and advancing the tools for assessing trends of land degradation at the local, regional and especially the global scale are critical for effectively, reliably and what is most important, impartially evaluating projects of "combating desertification" under the UNCCD (such as the implementation of the National Action Plans) and of projects addressing land degradation and sustainable land management (e.g. projects conceived and supported by the Global Environment Facility, the World Bank and others). Thus, a detection of trends provides both early warning for misuse of the land, as well as for failure or success of precautionary or rehabilitation measures.

Acknowledgements

I wish to thank Dr M.V.K. Sivakumar and Mr Ndegwa Ndiang'ui for inviting me to make this presentation at the International Workshop on Climate and Land Degradation and for encouraging me to write this chapter. I also wish to thank Steve Prince and Inbal Reshef for sharing with me information and ideas.

References

Arnalds O, Dorarinsdottir EF, Metusalemsson S, Jonsson A, Gretarsson E, Arnason A (2001) Soil Erosion in Iceland. Soil Conservation Service, Gutenberg.

Blaikie P, Brookfield H (1987) Land Degradation and Society. Methuen, London.

Bridges EM, Oldeman LR (1999) Global Assessment of Human-Induced Soil Degradation. Arid Soil Res Rehab 13:319-325

Chasek PS, Corell E (2002) Addressing desertification at the international level. The institutional system. In: Reynolds JF, Stafford-Smith DM (eds.) Global Desertification: Do Humans Cause Deserts? Dahlem University Press, Berlin, pp. 275-194

Diamond J (2005) Collapse. How societies choose to fail or succeed. Viking, New York.

Dregne HE (1977) Generalized map of the status of desertification of arid lands. A/CONF 74/31. United Nations Conference on Desertification, Nairobi, Kenya.

Dregne HE (1983) Desertification of Arid Lands. London, Harwood Academic Publishers

Dregne HE (2002) Land degradation in the drylands. Arid Land Res Manag 16:99-132

Dregne HE, Chou N (1992) Global desertification and costs. In: H.E. Dregne (Ed.), Degradation and restoration of arid lands. Texas Tech University, Lubbock, pp. 249-282

Eswaran H, Reich PF (1998) Desertification: a global assessment and risks to sustainability. Proceedings of the 16th International Congress of Soil Science, Montpellier, France.

Eswaran H, Lal R, Reich PF (2001a) Land degradation: An overview. In: E.M. Bridges et al. (Eds.), Response to land degradation. Science Publishers, Inc., Enfield (NH), pp. 20-35. Acessible at http://soils.usda.gov/use/worldsoils/papers/land-degradation-overview.html

Eswaran H, Reich P, Beinroth F (2001b) Global Desertification Tension Zones. In: Stott DE, Mohtar RH, Steinhardt GC (eds) Sustaining the Global Farm. Selected papers from the 10th International Soil Conservation Organization Meeting held May 24-29 1999 at Purdue University and the USDA-ARS National Soil Erosion Research Laboratory, pp. 24-28. The conference paper is accessible at http://soils.usda.gov/use/worldsoils/papers/tensionzone-paper.html

Evans J, Geerken R (2004) Discriminating between climate and human-induced dryland degradation. J Arid Environ 57:535-554

FAO (no date a) Land Degradation Severity. In: Land and Water TERRASTAT statistics. http://www.fao.org/ag/agl/agll/terrastat/wsrout.asp?wsreport=4&region=8&search=Display+statistics+%21#top Accessed February 2007

FAO (no date b) National Soil Degradation Maps in: http://www.fao.org/landandwater/agll/glasod/glasodmaps.jsp?country=%25&search=Display+map+%21 Accessed February 2007

FAO (1986) 1986 Yearbook. Volume 40, Food and Agriculture Organization of the United Nations, Rome, Italy. 306 pp.

FAO (2002) Soil Degradation Assessment. TERRASTAT CD-ROM (FAO Land and Water Digital Media Series # 20). ftp://ftp.fao.org/agl/agll/docs/landdegradationassessment.doc

GEF (1999) Report of the STAP expert group workshop on land degradation, Bologna, Italy, 14-16 June 1999. GEF/C.14/Inf.15

Grohs F (1994) Economics of soil degradation, erosion and conservation: A case study of Zimbabwe. Wissenschaftsverlag Vauk Kiel, KG, Kiel.

GRID (1991) Global Assessment of Human Induced Soil Degradation (GLASOD). A User Guide to the Global Digital Database. http://geodata.grid.unep.ch/results.php
Hillel DJ (1991) Out of Earth. Civilization and the life of the soil. Free Press, New York.
ISRIC (no date) World Soil Information
http://www.isric.org/UK/About+ISRIC/Projects/Track+Record/GLASOD.htm
Lantieri D (no date). Potential use of satellite remote sensing for land degradation assessment in drylands. Application to the LADA project. Accessed in March 2007 from LADA website: http://lada.virtualcentre.org/pagedisplay/display.asp?section=method
Le Houerou HN (1984) Rain use efficiency: A unifying concept in arid-land ecology. J Arid Environ 7:213-247
Lepers E (2003) Synthesis of the Main Areas of Land-cover and Land-use Change. Millennium Ecosystem Assessment, Final Report. Available at www.geo.ucl.ac.be/LUCC/lucc.html.
Lepers E, Lambin EF, Janetos AC, DeFries R, Achard F et al. (2005) A synthesis of rapid land-cover change information for the 1981–2000 period. BioScience 55: 19–26.
LUCC (no date) Land Use and Land Cover Change: Synthesis on the main areas of land-cover and land-use change http://www.geo.ucl.ac.be/LUCC/lucc.html
Middleton N, Thomas D (1997) World Atlas of Desertification. Arnold, London.
Millennium Ecosystem Assessment (2005a) Ecosystems and Human Well-Being: Synthesis. Island Press, Washington D.C.
Millennium Ecosystem Assessment. (2005b) Ecosystems and Human Well-Being: Desertification Synthesis. World Resources Institute, Washington D.C.
Nielsen TT, Adriansen HK (2005) Government policies and land degradation in the Middle East. Land Degrad Dev 16:151–161.
NRCS (no date) World Soil Resources Map Index http://soils.usda.gov/use/worldsoils/mapindex/
Oldeman LR (1988) Guidelines for general assessment of the status of human-induced soil degradation. Wageningen, ISRIC
Oldeman LR (1994) The global extent of soil degradation. In: Greenland DJ, Szabolcs I (eds.) Soil resilience and Sustainable Land Use, CAB International, Wallingford, pp. 99-118
Oldeman LR, Van Engelen VWP, Pulles JHM (1990) The extent of human-induced soil degradation. Annex 5. In: Oldeman LR, Hakkeling RTA, Sombroek WG (eds.) World map of the status of human-induced soil erosion: an explanatory note. 2nd ed.— Wageningen, The Netherlands: International Soil Reference and Information Centre.
Oldeman LR, Hakkeling RTA, Sombroek EG (1991) World Map of the Status of Human-induced Land Degradation. An Explanatory Note. International Soil Reference and Information Center, and the United Nations Environment Program. http://www.isric.org/isric/webdocs/Docs/ExplanNote.pdf
Prince SD, De Colstoun EB, Kravitz LL (1998) Evidence from rain-use efficiencies does not indicate extensive Sahelian desertification. Global Change Biol 4:359–374
Prince SD (2002) Spatial and temporal scales for detection of desertification. In: Reynolds JF, Stafford-Smith DM (eds.) Global Desertification: Do Humans Cause Deserts? Dahlem University Press, Berlin, pp. 23-40
Prince SD (2004) Mapping desertification in Southern Africa In: Gutman G, Janetos A, Justice CO et al. (eds.) Land Change Science: Observing, Monitoring, and Understanding Trajectories of Change on the Earth's Surface. Kluwer, Dordrecht, pp. 163–184.
Reshef, I. (2003) Reduced Productivity Mapping in Zimbabwe Phase II: Exploring new methods for LNS productive potential classification by incorporating soil data and implementing a K-prototypes clustering Algorithm. M.Sc. Thesis, University of Maryland at College Park
Safriel U, Adeel Z (2005) Dryland Systems. In: Hassan R, Scholes R, Ash N (eds.) Ecosystems and Human Well-being: Current State and Trends. Island Press, Washington, pp. 623-662
Symeonakis E, Drake N (2004) Monitoring desertification and land degradation over sub-Saharan Africa. Int J Remote Sens 25: 573-592

Tobler W, Deichmann V, Gottsegen J, Maloy K (1995) The global demography project. Technical Report TR-95-6. National Center for Geographic Information analysis. Univ. Santa Barbara, CA. 75 pp.
UN (1993) Agenda 21: Earth Summit – The United Nations Programme of Action from Rio (Report of the United Nations Conference on Environment and Development, Rio de Janeiro, 3-14 Jun, 1992). http://www.un.org/esa/sustdev/documents/agenda21/english/agenda21toc.htm
UN (no date) United Nations Convention to Combat Desertification. Published by the Secretariat of the UNCCD, Bonn. http://www.unccd.int
UNCCD (2004) UNCCD 10 years on. Secretariat of the United Nations Convention to Combat Desertification, Bonn.(ISBN 92-95043-00-8)
UNESCO (1977) World map of arid zones 1/25,000,000, Explanatory Notes. MAB Technical notes No. 7 UNESCO, Paris
WCED (UN World Commission on Environment and Development) (1987) Our Common Future. Oxford University Press, Oxford.
Wessels KJ, Prince SD, Frost PE, van Zyl D (2004) Assessing the effects of human-induced land degradation in the former homelands of northern South Africa with a 1 km AVHRR NDVI time-series. Remote Sens Environ 91:47–67
Wessels KJ, Prince SD, Malherbe J, Small J, Frost PE, VanZyl D (2007) Can human-induced land degradation be distinguished from the effects of rainfall variability? A case study in South Africa. J Arid Environ 68:271-279

CHAPTER 2

Status and Trends in Land Degradation in Africa

Lamourdia Thiombiano and Ignacio Tourino-Soto

Abstract. There is insufficient data on the extent, severity and trend of land degradation in Africa. Through a four steps approach, which is based on the identification of a pillar layer (FAO problem soils map) and the combination of dynamic factors (human activities, livestock, climate) to determine risk factors, the current paper aims at providing quantitative data on the status and trend of land degradation at agro-ecological and main river basin levels.

The results revealed that: (i) "hot spots" of land degradation are largely predominant at continental level, compare to the "bright spots" of very low to low degradation; (ii) there is an increasing trend of severity and extend of land degradation from the humid zones of the Congo and Zambezi basins (24 to 29%) to the dry areas of the Nile, Niger and lake Chad basins (78 to 86%); (iii) the interrelation and cumulative effects of water and wind erosion are also increasing along these agro ecological zones.

The study also stressed on the high spatial variability in the extent and trend of degradation process according to the various agro-ecological zones and river basins. This variability could be strongly linked to soils behaviour and level of resistance, to the quality of their surrounding environment as well as to the impact of investments for conservation of natural resources and for better land care.

2.1 Introduction

Land degradation is defined by FAO (2002) as the loss of production capacity of land in terms of loss of soil fertility, soil bio-diversity and degradation of natural resources.

The African continent, covering an area of about 3.01×10^9 hectares (FAO 1986) is seriously threatened by this phenomena as mentioned in various studies (Aubreville 1949, 1973; UNCOD 1977; Penning de Vries and Djiteye 1982; Baumer 1987; Brabant 1992; Sivakumar 1995; Sterk 1996; Thiombiano 2000, Bationo et al.1998, 2006). As a consequence, Africa accounts for 65 % of the total extensive cropland degradation of the world. According to the World Bank, at least 485 million Africans are affected by land degradation, and Africa is burdened with a US$9.3 billion annual cost due to this phenomenon. Various agricultural and non-agricultural uses of soils are pointed out for their predominant negative impact on African lands which include the lack of appropriate land use planning and mismanagement of natural resources by land users, particularly by poor farmers (Sonneveld 2002).

The main causes for land degradation in Africa include, among others, demography growth, conflicts and wars with expanded refugees settlements, inappropriate soil management, deforestation, shifting cultivation, insecurity in land tenure, variation of climatic conditions and intrinsic characteristics of fragile soils in diverse agro-ecological zones.

2.2 Evaluating the trends in land degradation in Africa

Despite the importance of land degradation, there are few accurate and updated data on its extent, severity and trend at continental level. This paper therefore aims at evaluating the trend of land degradation, based on available information, through a four-step approach.

2.2.1 Diversity of Agro-ecological zones, soils and land use systems

The African continent comprises a range of agro-ecological zones (FAO and IIASA 2000; IITA 2004) with the following characteristics as shown in Figure 2.1.

The main features of these agro-ecological zones in relation to land uses and soils heterogeneity are indicated in Table 2.1.

There is a high variability of agro-ecological zones and land use with heterogeneity of soils and landscapes. It is important to note that:

- A desert such as the Sahara, apart from "hosting " most of the shifting sand dunes also provide aeolian material over the entire Sahel (Mainguet 1991).
- Arid and semi-arid zones are characterized by the presence of old ergs (sand dunes), which are used as agricultural lands. For centuries, these lands have their fertility maintained through the use of a set of 15 technologies including expansion of organic manure (Millogo 1998; Thiombiano 2000).
- In dry zones, integrated crop and livestock production is progressively developed as an alternative to shifting cultivation.
- In sub-humid zones, soil cover destruction as a result of shifting agricultural practices is severe.
- Humid zones comprise old forests. According to FAO (2006), timber exploitation and other forms of mismanagement led to a net loss of forests exceeding 4 million ha per year between 2000 and 2005.
- In Highlands such as Kilimanjaro, the effect of climate change is illustrated by the reduction of the snow area and most of the ecosystems are threatened.
- The Mediterranean embraces specific zones such as the extreme northern and southern parts of Africa, especially the coastal areas of Algeria, Egypt, Libya, Morocco and Tunisia.

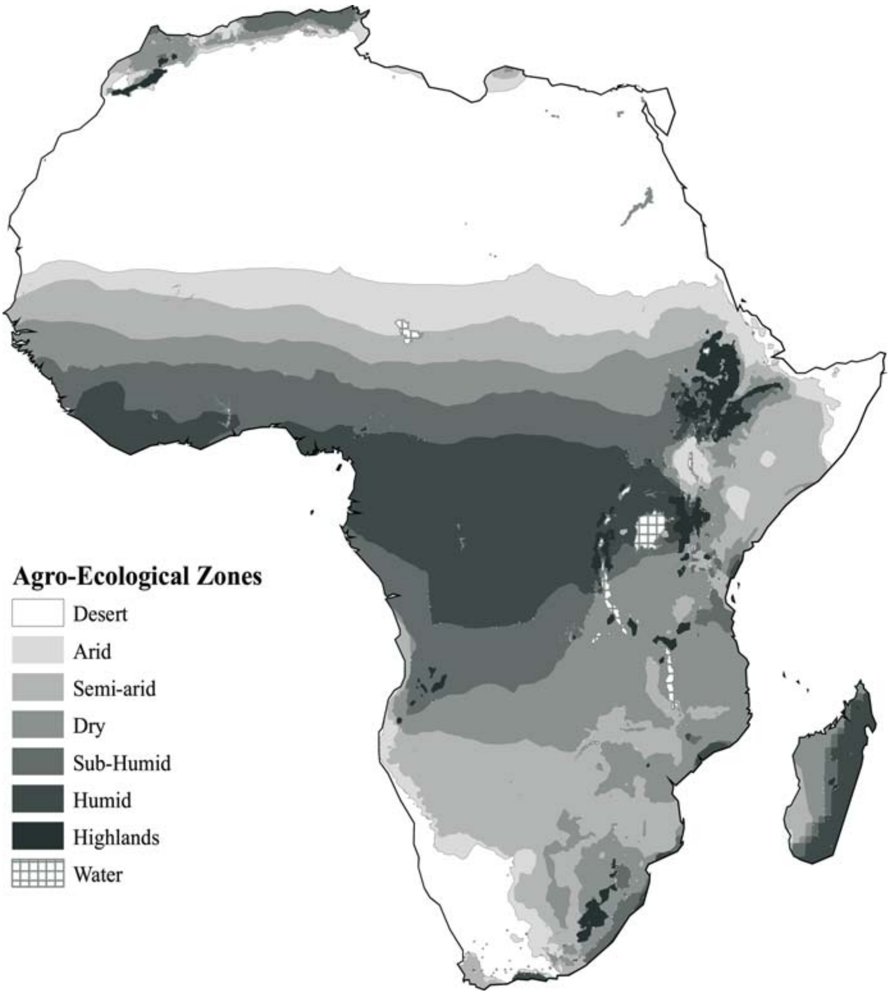


Fig. 2.1. Major agro-ecological zones based on FAO and IIASA (2000) and IITA (2004)

This high diversity of climatic conditions, the changing agricultural, forestry and livestock production systems, the heterogeneity of edaphic factors coupled with human population pressure make the task of evaluation of the extent, severity and trend of land degradation in Africa more complex.

Table 2.1. Main features of the agro-ecological zones of Africa in relation to land use and soil heterogeneity (Sources: FAO 1989, 1996; Mainguet 1991; Cloué and Dollé 1998; Millogo 1998; Bationo et al. 2006; IUSS 2006; Nocita and Thiombiano 2007).

FAO (AEZ)	Main Soil type (WRB, 2006)	Length of growing period (LGP) in days	Main land uses and farming systems
Desert (Sahara, Namib, Kalahari and Karoo deserts)	Arenosols and Regosols.	0	Oasis agricultural systems, nomadism, harvesting and hunting
Arid	Lixisols, Leptosols and Cambisols	<60	Millet based systems, Semi-nomadism and transhumance for livestock production.
Semi-arid and Dry (Sahel and Sudan savannah)	Regosols, Solonetz, Arenosols, Lixisols, Plinthosols	60-90 90-165	Integrated crop (millet) and livestock production (agro-pastoralism) systems Transhumance Sorghum, maize
Sub-humid (Guinea Savannah)	Ferralsols, Luvisols, Plinthosols and Gleysols	165-270	Agro-forestry systems based on sorghum, maize, root and fruit plants
Humid (High rain Forest)	Ferralsols, Acrisols and Gleysols,	270	Forest production (cocoa, coffee) and agricultural systems with root and tuber crops
Highlands	Nitisols, Ferralsols, Vertisols, Planosols		Grassland, pasture, coffee and tea plantations
Mediterranean	Calcisols, Gypsisols, Regosols, Arenosols, Luvisols		Wheat based system

2.2.2 Methodological approach to estimate land degradation extent in Africa

A four-step approach (Tourino and Thiombiano 2006) based on the LADA methodological framework (FAO 2002) was used to characterize the extent of land degradation in Africa (Fig. 2.2):

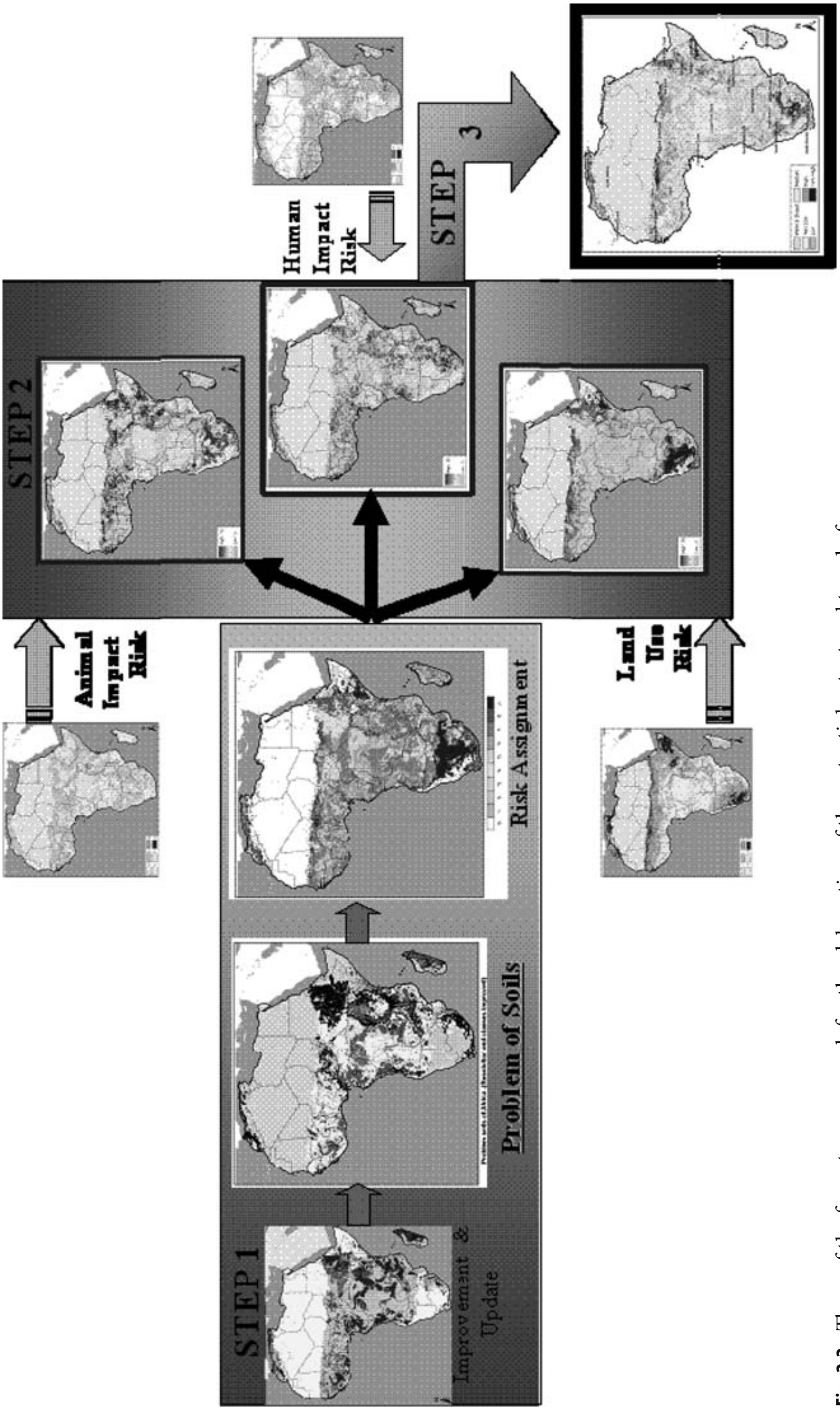


Fig. 2.2. Three of the four steps approach for the elaboration of the potential extent and trend of land degradation in Africa.

Step 0. The State of the art on land degradation in Africa through the compilation of previous studies and attempts to evaluate the extent of the phenomenon (Fournier and D'Hoore 1958; Oldeman et al. 1991; Escadafal et al. 1995).

Step 1. The information derived from the state of the art was combined with a pillar layer, with a spatio-temporal relative stability, which, in this case, is the FAO map of problem soils (Nachtergaele 1997).

Step 2. The map obtained from Step 1 was combined with dynamic factors considered as driving forces such as: (i) livestock impact (mainly cattle and goats) from FAO (2006); (ii) Human impact (land cover, bush fires and human footprint) from Mayaux et al. (2003), Sanderson et al. (2002), and Gregoire et al. (2002); (iii) Forests and protected areas from World Conservation Union and UNEP-World Conservation Monitoring Centre (2004).

Step 3. The previous three layers of step 2 are combined based on risk factors definition to obtain a resulting map of land degradation depicting potential risks, extent and spatial trend in relationship to the variability of agro-ecological zones and river basins.

2.2.3
Extent and trend of land degradation in Africa according to agro-ecological zones

The results obtained on the potential extent and trend of land degradation according to agro-ecological zones are illustrated in Figure 2.3.

The diagram (Figure 2.3), shows a trend of decreasing severity of land degradation from the deserts and arid areas to the humid and sub humid zones. While in the arid, semi-arid and dry sub-humid zones only 3 to 30.6 % of lands are non-degraded (very low to low), in the sub-humid and humid zones the non-degraded lands cover around 38.1 to 47.2%. In the case of highlands, almost 84 % are degraded at a severity ranging from medium to very high.

2.2.4
Extent and trend of land degradation in the main river basins

Figure 2.4 and Table 2.2 show the extent of land degradation in the 11 African main river basins.

From these results, its appears that the basins of the Orange, Niger and Nile rivers and the Lake Chad basin are characterized by a high to very high land degradation (78 to 86 %) while the Zambezi and Congo river basin are less degraded (29 to 24 %).

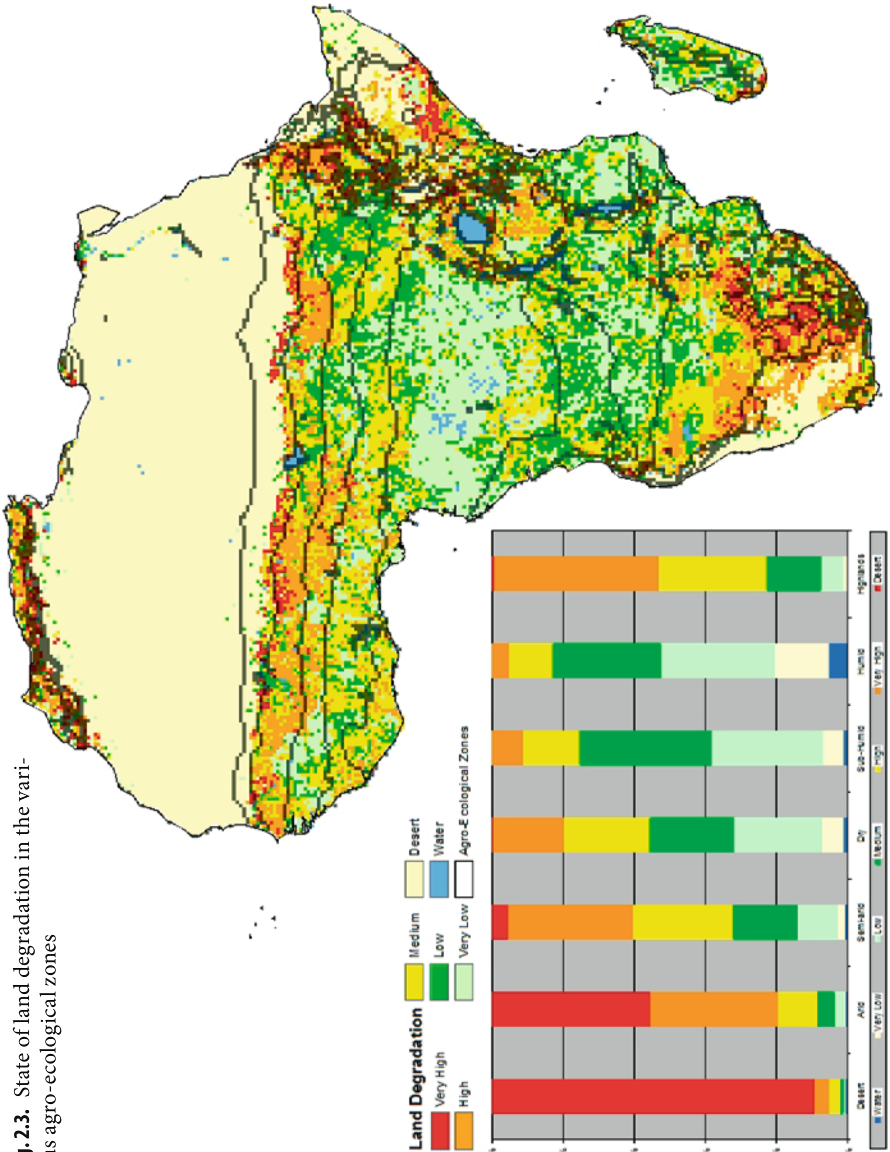


Fig. 2.3. State of land degradation in the various agro-ecological zones

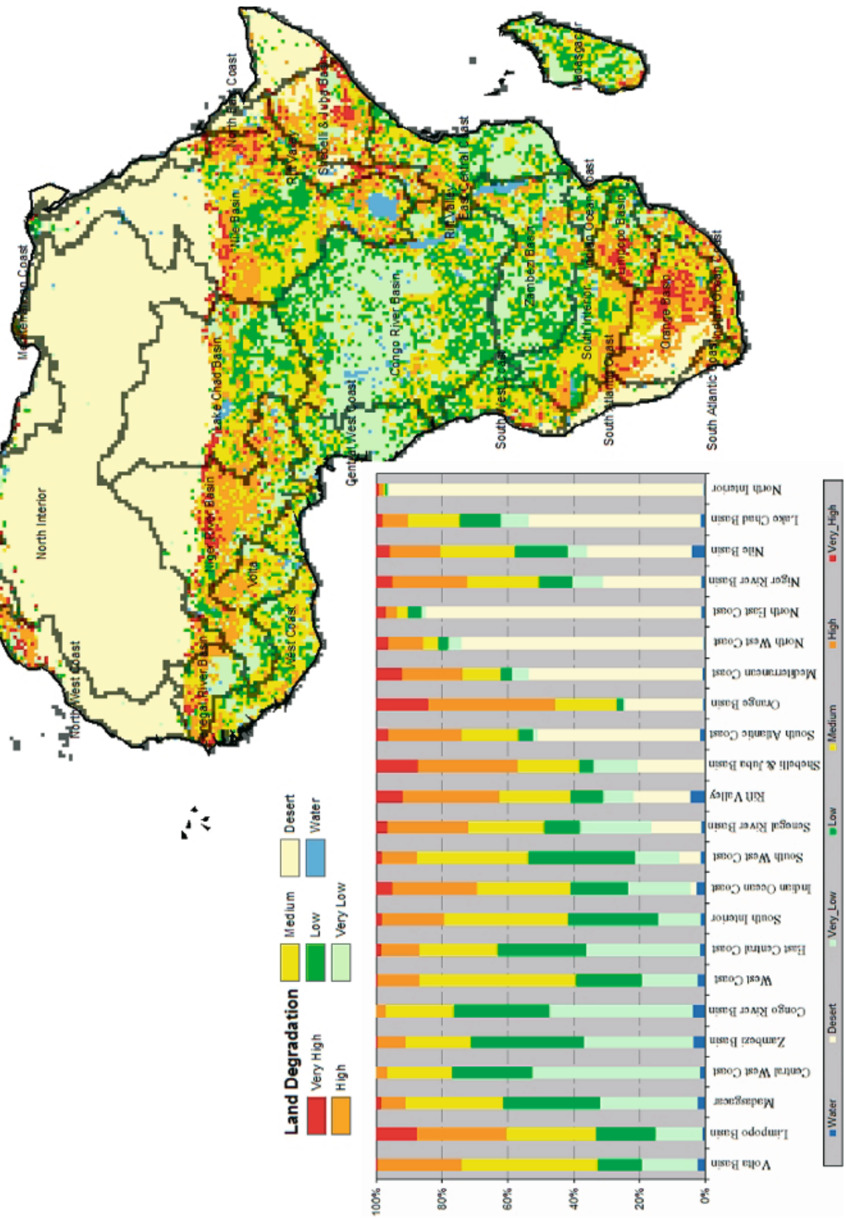


Fig. 2.4. Land degradation in the main river basins

Table 2.2a. Extent and severity of land degradation in the main river basins (km^2)

Basin_Name	Water	Desert	Very_Low	Low	Medium	High	VeryHigh
Central West Coast	9931.57	0.00	349328.55	166588.12	134247.84	23685.86	291.31
Congo River Basin	134748.47	16.40	1583541.66	1067337.53	750231.59	104295.91	1718.92
East Central Coast	14895.42	317.35	354998.49	275245.01	246049.33	118986.83	15653.60
Indian Ocean Coast	17457.41	13750.43	132688.07	121448.50	200154.42	180880.67	33203.61
Lake Chad Basin	27565.50	1286774.40	206702.16	304752.25	385213.76	194859.71	45756.97
Limpopo Basin	2926.61	0.00	63593.47	79958.94	119672.67	120636.31	55145.46
Madasgacar	12741.46	0.00	177976.24	175250.27	177747.63	45068.24	8468.26
Mediterranean Coast	4853.89	341268.31	33314.54	23041.50	74260.06	119949.51	50970.65
Niger River Basin	19497.55	647576.47	204301.26	210754.46	472880.85	491571.99	105656.00
Nile Basin	119726.68	1003866.57	188922.57	496508.83	717510.29	474920.03	131254.67
North East Coast	8225.18	643697.80	11566.57	30234.56	26302.83	25465.55	22870.77
North Interior	10417.73	5928837.01	33840.25	26935.61	46865.30	84541.78	46736.04
North West Coast	1560.73	587798.02	34236.70	22450.20	36346.29	85340.47	29642.29
Orange Basin	4488.30	251886.15	7312.67	20706.20	201147.00	411354.53	169683.54
Rift Valley	28007.29	108358.82	58379.78	63872.24	135867.41	186667.33	50903.13
Senegal River Basin	4721.74	67262.82	94805.17	47609.01	101318.18	107361.42	15455.85
Shebelli & Juba Basin	757.21	161139.07	105441.86	34481.71	148058.08	239619.28	99406.33
South Atlantic Coast	5428.79	191511.57	5392.14	17460.30	66042.60	87235.92	13972.29
South Interior	10609.68	1022.48	115484.35	250364.97	341867.33	173933.59	14687.06
South West Coast	6490.82	31493.37	67408.48	160779.28	168164.29	52019.18	8884.97
Volta Basin	9087.54	0.00	69050.23	53551.94	167840.18	102918.45	2040.14
West Coast	21997.80	26.04	170381.91	197495.97	472997.57	125878.93	5954.50
Zambezi Basin	49465.87	0.00	467772.31	480584.18	280916.88	117252.47	8255.08

Table 2.2b. Extent and severity of land degradation (%) in 12 selected basins

River basins/ AEZ	Water	Desert	Very Low	Low	Medium	High	Very High
Mediterranean							
Mediterranean Coast	1	53	5	4	11	19	8
Deserts							
Nile Basin	4	32	6	16	23	15	4
Lake Chad Basin	1	52	8	12	16	8	2
Humid zone							
Zambezi Basin	4	0	33	34	20	8	1
Congo River Basin	4	0	43	29	21	3	0
Arid, semi-arid and dry							
Shebelli & Juba Basin	0	20	13	4	19	30	13
Rift Valley	4	17	9	10	21	30	8
Senegal River Basin	1	15	22	11	23	24	4
Niger River Basin	1	30	9	10	22	23	5
Volta	2	0	17	13	41	25	1
Limpopo Basin	1	0	14	18	27	27	12

2.3 Estimates of soil loss

The high spatial variability in the extent and trend of the degradation process according to the various agro-ecological zones and river basins in Africa that were observed could be strongly linked to the behaviour and level of resistance of soils and their surrounding environment.

As an example (Table 2.3), the results obtained from several field studies (Azotonde 1997; Quansah 1997; Thiombiano 2000) revealed a high heterogeneity of soil loss according to the agro-ecological zones.

The soil loss is ten times higher in semi-arid zones compare to humid zones. This figure should be linked with the data on run-off that is 16 times higher on bare degraded soils of the Sahel compared to the low run-off in humid zones where soils are more structured. However, on the degraded *Terre be barre* (Raunet 1973) in Benin and Togo on the West coastal water unit, the overexploitation of Ferralsols in humid zones led to a high runoff and soil loss.

Table 2.3. Estimated soil and organic matter losses, runoff volume from semi-arid to humid zones

Agro-ecological zone (Country-River basin)	Type of soil	Soil loss (t ha^{-1} $year^{-1}$)	Runoff (%)	Organic matter loss (kg^{-1} ha^{-1} $year^{-1}$)
Humid (Avrankou, Benin, West Coastal Basin)	Degraded Ferralsols *(Terre de Barre)*	35.0	40	126
Sub humid (Volta basin)	Ferralsols	3.65	5.8	165
Semi-arid (Katchari, Burkina Faso, Niger Basin)	Bare Lixisols	37.3	95.3	108
Average		25.3	47	133

2.4 Discussion

The spatial high variability of land degradation according to agro-ecological zones and river basins shows clearly the potential impacts of climatic factors in the process. The types of degradation occurring within the region is largely due to water and wind erosion as major factors impacting on almost 80% of the total lands (Aubreville 1973, Oldeman et al. 1992; Pieri 1989; Perez 1994; FAO 2002).

Soil crusting in the Sahelian zone increases drastically run-off and sheet erosion (Perez 1994), which is estimated at 55.6 cm $year^{-1}$ on denuded soils (Thiombiano op. cit.). In Nigeria, the over-all total soil loss as a consequence of water erosion, is estimated up to 30 millions tonnes $year^{-1}$ (Ogunkule 2000).

In semi-arid and arid zones, wind erosion contributes to a large extent to soil transport (Sterk 1996; Thiombiano 2000). In the Sahel zone of Burkina Faso, based on the utilisation of a new type of soil catcher named “KATSOLS”, the transport of aeolian material was estimated up to 329 t ha^{-1} $year^{-1}$ (Thiombiano op. cit.); with 60% of this total amount obtained in the period from June to August at the beginning of the rainy seasons when storms start with wind speed over 10 ms^{-1}. This high variability of the impact of wind erosion with time is confirmed by Fryrear (1985) and Bielders et al. (1998).

The severity and increasing extent of land degradation from humid zones to arid and semi-arid areas as shown in figure 2.3, are the expression of the gradual interrelation and cumulative effect of water and wind erosion. Delhoum et al. (1998) have underlined the insufficient consideration of this interrelation while evaluating land degradation process particularly in semi-arid and arid zones. In the context of climate change increases of soil temperature and more frequent droughts and/or floods are expected according to the agro-ecological zones (Desanker et al. 2001). Consequently the trend for the extension of land degradation throughout the continent seems to be taking place, particularly in connection with increasing human impacts through various mismanagement practices, which are inappropriate to mitigate the variability of climate.

The mismanagement of the interrelation between agricultural and non agricultural lands results in a high trend of transfer of fertility (Hien 1995). Grass, and organic matter collected from the "common lands" are transferred to agricultural lands to improve their productivity.

At agro-ecological and river basins levels, the loss of soil organic matter due to land degradation is variable (Table 2.3). Plausible determining factors are the type of the initial organic matter in the soil, the level of soil exploitation and finally the severity of land degradation process. For instance the quantity of organic matter loss from the degraded "Terre de barre" in humid zone of Benin is 16% higher than the loss in semi-arid zones; while the loss in sub-humid zone is 50% higher, compared to the loss in dry areas.

From a land management perspective, it is important to mention that progressively farmers invest in their lands to maintain the level of production through soil fertility management and soil and water conservation practices (Ogunkule 2000; Mando 2000). Various technologies are used (Dreschel et al., 2005) for the conservation of soil and water and for the restoration of degraded lands: composts and organic manure, mulching techniques, agro-forestry, stones and earth bunds, rock dams, vegetation strips, and "zai"[1] techniques, etc... These investments contribute significantly to the expansion of bright spots as defined by FAO (2002).

Conclusions

Land degradation severity, extent and trend is variable in Africa, depending on the nature of soil, the type of agro-ecological zone and the level of human and livestock impacts on natural resources. But at the continent scale, the "hot spots" of land degradation are largely predominant compared to the bright spots of very low to low degradation resulting from conservation of natural resources or investments for better land care.

There is an increasing trend of severity and extent of land degradation from the humid zones of the Congo and Zambezi basins to the dry areas of the Nile, Niger and lake Chad basins. The interrelations and cumulative effects of water and wind erosion are also increasing along these agroecological zones. In this context, it is expected that the interrelation between land degradation and climate change may lead to an expansion of land degradation.

[1] Zai = traditional technique for bare soil productivity rehabilitation which consist in putting 10 to 30g of organic matter in a hole of 15 cm diameter and at 15 cm depth before seeding (Kabore 1994)

References

Aubreville A (1949) Climats, forêts et désertification de l'Afrique tropicale. Soc. d'Edit.géo. marit. et coloniales, Paris.352 p.

Aubreville A (1973) Rapport de la Mission Forestière Anglo-Française Nigeria – Niger (décembre 1936 – février 1937). Revue Bois et Forêts des Tropiques 148:3-16

Azotonde A (1997) Incidence de l'érosion sur la productivité des terres de barre du sud Benin. Proceedings of the Workshop on erosion induced loss in soil productivity. FAO, SRI Accra, pp. 37-52

Bationo A, Lompo F, Koala S (1998) Research on nutrient flows and balances in West Africa: state of the art. Agric. Ecosyst. Environ. 71:19-35

Bationo A, Hartemink A, Lungu O, Naimi M, Okoth P, Smalling E, Thiombiano L (2006) African Soils: their productivity and profitability of fertilizer use. Background paper presented for the African Fertilizer Summit, 9-13 June 2006, Abuja, Nigeria. 26 pp.

Baumer M (1987) Agroforesterie et désertification. CTA, Wageningen. Pays-Bas. 260 pp.

Bielders C, Rajot JL, Koala S (1998) Wind erosion research in Niger : The experience of ICRISAT and Advanced Research Organizations. In : Sivakumar MVK, Zobisch MA, Koala S, Mokanen T (eds). Wind erosion in Africa and West Asia: Problems and its control strategies. Proceedings of the ICARDA /ICRISAT /UNEP /WMO Expert Group Meeting, 22-25 April 1997. Cairo Egypt. ICARDA, Aleppo, Syria. pp. 95-125

Brabant P (1992) La degradation des terres en Afrique. Special Environnement en Afrique. Afrique contemporaine. 161:90–108

Cloué Y, Dollé V (1998) Aridité, oasis et petite production, exigences hydrauliques et fragilité sociale: une approche par analyse spatiale et socio-économique. Sécheresse 9:83-95.

Delhoum J. P., Thiombiano L., Bakiono G., Gathelier R., Kabore O.,1998 – L'interelation éerosion hydrique/érosion éolienne en milieu sahelien: cas de la zone Nord du Burkina Faso. Poster, symposium n31. 16 ème Congrès Mondial de la Science du Sol. Montpellier, AISS, 7 p.

Desanker, P, Magadza C, Allali A, Basalirwa C, Boko M, Dieudonne G, Downing T, Dube PO, Giheko A, Gihendu M, Gonzalez P, Gwary D, Jallow B, Nwafor J, Scholes R (2001) Africa. In: McCarty JJ et al. (eds) Climate change 2001: Impacts, adaptation, and vulnerability. Cambridge University Press, Cambridge. pp. 487-531

Drechsel P, Olaleye A, Adeoti A, Thiombiano L, Barry B, Vohland K (2005) Adoption Driver and Constraints of Ressources Conservation Technologies in sub-Saharan Africa. http://www.iwmi.cgiar.org/africa/west_africa/projects/AdoptionTechnology/Technology_Adoption-article.htm (version without figures)

Escadafal R, Mulders MA, Thiombiano L (1995) Monitoring Soils in the environment with remote sensing and GIS. Collect. Coll. et Sem. ORSTOM. 592 pp

FAO (1986) Atlas of African agriculture; African agriculture the next 25 years. Food And Agriculture Organization, Rome, Italy. 72 p.

FAO (1989) Soil Map of the World. World Soil Resources report 60. Food And Agriculture Organization, Rome, Italy. 125 pp.

FAO (1996) Agro-ecological zoning Guidelines. FAO Soils Bulletin 76. Food And Agriculture Organization, Rome, Italy. 78 pp.

FAO and IIASA (2000) Global Agro-ecological Zones. Land and Water Digital Media Series CD-ROM 11. Food and Agriculture Organization of the United Nations Rome, Italy and International Institute for Applied Systems Analysis Laxenburg, Austria

FAO (2002) Land Degradation Assessment in Drylands (LADA) Project: Meeting Report, 23-25 January 2002 (World Soil Resources Reports)

FAO, 2006 – Net rate of forest loss in Africa second highest in the world. Continent leads the world in forest fires. FAO NEWSRELEASE 06/26e

Fournier F, D'Hoore J (1958) Carte du Danger d'Erosion en Afrique au Sud du Sahara. Fondé sur l'Agressivité Climatique et la Topographie [Erosion risk map]. Communauté Economique Européenne. Commission de Coopération Technique en Afrique (CCTA), 1:10000000.
Grégoire J-M, Tansey K, Silva J (2002) The GBA2000 initiative: Developing a global burned area database from SPOT-VEGETATION imagery. Int J Rem Sens 24:1369-1376
Fryrear DW (1985) Soil cover and wind erosion. Trans Amer Soc Agric Eng 28:781-784.
Hien GF (1995) La régénération de l'espace sylvo-pastoral au Sahel. Une étude de l'effet des mesures de conservation des eaux et des sols au Burkina Faso. Tropical Resource Management Paper 7. Université de Wageningen, 233 pp.
IITA (2004) Agroecological zone for Africa. Geospatial Laboratory of International Institute of Tropical Agriculture, Ibadan, Nigeria.
IUSS (2006) World Reference Base for Soils Resources 2006. World Soil Resources Reports 03. Food And Agriculture Organization, Rome, Italy. 132 pp.
Kabore V (1994) Amélioration de la production végétale des sols degradés du Burkina Faso par la technique des poquets (ZAI). Thèse, Ecole Polytechnique Fédérale de Lausanne. Lausanne, pp 95
Mainguet M (1991) Desertification. Natural background and human mismanagement. Springler-Verlag, Berlin. 386 pp.
Mando A (2000) Integrated Soil management for sustainable Agriculture and Food Security. Country Case Study : Burkina Faso. FAO Accra, pp.1-32
Mayaux P, Bartholomé E, Massart M, Van Cutsem C, Cabral A, Nonguierma A, Diallo O, Pretorius C, Thompson M, Cherlet M, Pekel J-F, Defourny P, Vasconcelos M, Di Gregorio A, Fritz S, De Grandi G, Elvidge C, Vogt P, Belward A (2003) A land cover map of Africa. Joint Research Centre, Office for Official Publications of the European Communities, Luxembourg. 56 pp.
Millogo K (1998) L'histoire de l'occupation humaine du Sahel au Burkina Faso. Communication au Tour B7/Afrique de l'Ouest. AOCASS/AISS. 7 pp + Annexes
Nachtergaele F (1997) Problem Soils of Africa. Land and Plant Nutrition Management Service, Food And Agriculture Organization, Rome, Italy.
Nocita M, Thiombiano L (2007) Potential for Conservation Agriculture development and Carbon Sequestration increasing along three Megatransects in Sub-Saharan Africa. Paper presented at the 4th ASSS International Conference. Accra, Ghana. 15 pp.
Ogunkule (2000) Integrated Soil management for sustainable Agriculture and Food Security. Country Case Study : Nigeria. FAO, Accra, pp.77- 99
Oldeman LR, Hakkeling RTA, Sombroek WG (1991) World map of the Status of Human-induced Soil Degradation: an explanatory note, second revised edition. ISRIC, Wageningen and UNEP, Nairobi. 27 pp + 3 maps
Penning de Vries FWT, Djiteye MA (1982) La productivité des paturâges sahéliens. Une étude des sols, des végétations et de l'exploitation de cette resource naturelle. PUDOC. Wageningen, Agricultural Research Report No. 918, 525 pp.
Perez P (1994) Genese du ruissellement sur les sols cultivés du sud Saloum (Sénégal). Du diagnostic a l'aménagement de parcelle. Thèse de doctorat ENSA Montpellier, 250 pp.
Pieri C (1989) Fertilité des Terres de savannes. Bilan de trente ans de recherches et de developpement agricole au sud du Sahara. CIRAD, France. 444 pp + planches.
Quansah C (2000) Integrated Soil management for sustainable Agriculture and Food Security. Country Case Study. Ghana. FAO Accra, pp.33 – 75.
Raunet M (1973) Contribution à l'étude pédo-agronomique des Terres de Barre du Dahomey et du Togo. Agr Trop 28:1049-1069
Sanderson EW, Jaiteh M, Levy MA, Redford KH, Wannebo AV, Woolmer G (2002) The human footprint and the last of the wild. BioScience 52: 891-904
Sivakumar MVK (1995) Combating Land Degradation in Sub-Saharan Africa : Summary Proceedings of the International Planning Workshop for a Desert Margins Initiative, 23-

26 January 1995, Nairobi, Kenya. International Crops Research Institute for the Semi-Arid Tropics, Patancheru, India. pp.
Sterk G (1996) Wind erosion in the Sahelian zone of Niger: processes, models, and control techniques. Tropical Resource Management Papers 15. 151 pp.
Sonneveld BGJS (2002) Land under pressure. The impact of water erosion on food production in Ethiopia. Centre for World Food Studies, The Netherlands. 249 pp.
Thiombiano L (2000) Etude des facteurs édaphiques et pédopaysagiques dans le développement de la désertification en zone sahélienne du Burkina Faso. Thèse de Doctorat d'Etat. Université de Cocody. Volume I, 200 pp + Annexes.
Tourino I, Thiombiano L (2006) Land degradation in Africa. Status and Database for Evaluation of its extent at national, regional and hydrological units scale. FAO Report, 35 pp.
UNCOD (1977) Desertification. Its causes and consequences. Compiled and edited by the Secretariat of the UN Conference on Desertification, Nairobi. 448 p.
World Conservation Union and UNEP-World Conservation Monitoring Centre (2004) World Database on Protected Areas, Version 2, WCMC, Cambridge, UK

Status and Trends in Land Degradation in Asia

Hong Ma and Hongbo Ju

Abstract. Land degradation is a universal problem; it has cumulative effects at regional and global scales. This paper, based on the 500-meter resolution satellite image (band 1~7), which was acquired in 2003, and the correlative statistical data, examines the status of land degradation and desertification in the Asian Region. The perspective trends of land degradation are analyzed and indicated. The primary purpose of this study was to assess the major causes of land degradation and desertification in Asia, to suggest procedures and methods for combating desertification and mitigating the effects of land degradation and promote sustainable development.

3.1 Introduction

Land degradation, defined as lowering and losing soil functions, is becoming more and more serious worldwide. Land degradation increasingly threatens agricultural production and terrestrial ecosystems. The irrational human activities and land use patterns are the main factors causing land degradation.

Desertification is definition by the United Nations Convention to Combat Desertification (UNCCD) as "land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climate variation and human activities". Desertification may result in soil erosion, decrease of soil production ability, and loss of biodiversity and may accelerate the process of environmental degradation in the future. Desertification exacerbates poverty and political instability.

Asia is the largest continent in the world (Fig 3.1). The total area of the Asia Region is about 44 million km2, accounting for 29.4% of the total land area in the world. Asia has the largest area under drylands. In Asia, the desertification mainly occurs in the arid and semi arid areas. Failures of resource management policies are aggravated by overgrazing, overexploitation of water and land resources, overcultivation of marginal lands, and the rapid increase in population, 90% of which lies within arid, semi-arid and dry subhumid areas (Land Desertification 2005).

Desertification has come to the forefront of global concerns, as demonstrated in the number of international conferences and conventions, most recently, the UNCCD.

Keeping desertification from expanding is an important aspect for co-existence of humans and nature. Containment of desertification is the global common responsibility and duty. Fruitful and successful implementation will assuredly facili-

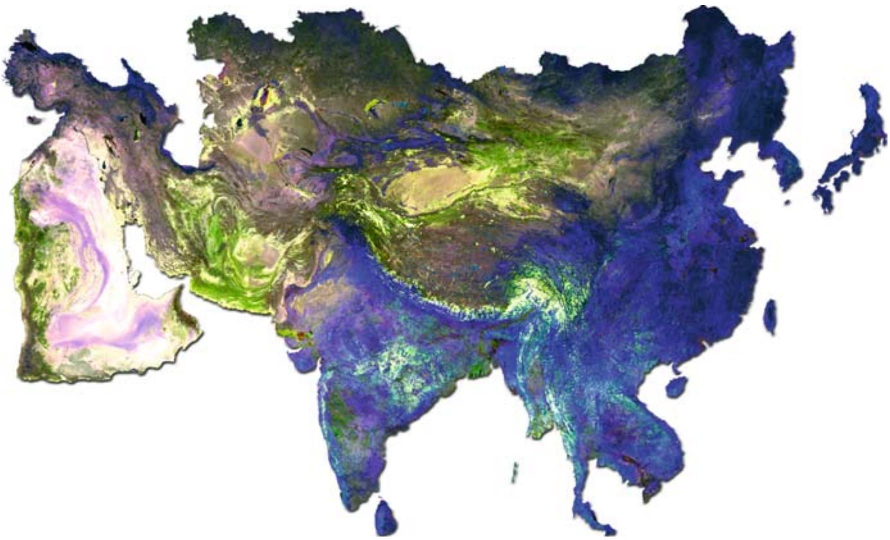


Fig. 3.1. The MODIS Image of the Asian Region

tate Asian countries actions for combating desertification and improve Asian natural environment and contribute towards sustainable development.

3.2 Desertification Monitoring and Assessment in Asia

Guided by the provisions of the UNCCD, The Asian Regional Thematic Programme Network on Desertification Monitoring and Assessment, abbreviated as TPN1, was launched in July 1999 in Beijing, China.

China has been identified as the host country to coordinate TPN1 activities among the member countries.

The Task Group Meeting on Benchmarks and Indicators for Desertification Monitoring and Assessment under the TPN1 was held in the Chinese Academy of Forestry. A proposed common set of benchmarks and indicators has been agreed upon at the meeting for comments, suggestions and further development. The proposed indicator system includes four aspects: Pressure indicators characterize driving forces, both natural and man-made, affecting the status of natural resources and leading to desertification. They will be used to assess desertification trends and for early warning. State indicators characterize the status of natural resources including land. Desertification impact indicators will be used to evaluate the effects of desertification on human beings and environment. Implementation indicators will be used to assess the actions taken for combating desertification and to assess its impacts on natural resources and human beings.

From the end of 2001 to early 2003 feed back on the Benchmark and Indicators proposal have been received from most of the TPN1 member countries and

Fig. 3.2. Desertification status map of the Asian Region

the proposal has been firstly revised to reflect part of the comments and suggestions.

According to the characteristics of desertification, and based on the benchmarks and indicators system, the proposed Asian Regional Desertification Status Map will serve users at national, regional and international levels for understanding the causes and progress of desertification and ecosystem vulnerability to desertification and land degradation. By applying remote sensing techniques to the Asian region, applied studies of satellite images in desertification monitoring and assessment are being conducted. The first draft of the desertification status map of Asia had been completed (Fig. 3.2). This map is a useful and visible reference for the prognosis of desertification and for planning preventive or combative measures against it by showing the causes and dynamics of desertification with respect to the process itself and the environmental vulnerability to desertification.

Remote sensing techniques, geographic information systems (GIS), and the global positioning system (GPS) technology development, have provided the powerful technical support for land degradation monitoring and assessment. Also they provided early-warning indicators of desertification trends (Cheng Shui-ying et al. 2005).

In the implementation of the TPN1 activities, many countries and institutions have participated. All of these efforts and results will contribute to combat desertification, a serious hazard to our planet.

India established a national network and regional action programmes were formulated for the Asian region. The aim is to strengthen the existing capacities of member countries in the Asian region to take suitable measures for combating desertification. By using satellite data, the desertification status map was made at the national level. A method for monitoring and assessment of desertification

using remote sensing has been developed in a large area and at a large scale (TPN1 2000; Ministry of Environment and Forests 2001).

Japanese scientists have made a detailed study on desertification monitoring and assessment. They have developed methods for monitoring of biological land productivity and evaluation of sustainability. As a key indicator, the social and economic aspects were combined for assessing and estimating potential land productivity by applying satellite remote sensing and GIS technologies (TPN1 2000).

Mongolian scientists collected and analyzed vast amounts of data that has been verified through ground-truthing, on relief, soil type erosion, salinity, vegetation cover, biomass and fodder resources, ground water level, wind speed and frequency, days with dust storm, precipitation, drought duration, fauna and flora species and produced the desertification map. The map shows that a large part of the country suffers from a moderate or high degree of degradation. To obtain data from vast areas, the remote sensing data were used for making the land cover map from NOAA NDVI composite data, and for monitoring purpose the GIS based databases have been developed on desertification, integrating all the above mentioned data (TPN1 2000).

In Iran, activites covered included plantation and irrigation system protection, mitigating the effects of air pollution and dust storms and monitoring and management of droughts. Satellite imagery is used in monitoring drought conditions through vegetation indices and other approaches. Actions have been taken for combating desertification in a large area.

3.3. Status and Trends in Land Degradation in Asia

Asia is encountering multiple challenges in the control of land degradation and desertification. The Asian region countries face problems of wind erosion, water erosion, soil salinization, large population, pasture degradation and vegetative degradation as a result of overgrazing and biodiversity losses. These problems cause a decline in the productive capacity of the land; induce increasingly frequent floods, droughts and sandstorms and cause eco-environmental degradation in large areas of the Asia region (Winslow et al. 2004).

3.3.1 West Asia

West Asia is facing environmental problems of land degradation and desertification at one of the highest degrees of hazard. For most areas shifting sand dunes are incapable of sustaining plant life. West Asia has a special and unusual mediterranean climate. Wind erosion, water erosion, soil salinization, large population and low productivity has accelerated desertification.

Most marginal lands in west Asia are permanent pastures of 1.35 millions km^2 and 85% of them are considered to be in danger of desertification. The removal of natural vegetation and inappropriate cultivation methods are degrading and depleting valuable and limited biological, soil, and water resources at a fast rate.

This region is considered to be having one of the highest annual population growth rates in the world. This varies from one country to another but on an average it is more than 2.4%. It is not surprising that population pressure in particular may be forcing further expansion of cropland and permanent pastures at the expense of forest and woodlands. In addition, the changing consumption patterns and life styles, resulting in increasing food demand, have hastened land degradation in this arid environment.

Saudi Arabia is the biggest country in west Asia area. The majority of areas in Saudi Arabian are the deserts, and the environment is worsening. The area is characterized by harsh environment, fragile ecosystems and limited water resources and arable lands. By the end of the twentieth century and in spite of the national, regional and international efforts to combat desertification and mitigate the effects of drought and desiccation, desertification is still one of the major environmental problems in this area.

Iran located in the arid zone, has both plateaus and mountainous regions, with the majority located in the Iranian plateau. The eastern area is the dry basin, accounting for a third of the land total area.

According to the data collected in November 2005, (Iran: Cost Assessment of Environmental Degradation) Iran's rangelands total about 90 million ha and the main source of degradation in rangelands is overgrazing. Iran has 286 wetlands and the most serious threats to wetlands have been their drainage and reclamation for agriculture and the diversion of water supplies for irrigation. The irrigated agricultural land in Iran amounts to 7.4 million ha. Around 60% of the irrigated agricultural land in Iran suffers from different degrees of soil salinity. The deforestation typically causes large scale erosion, loss of soil nutrients and the land mass has become a barren, sterile land.

3.3.2 South Asia

South Asia has a much higher population density, creating severe land pressures. Intensive over-grazing, marginal cultivation, and sand dunes, which have a high rate of movement, expanded the desertification.

A large proportion of India is covered by dry lands. Environment issues such as deforestation, soil erosion, overgrazing, and desertification have long been concerns in India, affecting the way of life for its inhabitants. The problem is more severe in the arid lands in the northwestern part of the country, especially in the desert tracts. Thar Desert in western India is the biggest desert in the south Asian area. The majority of area is barren and the intense dust storms are important disasters. The huge and growing population is placing great strains on the natural resources and the inhabitants have been moving about in search of pasture life. Thar desert is extending at the rate of 100 ha every year causing damage to approximately 13,000 ha of cultivated land and pastures in India and Pakistan.

3.3.3 Central Asia

The rugged dry land countries of Central Asia face drought and desertification risk on a wide scale, and have limited resources to combat it.

Changes to the Aral Sea Basin are regarded as one of the most extreme cases of environmental degradation in the twentieth century.

The Aral Sea in Central Asia was considered the world's fourth largest inland sea in surface area in 1960. It was also one of the world's most fertile regions. By 1992 its area had decreased by 54%. Lake levels had fallen more than 16 m and volume dropped by 75%. In 1989, the sea bed receded into two separate parts. A scheme to achieve self-sufficiency in cotton production diverted massive amounts of water from the rivers flowing into the Aral Sea. Desiccation of the sea zone triggered other processes such as salinization and pollution of waterways. The dry sea creates serious sand storms picking up millions of tons of salt and scattering it. The bottom of the dry sea has formed an area of approximately 36,000 km^2 of salt beach. Desertification has been rapidly spreading and about 80% of the northern area of the former Aral Sea is desertified. The progressive desertification has reduced the productivity of pastureland and destroyed the forests and meadows. The plentiful plantation and 15% of meadow and the massive forest resources that are around the Aral Sea have been swallowed and the fish in the Aral Sea have died out (Fig. 3.3).

The problem of the Aral sea has not only puzzled the Central Asia region, but has already become a global ecological crisis (Alles 2005).

Mongolia in Central Asia is a landlocked country with sharp continental climate (low precipitation, high daily and seasonal variations of temperature, strong sand and dust storms), which aggravates the risk of desertification.

In Mongolia the main reason for desertification is land degradation as a result of irrational utilization of land, water and forest resources, overgrazing, cutting trees and shrubs for fuel and cultivation in the background of natural factors. Animals such as rodents, grasshoppers and goats fully destroy vegetation. They increase desertification.

Scientists estimated that 90% of Mongolia's area could be subject to desertification and about 41% of the area had already been severely affected by desertification (TPN1 2000).

China is one of the countries affected by desertification over a large area, with a wide distribution and adverse impacts. The usable land resource in China is very limited. "The Chinese desertification report" by the State Forestry Administration in 2005 indicated that about 2.64 million km^2 or 27.46 percent of China's total land area is affected by desertification (State Forestry Administration 2005).

According to China's Environmental Protection Agency, the Gobi Desert, which stretches across southern Mongolia and northern China, grew by 20,000 square

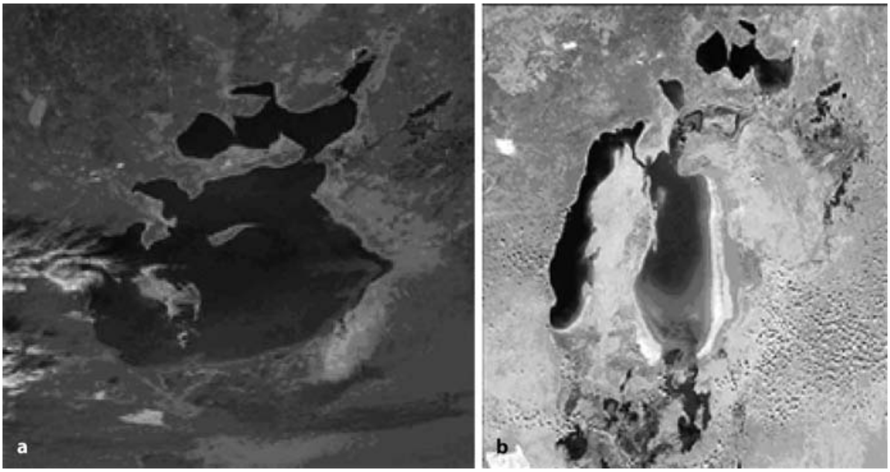


Fig. 3.3. (**a**) Aral Sea in 1985 and (**b**) in 2005

miles from 1994 to 1999, and its steadily advancing edge now sits a mere 150 miles north of Beijing. (Fig. 3.4).

3.4 Causes of land degradation in Asia

The causes of land degradation in Asia could be described as follows:

3.4.1 Increasing population

Asia is the most populated area that has been influenced by desertification in the world. With the rapid economic development in Asian countries, the rapidly growing population is placing ever-increasing demands on the land, clearing natural vegetation and tilling soil without fallow or nutrient replenishment. Hence the area under land degradation is increasing.

3.4.2 Increasing pressure on land

The rapid population growth and the concurrent increase in demand for agricultural land, food, water and shelter has put pressure on the land and water resources. This is resulting in environment degeneration in the region and the trend is intensifying unceasingly.

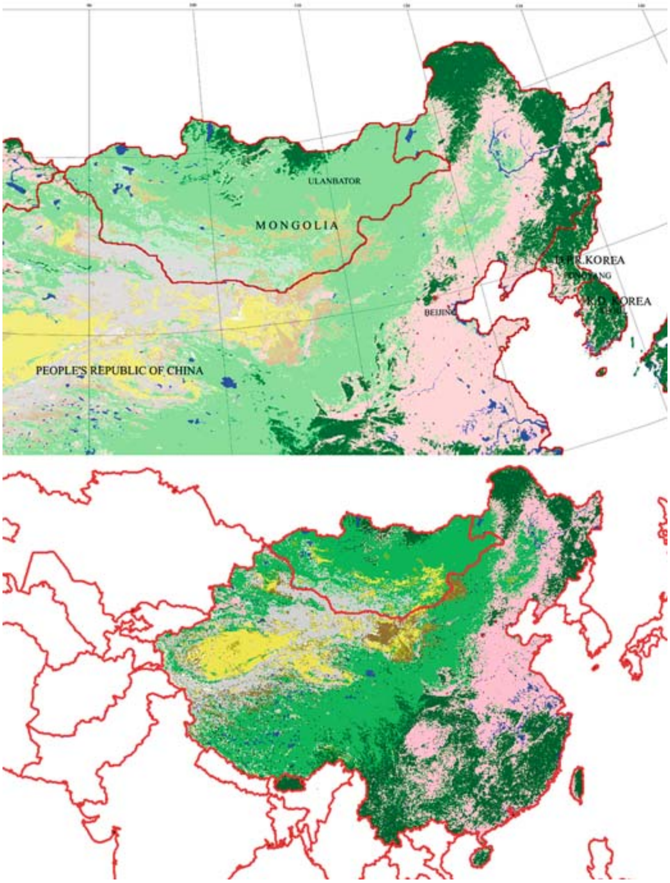


Fig. 3.4. Gobi Desert across southern Mongolia and northern China

3.4.3
Decline in soil and water resources

Due to the decline in natural vegetation and unsustainable agriculture, the capacity of soil and water resources to support life has been steadily reduced. According to the data from UNEP in 1997, of the 1.96 billion ha of soil resources in the world that have been degraded, Asia has the highest rate of approximately 38%.

3.4.4
Decline in natural forests and grasslands

Due to overgrazing and deforestation, natural vegetation cover continues to decline. There is a great impact on biodiversity which is declining.

3.4.5
Increasing atmospheric carbon and changing climate

Scientists agree that global climate change such as global warming is attributable to elevated levels of atmospheric carbon dioxide and that it is having an impact on the increasing droughts and desertification in the Asian region.

3.4.6
Deterioration in the living conditions for many people

With increasing unsustainable use of resources, land degradation leads to further degradation of land resources, which leads to increased poverty and many people have to face deteriorating living conditions. About 35% of the arable land in Asia has been influenced by desertification. Nearly 1.3 billion people or 39% of the total population in Asian region, are exposed to desertification and the arid conditions.

3.5
Conclusions

Desertification is the degradation of ecosystems on the surface of the earth.The study of land degradation is a science in which natural and social sciences overlap and interact with each other. The research for land degradation status, which is referred to above, laid the foundation for assessing current land degradation trends in the Asia Region.

Asia is one of the areas affected severely by desertification, with more than one half of the arid areas especially in the Central Asia region most exposed.

Research data indicated that desertification has been kept within limits only to some extent. In reality, it is still expanding over a large-scale and many problems have not yet been solved.

Use of satellite remote sensing technology for desertification monitoring and assessment over a large area and at a large scale is in the early stages. In developing strategies for economic and technological advancement, there is a need to prevent ecosystems from further degradation, and restore the productivity of ecosystems and natural beauty that have been affected. Therefore there is a need for more accurate, timely and systematic monitoring of desertification and future trends of projection. This will enable implementation of better environmental measures to control ongoing land degradation, recover those areas that have been damaged, improve ecosystems and in balance with rational use of natural resources.

Some developed countries have successfully implemented advanced space technologies. The need for global cooperation in combating desertification and mitigating the effects of drought has been well recognized by the international community. To achieve the goal of combating desertification in Asia, there is a need for wider development of technology support and collaboration.

Acknowledgments

This work is supported by the Secretariat of the UNCCD and the World Meteorological Organization. Image processing and mapping have been carried out by the Asian Thematic Programme Network on Desertification Monitoring and Assessment (TPN1).

References

Alles DL (2005) Freshwater Shortage and Desertification. Western Washington University, USA.

Cheng Shui- ying, LiTuan- sheng, Xian (2005) Advances in Research on Land Degradation, China

Land desertification (2005) http://www.biox.cn/content/20050414/10407.htm

Ministry of Environment and Forests (2001) National Action Programme to Combat Desertification. Status of Desertification. Ministry of Environment and Forests, Government of India, New Delhi, India.

State Forestry Administration (2005) Chinese desertification and desertification bulletin, State Forestry Administration, China.

TPN1 (2000) Workshop of the Asian Regional Thematic Programme Network on Desertification Monitoring and Assessment (TPN1), UNU, Tokyo, Japan.

Winslow M, Shapiro B, Thomas R, Shetty SVR (2004) Desertification, Drought, Poverty and Agriculture: Research Lessons and Opportunities. International Crops Research Institute for the Semi-Arid Tropics, Patancheru 502324, AP, India.

CHAPTER 4

Trends in Land Degradation in Latin America and the Caribbean, the Role of Climate Change

Fernando Santibáñez and Paula Santibáñez

Abstract. Latin America has a rich reserve of genetic resources. About 40% of the known living species are present in this Region. The continent represents an important reserve of cultivated land and fresh water. About one third of the forest of the world lives in their important tropical and temperate biomes, much of them are in pristine condition. Despite its genetic richness, important deforestation has affected mainly coastal ecosystems, settlement of the most part of its population. Originally, this continent had 6.93 millions km^2 of forests. At present only 3.66 of its original forest coverage remain. Present rate of forest loss is 15,000 km^2 yr^{-1}, that is to say, almost 3 ha per minute. About 45% of croplands in South America and 74% in Meso-America are degraded. The arid lands are threatened by desertification and very often by droughts. Both phenomena have high social costs pushing millions of people to move to cities, creating social pressure in urban areas. This is one of the sources of crime increase and political instability in many countries. At present, the tropical rain forest continues to be cleared, mainly using fire, to open lands for annual crops and pastures. There are some biomes like temperate forest in Chile and Argentina, the Mata Atlantica in Brazil, the dry subtropical forest of the Chaco, that have been reduced to small patches.

The main source of human pressure on the environment comes from unsound agricultural practices and interventions on natural ecosystems to extract goods and services. In addition, climate has been fluctuating forcing important landscape changes in the last thousand of years. Climatic trends are evident in extensive areas of the continent. Temperature in tropical Andes shows a significant warming of about 0.33°C per decade since the mid-1970s. Minimum temperature has increased as much as 2°C in some coastal areas. In the South Western Pacific coast, rainfall has shown a clear negative trend throughout the 20th century. A contrary trend has been observed in the Atlantic coast of Argentina and Southern Brazil. Climatic variability seems to be increasing, making more frequent extreme climatic events of drought and floods. In the overall continent a rapid reduction in the permanent ice bodies is observed, mainly Andean permafrost and glaciers, which moved upward their lower front about 300 m or more in a century. Main biomes of the continent are subjected to different natural and human drivers or pressure. Among the most threatened biomes are the Caatinga in Brazil, the Amazon rain forest, temperate forest of the Patagonia, the arid and semiarid *Sclerofylous* forest and highlands of Puna.

Increasing climatic hazards are forcing farmers to opt low input agriculture in order to reduce economic risk. This leads to a marginal agriculture, associated with low yields and income, and consequently, social deterioration and very often, the

primary cause of massive migrations. In some areas, farmers will never be able to adapt to these conditions at the required speed. Currently, prices of agricultural products are at the lower limit to support reductions on yields, so, farmers are in an extremely vulnerable condition.

4.1 Introduction

Latin America was under populated until the eighteenth century. It was located far from the most populated centres of the world, like China, Africa and Europe where the first human concentrations emerged. This continent was characterized for civilizations demographically dispersed in the territory, living in a relative harmony with their natural resources. Demographic expansion started very slowly, only 500 years ago, after the arrival of European to colonize this land. For that reason this continent still conserves the most part of its original genetic resources and biomes.

Latin America has probably the richest reserve of genetic resources of the world. This region provides habitat for about 40% of the known living species, has an important reserve of cultivated land and fresh water. About one third of the forests of the world thrive in this region in their important tropical and temperate biomes. Some areas of the Amazonian mass and of temperate sub Antarctic forest are among the less disturbed ecosystems that are still in pristine condition. Antarctic waters are well known for their rich marine biodiversity. Despite its genetic richness, important deforestation has affected mainly coastal ecosystems. Originally, this continent had 6.93 millions km^2 of forests. At present it has been reduced to 3.66 millions. Present rate of forest loss is 15,000 km^2 per year i.e. almost 3 ha min^{-1}.

4.2 Soils

The agricultural potential of the region is estimated at 576 million ha (GEO 2002). About 24% of the Americas are arid or semiarid (Sivakumar 2007). The major cause of land degradation is the use of unsound cultivation practices. In South America, about 45% of croplands are affected by land degradation. In Meso-America these figures are more dramatic, rising up to 74% of cropland.

The main source of deforestation in the Amazon is the expansion of croplands into previously forested areas. After some years, the soil degrades and crops are abandoned to give way to permanent pastures. Soybean production has been the main cause for the expansion of agricultural frontier in northern Argentina, eastern Paraguay and central Brazil.

The arid lands are threatened by desertification and very often by droughts. Both phenomenons have high social costs pushing millions of people to move to cities, creating social pressure in urban areas. This is one of the sources of increase in crime and political instability in many countries.

Irrigated lands are about 15 millions ha, the most part of them show symptoms of soil degradation. Nearly 20% of physical surface is already degraded

4.3 Biodiversity

The region contains 40% of the plant and animal species of the planet. The biota of all countries is threatened. In Brazil alone 103 bird species are threatened. Peru and Colombia occupy the fifth place in the world with 64 species each. A third of Chilean vertebrates are threatened. Brazil also has 71 mammal species which are threatened (the fourth highest in the world). More than 50% of Argentinean mammals and birds are also threatened.

Highlands of Bolivia, with an altitude as high as 3800 m in the border of Titicaca Lake, support intensive cultivation of annual crops (potatoes, quinoa). Herders of Lamas and Alpacas very often keep a stocking rate higher than carrying capacity of degraded grasslands, intensifying vegetation regression and soil degradation. The main processes of soil degradation in Highlands and mountain areas are water and wind erosion. The intensive extraction of water from wetlands is pushing them to desiccation, affecting the integrity of rich, biodiverse and unique ecosystems, having more than 70% of endemic species.

The Valdivian Forest in Chile (dominated by *Nothophagus* sp.) is one of the last extensive temperate rainforests of Southern Hemisphere. After a century of wood extraction, only 18% of the original Alerc forest survives. This is the second longevous species in the world (trees aged more than 2500 years). At present it is very likely that this unique species is under threat in her critical territory and forest structure to guarantee her conservation.

At present, the rainy tropical forest continues to be cleared, mainly using fire, to open lands for annual crops and pastures. In just one year (2000), more than 12,260 km^2 of rainforests were cut in the Amazon basin. In the South Eastern coast of Brazil, the Mata Atlantica vegetation, considered a rich genetic reserve, has been reduced to small patches.

South America's share of total tropical deforestation is 610,730 km^2 decade^{-1}, while Central America and Mexico's share is 111,200 km2 decade-1. These figures indicate a total rate of tropical deforestation which is higher than the rates of deforestation that occurs elsewhere in the world.

4.4 Water

Latin American continent has big river basins with abundant water resources: the Amazon, Orinoco, São Francisco, Paraná, Paraguay and Magdalena rivers represent more than 30% of continental runoff. Nevertheless, two-thirds of its territory is arid or semi-arid. These areas are located in central and northern Mexico, northeastern Brazil, West and South of Argentina, Northern Chile, Bolivia and South Western Peru. Normally arid and semiarid parts have high agricultural potential if irrigated. An area of 697,000 km^2 is currently irrigated, corresponding to 3.4% of the Latin American territory. Irrigated areas are affected by salinization and waterlogging due to bad management of irrigation systems.

4.5
Human drivers and ecosystems

Human drivers are normally called pressures upon natural resources. The main source of human pressure on soil comes from unsound agricultural practices and interventions on natural ecosystems to extract goods and services. As consequence of these human interventions the natural equilibriums are altered triggering the chain of degrading processes (Sivakumar 2007). Food, raw materials and energy production, as well as mining and industrial activity, urbanization, tourism and other human activities, exert direct or indirect pressures on natural resources. All these human actions cause loss of mass, energy or information contained in natural systems, often taking them to irreversible simplification levels. Human actions on natural systems, tend to accelerate processes leading to dissipate energy, reducing its stock of internal energy and its stability or complexity (Mosekilde and Mosekilde 1991).

Natural systems have the capability to absorb small temporary imbalances or pressures, restoring by themselves, i.e., recovering their structural and functional integrity. This resilience allows the ecosystems to stay unaffected through lingering periods of time despite changes of their environment (Schnoor 1996). Furthermore, natural systems have become stronger due to the slow and subtle climate changes which occurred through the ages.

When the imbalances go beyond the system's resilience capacity, transformations become permanent, a state from which the system will not recover by itself. In such cases, the system has lost information or essential components, unrecoverable in human scales of time. Practically any component of a natural system can be modeled as a balance among the forces that it pushes to its degradation and those that moves to its recovery. The important thing is to know which is the role of population in the input and output of matter, energy and information to and from the natural systems.

Less resilience capacity of natural systems implies higher vulnerability. In general, the most complex systems, or those that must complete longer cycles, tend to be more vulnerable, as is the case of temperate forest and wetlands. In many cases the reproduction of the plant species and animals depends on delicate balances that, when suffering distortions, can impede the spawning of new generations that could guarantee the stability of an ecosystem. The simple removal of a plant species can put in risk the subsistence of an animal species that bases its subsistence on it, which in turn, can also put in risk the survival of predators, triggering a series of processes whose end result is difficult to foresee.

The pressures exerted by humans are not easily describable by a single parameter. Many times they are the result of multiple derived factors of human actions over the environment. Additionally, an action can have effects on different environmental components simultaneously, exercising multiple pressures over several natural resources. This is the case for agriculture, an activity for which the natural ecosystem balances must be radically modified exerting overwhelming pressures over plant and animal biodiversity, soil and water resource, all at once.

4.6
Desertification

Basically, desertification is the simplification and loss of the natural balances of the ecosystems characteristic of climates with water deficit, affecting the life quality of the inhabitants. The arid climate ecosystems have, in general, high levels of resilience. Nevertheless, they are considered fragile due to the high levels of water stress that affects the vegetation communities and the poor soil protection as a consequence of the reduction of plant cover.

One of the most relevant human interventions that triggers or worsens the desertification process is the extraction of plant biomass, used as forage or fuel purposes. This reduces plant cover coverage, partially increasing soil vulnerability to the eroding action of climatic elements. Erosion of soil reduces it's fertility and it's water holding capacity, which in turn triggers a chain of processes that, through positive feedback, increases the ecosystem deterioration. Figure 4.1 shows a diagram of causes for this chain of processes.

All the processes that lead to desertification are gradual and continuous. Although degradation of the environmental components happens, in general with some simultaneity, under determined managing conditions and depending on the nature of each ecosystem, it is possible that some components degrade faster than others do. This makes each degradation situation different from others, which

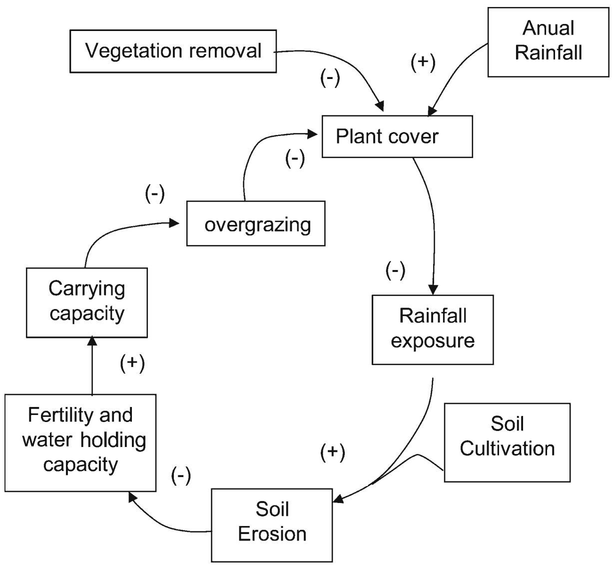


Fig. 4.1. Diagram of causality representing the main processes leading to soil degradation. Climatic variability and precipitation intensity exacerbate the negative impacts of this vicious circle.

makes it difficult to generalize a single route toward desertification. Nevertheless, it is necessary to use a numerical language that allows the representation and comparison of the various degradation profiles of the different ecosystems that compose a territorial system.

4.7 Present trends of Climate

Land degradation is a consequence of a combination of human and climatic drivers. Climate has been forcing important landscape changes in the last thousand of years. Climatic trends are evident in extensive areas of the continent (Telegeinski-Ferraz et al. 2006). Temperature records in tropical Andes show a significant warming of about 0.33°C per decade since the mid-1970s. Minimum temperature in Chiclayo, Peru's north coast, increased 2°C from the 1960s to 2000. Similar trends were observed in Chile (Rosenblüth et al. 1997). This trend has also been observed in the high plateau region in extreme southeastern Peru where minimum temperature has risen 2°C from 1960 to 2001. (http://www.climatehotmap.org/samerica.html). In the 20th century, temperature changed faster than in the preceeding centuries, showing a clear acceleration in recent decades (Villalba et al. 2003)(Fig. 4.2). Daily time series have shown no consistent changes in the maximum temperature while significant trends were found in minimum temperature, in Western and Eastern coastal regions of South America (Vincent et al. 2005). In the South Western Pacific coast, rainfall has shown a clear negative trend throughout the 20th century. A contrary trend has been observed in the Atlantic coast of Argentina and Southern Brazil, like in many other parts of the world (IPCC 2007). Mean annual precipitation in the humid Pampa increased by 35% in the last half of the 20th century (Fig. 4.3).

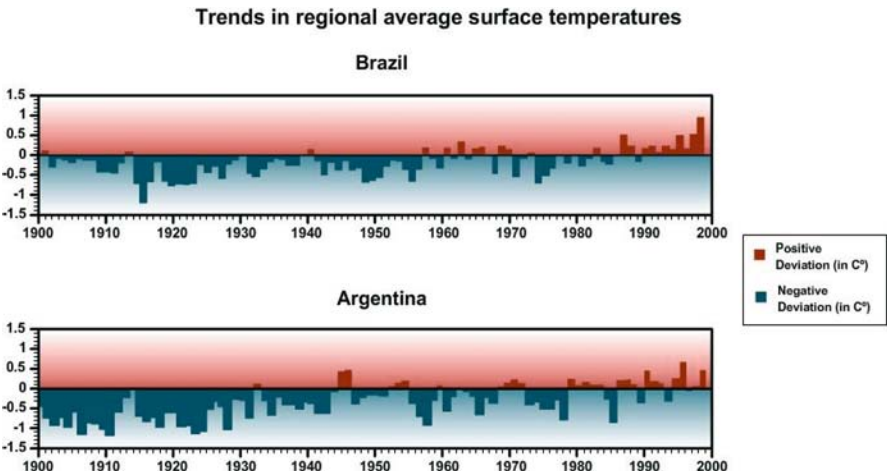


Fig. 4.2. Surface temperature changes in Brazil and Argentina over the last century (Source: Grid Arendal : http://maps.grida.no/go/region).

Climate variability seems to be increasing, making more frequent extreme climatic events of drought and floods (Aguilar et al. 2005). In the Amazonian basin, water regime tends to move to a more arid condition due to deforestation which is reducing vapor transfer to the atmosphere (Durieux et al. 2003). Amazonian rain forest is one of the few examples of clear interaction among forest cover and mesoclimatic regime.

Overall, in the continent a rapid reduction in the permanent ice bodies is observed, mainly the Andean permafrost and glaciers, which moved upward their lower front about 300 m or more in a century (Figure 4.4). Some glaciers from the Southern Argentina and Chile have retreated hundreds of metres which reduced their thickness at a rate of 100 cm per year. Glaciers in Patagonia have receded by an average of almost a mile (1.5 km) over the last 13 years. In 1972 Venezuelan An-

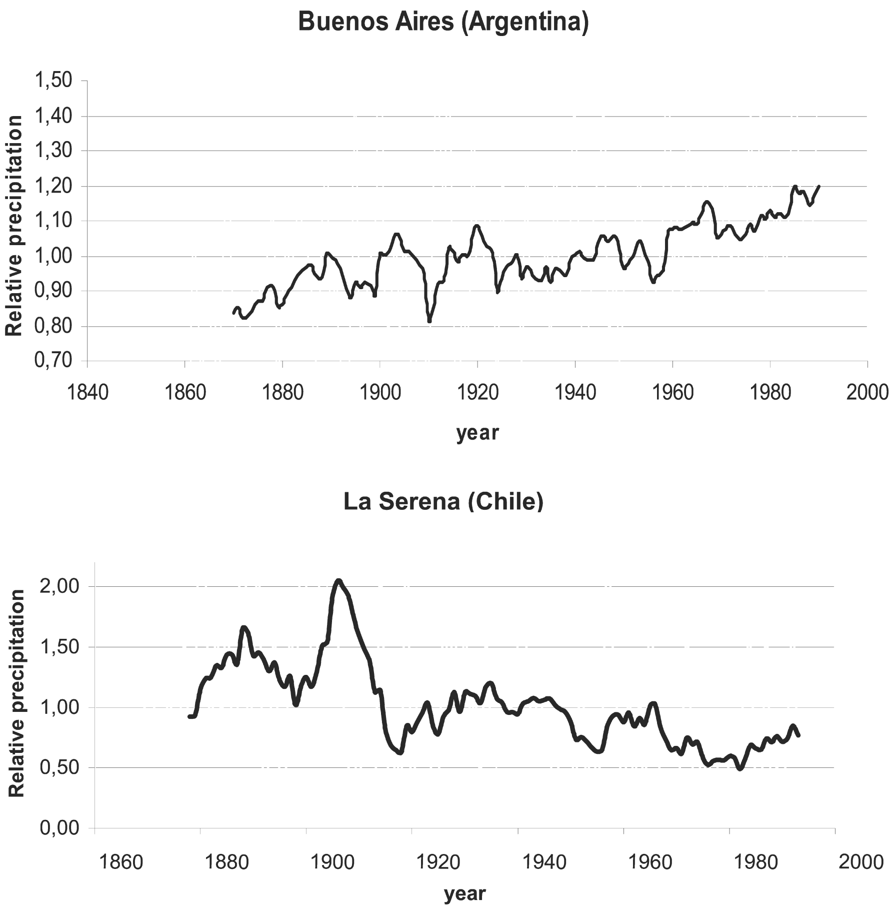


Fig. 4.3. Running average (10 year period) of annual rainfall in Buenos Aires (Argentina) and La Serena (Chile)

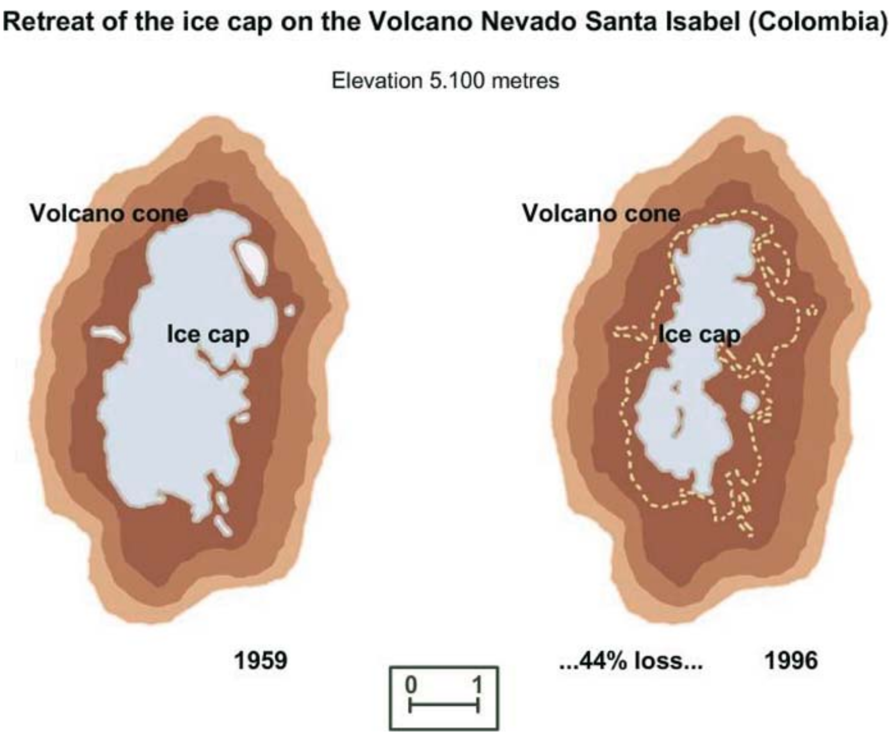


Fig. 4.4. Retreat of Ice cap on Volcano Nevado Santa Isabel (Colombia). (Source: Grid Arendal : http://maps.grida.no/go/region).

des had 6 glaciers, while at present only 2 remain, and it is expected that these will be gone within the next 10 years. All these trends are affecting the global hydrology of the Andean basins and water availability for irrigation of important agricultural areas in Chile, Argentina and Peru.

4.8 Ecosystems

Ecosystem vulnerability depends on climatic agressivity and variability, soil type, vegetation resilience and landforms. Social vulnerability depends on ecosystem vulnerability, economic resources, access to technology and social structures and assistance networks.

Highlands of the Andean region are very sensitive to climatic variations due to the presence of large human settlements, the complex landforms and a dynamic hydrological system. Landslides and avalanches are a permanent threat for small villages and agricultural lands.

In Mediterranean climates, having a long dry spring and summer, precipitation is concentrated in a short rainy period of 3 to 4 months. When the first rains arrive, a dry bare soil is intensively eroded provoking massive sedimentation of rivers and lower lands. This phenomenon was exacerbated in the last century as a consequence of soil denudation, where dense chaparral and savannas were replaced by degraded annual herbs which are unable to protect soil from water and wind erosion. In some areas close to the cities, the Andean piedmont has been urbanized provoking a rapid run off and flooding during intensive precipitations.

Main biomes of the continent are subjected to different natural and human drivers or pressures. Pressures with a human origin depend on population density and productive use of natural resources. Natural pressures depend basically on climate change, that is forcing ecosystem to adapt to new environmental conditions and creating more adverse conditions for soil conservation. Normally human and natural drivers interact negatively making it difficult to sustain the integrity of ecosystems. Another component of land degradation is ecosystem vulnerability, which can be defined as the property of natural vegetation, animal species and physical environment as a functional unity, to resist, absorb or to neutralize an external perturbation without having permanent modifications. Different biomes have different vulnerabilities depending on their capacity to restore their original condition after a human intervention or a natural environmental change. Figure 4.5

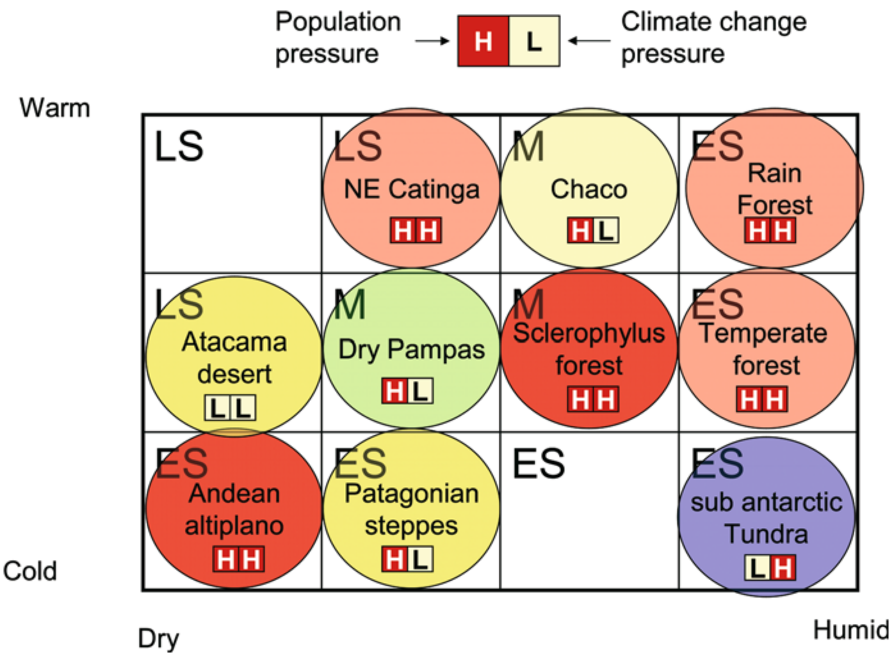


Fig. 4.5. Relative situation of the main Latin American and Caribbean biomes, related climate change, human drivers and sensitivity (H=high pressure, L=low pressure, LS=less sensitive, M=medium sensitive, ES=extreme sensitive)

presents an estimation of present human and natural pressures, and estimated sensitivity of the main biomes.

4.9 Agriculture

Soil degradation is affecting the productivity of agricultural lands, ecosystems as well as natural plant cover and biodiversity and the livelihood of populations.

Land degradation is the result of a number of causes, as unsound agricultural practices, ecosystem fragility, human pressure and climate which is getting more hazardous. Land degradation is the first phase of a long chain of processes affecting the integrity of the ecosystems, ecosystem services and the capacity of the territory to sustain human activities. One example of this is the El Niño-La Niña phenomenon. During the El Niño phase, Pacific water warms 2 to 4 degrees bringing intensive precipitations in the Southern Cone (Peru, Chile, Argentina, Pacific and Atlantic coasts), while droughts affect Colombia, Venezuela, Mexico, North Eastern Brazil and the Amazon basin. The cold phase is associated with inverse effects. This phenomenon is a real threat for human settlements, being the main cause of floods and landslides. Periodic droughts create unfavourable conditions for investments in agriculture. This El Niño Southern Oscillation (ENSO) is probably the main driver for climatic variability in the continent, making precipitations highly hazardous, forcing farmers to resort to agriculture of low inputs in order to reduce economic risk. This leads to a marginal agriculture, associated with low yields and income, and consequently, social deterioration and very often, the primary cause of massive migrations. This has been the case in North Eastern Brazil, Northern Argentina, Northern Chile and Mexico (MA 2002; NRC 2002).

Land degradation is the end result of a long chain of processes having different beginnings (Pielke et al. 2007). The most common is social marginality and lack of economic and technological resources (Fig. 4.6). Under these conditions, farmers, often small owners, tend to minimize cost using basic and aggressive techniques of soil cultivation, leading to soil erosion. A second cause has historically been mining. High energy requirements of metal foundry, stimulated deforestation of fragile ecosystems to provide mines with fuel wood and charcoal. The third cause was industrial agriculture that used high levels of fertilizers, pesticides and machinery. This combination led to the loss of organic matter, soil compaction and, after some years, a global decay in soil productivity. In all cases there was a combination of human pressure and climate aggressivity threatening important ecosystems. In tropical areas, sugarcane cultivation during the last three centuries and especially in the late 18th century, was the primary cause for forest cover removal to install unsustainable production systems. Much of this land had only shallow and fragile soils which are highly erosion prone due to the steepness of the slopes it occupied. Consequently a loss of significant amounts of topsoil was observed from many areas, especially in the volcanic soils of Meso America. Although the worst affected areas are no longer in cultivation, the natural vegetation that has recolonised these areas is much poorer in species composition and biomass than the original vegetation.

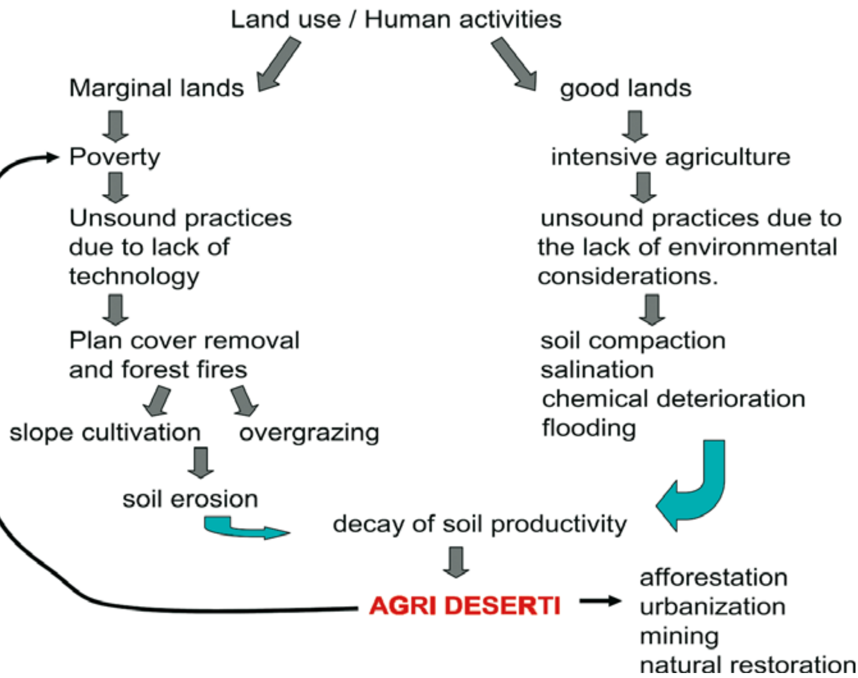


Fig. 4.6. Paths to land degradation. Good lands with intensive agriculture and marginal lands with low input agriculture follow different path by the end results are similar. The Agri Deserti is a completely degraded land unsuitable for agriculture.

In arid and semiarid parts of the continent, low and variable rainfall creates a permanent water stress that produce poor stands of sparse vegetation, which provide ineffective protection to the soil from the erosive effects of rainfall and wind.

The effect of climatic variations on crop productivity is difficult to predict due to the complexity of the cause and effect relationships among plant ecophysiology and climate. In some case the effect of higher temperature is clearly negative, in some others, clearly positive. The balance of negative and positive impacts will determine the behavior of crops in new climatic scenarios. A rise of temperature in cold climates will be certainly positive, stimulating growth rate and biomass accumulation. If this phenomenon is accompanied by precipitation reduction, the negative effect of this will oppose to the positive change in temperature regime. The final result will depend on which of the two phenomena will predominate over the other. In tropical regions, a rise of temperatures will create conditions for thermal stress which is deleterious for crops. Simultaneously a higher CO_2 content will allow plants to better support these stressing conditions, due to higher photosynthetic rate, which provide more carbohydrates to maintain higher respiration rates. What is expected in all climates is the fact that global warming will accelerate life cycles of pest and insects, increasing sanitary equilibrium of plants. Analogously, life cycle of plants will be accelerated reducing time for biomass accumulation. This will affect yields negatively. To neutralize this phenomenon, cultivated areas should move to fresher climates when possible or change sowing dates looking for the lower temperatures during the year. Areas where these two possibilities are unlikely, agricultural yields will fatally drop.

In hot tropical climates, temperature rise will force crop yield to decrease, by shortening the duration of crop growth cycle. Phenology will occur faster reducing the duration of phonological phases, consequently, production of fruits, grains and plant aerial organs will drop. In arid climates of the continent (NE Brazil, Northern Mexico, Peru and Chile, and Southern Argentina), this negative impact is reinforced by a decreasing annual rainfall. In humid tropical climates (Amazon basin, Northern Argentina and Meso America) the higher temperatures interact with a more aggressive and unstable precipitation pattern in the recent decades. Along the Central American-Caribbean watersheds, coffee and banana crops could be additionally stressed if climate change leads to increasing frequency of storms and heavy precipitation (Campos et al. 1997). Ozone depletion (WMO 2003) will also contribute, in the Southern part of the continent, to increase UV levels that impair the growth of some crop species due to its deleterious effect of auxines. One exemption is the grapevine, species that benefit from increased levels of UV, which increase the synthesis of flavonoids improving the quality of wine.

Global warming also will create better conditions to extend the geographic distribution of insects and pests. Higher temperature accelerates reproduction, shortening the time to complete life cycle of insects and pathogenic agents (Porter et al. 1991). Changes in precipitation regime can increase sensitivity of hosts, reducing predator populations and competitors (Löpmeier 1990; Parry et al. 1990). There is some evidence of poleward expansion of pest and insect distribution ranges which can create new sanitary risks in the temperate climate (Porter et al. 1991). This expansion is expected to continue affecting highlands and temperate agriculture. An example of this was the arrival of late potato blight (Phytophthora infestans) in Central Chile in the early 1950 (Treharne 1989). Figure 4.7 shows positive and negative effects of climatic warming.

In extensive areas, farmers have limited financial resources and adopt low input farming systems having little capacity to adapt to the new conditions imposed by climate change. Adaptive capacity requires efficient irrigation and water management systems, highly technified management of pests and diseases, a strict control of climatic risks by managing early warning systems and information systems (GCOS 2003), adaptation of genetic resources (to change crop seasonality and increase resistance to pest and diseases), highly technical management of pesticides and fertilizers (to prevent contamination of waters and foods). In some areas farmers will never be able to adapt to these conditions at the required speed. Marginal agricultural populations may suffer significant disruption and financial loss even facing relatively small changes in crop yield and productivity (Parry et al. 1988; Downing 1992; GEF 2006). Currently, prices of agricultural products are at the lower limit to support reductions on yields, so, farmers are in an extremely vulnerable condition.

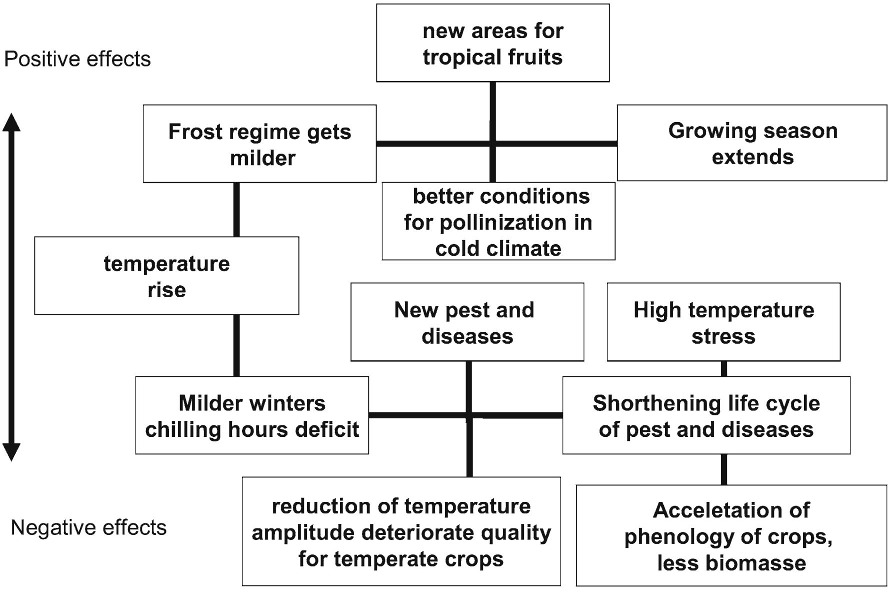


Fig. 4.7. Summary of positive and negative effects for crop species of temperature rise

Due to higher prices of energy, pesticides and fertilizers, estimated net economic impacts of climate change on crops are negative for several Latin American countries (Reilly et al. 1994).

Globally the continent will endure important climatic modifications all over its territory (Table 4.1). Changes in South America, especially in coastal areas, could be moderated by the important mass of oceans in the Southern Hemisphere. Despite this, an important modification is expected in the behavior of climatic oscillation such as El Niño-La Niña, which will continue to be a driver for climatic variability in almost all continental extension (Paeth et al. 2006). Displacemen of isotherms and isohyets are occurring faster than adaptation mechanisms of natural ecosystems; this could become a severe threat for important biomes of this continent, mainly in the Amazon basin and temperate rain forests. Modification of rainfall regimes, the retreat of ice bodies and increased rates of evaporation, could reduce runoff and available water in the next decades. Global warming will force important adaptation in agricultural systems, this includes the better use of technology and a shift in crop seasonality. Only modern agriculture will adapt to these new conditions impacting severely small farmers who dominate in extensive areas of the continent. After analyzing these trends, some questions arise: Will we halt this tendency before a real crisis? How much will we pay to adapt to a new climate? Will we be able to adapt completely to new planetary situations?. These questions imply a real effort to restore the planet to the normal situation.

Table 4.1. Main Changes forced by global warming in Latin America and the Caribbean

Glaciers and permafrost	Upward displacement of at least 300 meters of lower border of Andean glaciers, decrease in the Antarctic Ice extent, retreat of the Patagonia glaciers, reduction of permafrost, reduction of solid precipitation and snow reserves in the Andes and high elevations.
Soil	More intense storms could increase risk of soil erosion. Even in arid environments occasional intense storm could threaten bare soils.
Freshwater	Increased runoff in winter reducing availability of water in spring and summer. Loss of capacity of hydrological regulation of the main river basins in the Andes Mountain based on snow reserves. Decreasing precipitation is reducing potential for rainfed agriculture in arid environments. As consequence of this, groundwater is being overused, increasing depth of water tables.
Water quality	Intensive storms are more frequent, causing more soil erosion and sediment transportation to rivers. Higher temperatures tend to reduce dissolved oxygen impairing aquatic organisms. Stalinization of river deltas due to the increase in sea level.
Climatic variability	Extreme climatic event are increasing its frequency, making life hazardous. This is affecting wildlife and agriculture. Some ecosystems from the Atacama Desert border are in ecological regression due to the increased climatic variability which magnifies human pressures. Drought, floods and landslides are affecting agriculture and human settlements. In some cases causing loss of human lives. In May 2000, the region of Buenos Aires, Argentina supported the heaviest rains in 100 years, 342 mm fell in just 5 days. Similar phenomenon affected Venezuela in December 1999, causing massive landslides and flooding that killed approximately 30,000 people.
Rangelands	Important areas of the continent support extensive cattle production, in some cases this activity represent un important export product (Uruguay and Argentina). These agricultural ecosystems are threatened by water and wind erosion due to increased climatic aggresivity.
Forests	The continent holds one of the bigger world forest reserves. Tropical forest is threatened by a combined action of humans and climate. Tropical forest soils in the Amazon basin are very sensitive. After a slight deforestation, exposed soil start
Biodiversity	Global warming and changes in water regime are threatening important biodiversity of tropical rain forest (Amazon basin and Central America), Semiarid tropical steppes (Caatinga from the NE Brazil), Cold Steppes of the Andean highlands (mainly Peru, Bolivia, Argentina and Chile), Subdesertic and semiarid temperate Steppes in Mexico, Peru, Chile and Argentina, Humid temperate forest (evergreen and deciduous) in Chile and Argentina and Cold Patagonian Steppes. Primary factors of degradation of these biomes is soil desiccation and droughts, displacement of isotherms faster than species adaptation and frequent intense storms which degrades or saturate soils. Temperature increase also creates favorable conditions for new species of insects or diseases. Rising sea level is leading to saltwater inundation of coastal mangrove forests in Bermuda.

Table 4.1. *Continued*

Soil Carbon reserves and organic mater	Higher temperatures favor organic mater degradation when soils are cultivated. This accelerates the loss of carbon from cultivated soils. This is the normal situation in tropical soils, which is shifting to temperate zones.
Crop seasonality	Higher temperatures will be compensated with changes in crop seasonality. Sowing dates will move towards the coldest season to maintain yields. In Mediterranean climates this could help in a better use of winter rains, reducing water requirements. This paradox was already seen using simulation models in South America.
Human health	Until 90's decade Aedes aegypti mosquitoes that can carry dengue and yellow fever viruses populated lower lands up to 1000 m. Recently appeared at regions above 2000 m.

Source: Adapted from Santibáñez (1991), IPCC (2007), van Dam et al. (2002) and Campos (1996)

References

Aguilar E, Peterson TC, Ramírez Obando P, Frutos R, Retana JA, Solera M, González Santos I, Araujo RM, Rosa Santos A, Valle VE, Brunet India M, Aguilar L, Álvarez L, Bautista M, Castañón C, Herrera L, Ruano E, Siani JJ, Obed F, Hernández Oviedo GI, Salgado JE, Vásquez JL, Baca M, Gutiérrez M, Centella C, Espinosa J, Martínez D, Olmedo B, Ojeda Espinoza CE, Haylock M, Núnez R, Benavides H, Mayorga R (2005) Changes in precipitation and temperature extremes in Central America and northern South America, 1961–2003, J Geophys Res 110, D23107, doi:10.1029/2005JD006119.

Campos M, Hermosilla C, Luna J, Marin M, Medrano J, Medina G, Vives M, Diaz J, Gutierrez A, Dieguez M (1997) Global Warming and the Impacts of Sea Level Rise for Central America: an Estimation of Vulnerability. Workshop organized by U.S. EPA, Chinese Taipei, USCSP, Government of The Netherlands, and NOAA, 24-28 February 1997, Taipei, Taiwan.

Campos M (1996) Estimación de la Vulnerabllidad de los Recursos Hidricos, Marinos-Costeros y Agricolas en Centroamerrica, ante un Potencial Cambio Climático, USCSP/Proyecto Centroamericano sobre Cambio Climático (*In press*).

Downing TE (1992) Climate Change and Vulnerable places: Global Food Security and country studies in Zimbabwe, Kenya, Senegal and Chile. Research Report 1, Environmental Change Unit, University of Oxford, United Kingdom, 54 pp.

Durieux L, Toledo LA, Laurent H (2003) The impact of deforestation on cloud cover over the Amazon arc of deforestation. Remote Sens Environ 86:132–140

Friederich S (1994) Wirkung veräderter Klimatischer factorem auf pflanzenschaedlinge. In: Brunnert H, Dämmgen U (eds.) Klimaveraenderungen und Landwirtschaft, Part II Landbauforsc, Vlkenrode, 148, 1726 pp.

GCOS (2003) The Second Report on the Adequacy of the Global Observing Systems for Climate in Support of the UNFCCC. WMO-IOC-UNEP-ICS, GCOS-82, Technical Document No. 1143,World Meteorological Organization, Geneva, Switzerland, 85 pp.

GEF (2006) A conceptual design tool for exploiting interlinkages between the focal areas of the GEF Scientific and Technical Advisory Panel (STAP) ,www.unep.org/stapgef

GEO (2002) Global Environmental Outlook 3. Past Present and Future Perspectives. UNEP. Earthscan, London. 446 pp.

IPCC (2007) Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. (www.ipcc.ch).

Löpmeier FJ (1990) Klimaimpaktforschung aus agrarmeteorologischer sicht. Bayer Landw Jarhb 67:185-190

MA (Millennium Ecosystem Assessment) (2002) Millennium Ecosystem Assessment Methods. Reid W, Ash N, Bennett E, Kumar P, Lee M, Lucas N, Simons H, Thompson V, Zurek M (eds.) Millennium Assessment

Mosekilde E, Mosekilde L (eds.) (1991) Complexity, chaos and biological evolutions. Plenum press, New York.

NRC (2002) Abrupt Climate Change: Inevitable Surprises. Committee on Abrupt Climate Change, Ocean Studies Board, Polar Research Board, Board on Atmospheric Sciences and Climate, Division on Earth and Life Sciences, National Research Council, National Academy Press, Washington, DC, USA, 230 pp.

Paeth H, Scholten A, Friederichs P, Hense A (2006) Uncertainties in climate change prediction: El Nino-Southern Oscillation and monsoons, Global and Planetary Change (In Press)

Pielke RA, Adegoke J, Chase T, Marshall C, Matsui T, Niyogi D (2007) A new paradigm for assessing the role of agriculture in the climate system and in climate change. Agric For Meteorol 142:234–254

Parry ML, Porter JH, Carter TR (1990) Agriculture: climate change and its implications. Trends Ecol Evol 5:318-322

Parry M, Carter TR, Konijn NT (eds.) (1988) The Impact of Climatic Variations on Agriculture. Vol. 2, Assessment in Semi-Arid Regions. Kluwer Academic Publishers, Dordrecht, The Netherlands, 764 pp.

Pielke RA, Adegoke J, Chase TN, Marshall CH, Matsui T, Niyogi D (2007) A new paradigm for assessing the role of agriculture in the climate system and in climate change. Agric For Meteorol 142:234–254

Porter JH, Parry ML, Carter TR (1991) The potential effects of climate change on agricultural insect pests. Agric For Meteorol 57: 221-240

Reilly J, Hohmann N, Kane S (1994) Climate change and agricultural trade: who benefits, who loses? Global Environ Chang 4:24-36.

Rosenblüth B, Fuenzalida H, Aceituno P (1997) Recent Temperature Variations In Southern South América. Int J Climatol 17:67–85

Santibañez QF (1991) Possible variations agroclimatiques en Amerique de Sud au XXIème siècle. La Météorol 38:17-24

Schnoor J (1996) Environmental modeling. John Willey & Sons, Inc, A Willey-Interscience Series, New York, 683 pp.

Sivakumar MVK (2007) Interactions between climate and desertification. Agric For Meteorol 142:143-155

Teleginski-Ferraz S, Tércio A, da Rocha R, Santiago VC (2006) Precipitation and temperature variability over south America from 1860 to 2100. Proceedings of 8 ICSHMO, Foz do Iguaçu, Brazil, April 24-28, 2006, INPE, pp. 1527-1534.

Treharne K (1989) The implications of the "greenhouse effect" for fertilizer and agrochemicals. In: de Bennet RM (ed.) The Greenhouse Effect and UK Agriculture 19. Centre for Agricultural Strategy, University of Reading, United Kingdom, pp. 67-78.

van Dam R, Gitay H, Finlayson M (2002) Wetlands and Climate Change 2003. Ramsar Convention COP paper. (www.ramsar.org/cop8_doc_11_e.htm).

Villalba R, Lara A, Boninsegna JA, Masiokas M, Delgado S, Aravena JC, Roig FA, Schmelter A, Wolodarsky A, Ripalta A (2003) Large-scale temperature changes across the southern Andes: 20th-century variations in the context of the past 400 years. Clim Chang 59:177-232

Vincent, LA, Peterson TC, Barros VR, Marino MB, Rusticucci M, Carrasco G, Ramirez E, Alves LM, Ambrizzi T, Berlato MA, Grimm AM, Marengo JA, Molion L, Moncunill DF, Rebello E, Anunciação YMT, Quintana J, Santos JL, Baez J, Coronel G, Garcia J, Trebejo I, Bidegain M, Haylock MR, Karoly D (2005) Observed trends in indices of daily temperature extremes in South America 1960-2000. J Clim 18:5011-5023

WMO (2003) Scientific Assessment of Ozone Depletion: 2002. Global Ozone Research and Monitoring Project, Report No. 47, World Meteorological Organization, Geneva, Switzerland, 498 pp.

Trends in Land Degradation in Europe

Luca Montanarella

Abstract. The adoption of the EU Thematic Strategy for Soil Protection by the European Commission on 22 September 2006 has given formal recognition of the severity of the soil and land degradation processes within the European Union and its bordering countries. Available information suggests that, over recent decades, there has been a significant increase in soil degradation processes, and there is evidence that these processes will further increase if no action is taken. Soil degradation processes are driven or exacerbated by human activity. Climate change, together with individual extreme weather events, which are becoming more frequent, will also have negative effects on soil. Soil degradation processes occurring in the European Union include erosion, organic matter decline, compaction, salinisation, landslides, contamination, sealing and biodiversity decline. Effective soil protection policies can only be based on a detailed assessment of the costs of non-action, and the potential economic benefits from enhanced soil protection strategies in Europe. The total costs of soil degradation *that could be assessed* for erosion, organic matter decline, salinisation, landslides and contamination on the basis of available data, would be up to €38 billion annually for EU25. These estimates are necessarily wide ranging due to the lack of sufficient quantitative and qualitative data. The Soil Thematic Strategy of the European Union paves the way towards adequate measures in order to reverse the negative trends in soil and land degradation in Europe and will have also an extensive impact at the global scale by promoting similar actions in the framework of internationally binding agreements related to land degradation, like the UNCCD, UNFCCC and CBD.

5.1 Introduction

The adoption of the EU Thematic Strategy for Soil Protection by the European Commission on 22 September 2006 has given formal recognition of the severity of the soil and land degradation processes within the European Union and its bordering countries. The Strategy includes an extended impact assessment (SEC(2006)620) that has quantified soil degradation in Europe, both in environmental and economic terms, and that is the basis for this report.

This impact assessment is based mainly, but not exclusively, on reports by the Joint Research Centre (JRC) of the Commission and the Working Groups set up to assist the Commission, and reports carried out for the Commission in assessing the economic impacts of soil degradation and economic, environmental and social impacts of different measures to prevent soil degradation.

Available information suggests that, over recent decades, there has been a significant increase in soil degradation processes, and there is evidence that these processes will further increase if no action is taken. Soil degradation processes are driven or exacerbated by human activity. Climate change, together with individual extreme weather events, which are becoming more frequent, will also have negative effects on soil.

Soil degradation processes occurring in the European Union include erosion, organic matter decline, compaction, salinisation, landslides, contamination, sealing and biodiversity decline.

5.2 Erosion

5.2.1 Qualitative analysis

Erosion is a natural process, which can however be significantly accelerated by human activities. It is known to be a serious problem throughout Europe, especially in the Mediterranean zone, but snowmelt erosion happens in Scandinavian countries and wind erosion is common in Central and Western Europe.

Main human-induced driving forces include:
- Soil disturbance eg., ploughing up-and-down slopes.
- Removal of vegetative soil cover and/or hedgerows.
- Increased field size (open fields).
- Abandonment of terraces.
- Late sowing of winter cereals.
- Overstocking.
- Poor crop management.
- Inappropriate use of heavy machinery, in agricultural and forestry practices, but also during construction works.

Soil erosion is increasing in Europe (EEA 1995). As precise estimates are not possible due to the lack of comparable data, it is difficult to assess the total area of the EU affected by erosion. The EEA estimated 115 million ha, or 12% of Europe's total land area, to be affected by water erosion, and that 42 million ha are affected by wind erosion, of which 2% severely affected.

Due to the difficulty to assess the affected area, erosion *risk* has been proposed as an indicator of actual erosion, which can be assessed on the basis of predictive models such as PESERA (Kirby et al. 2004). This model covers most of the EU25, except Sweden, Finland, Malta and Cyprus, where Corinne Land cover data is not available (Fig. 5.1).

PESERA predicts that overall 3.4% of the area of the 21 Member States covered (1.6 million ha) is at risk from erosion of more than 10 tonnes (t) ha^{-1} yr^{-1}, 18% (54

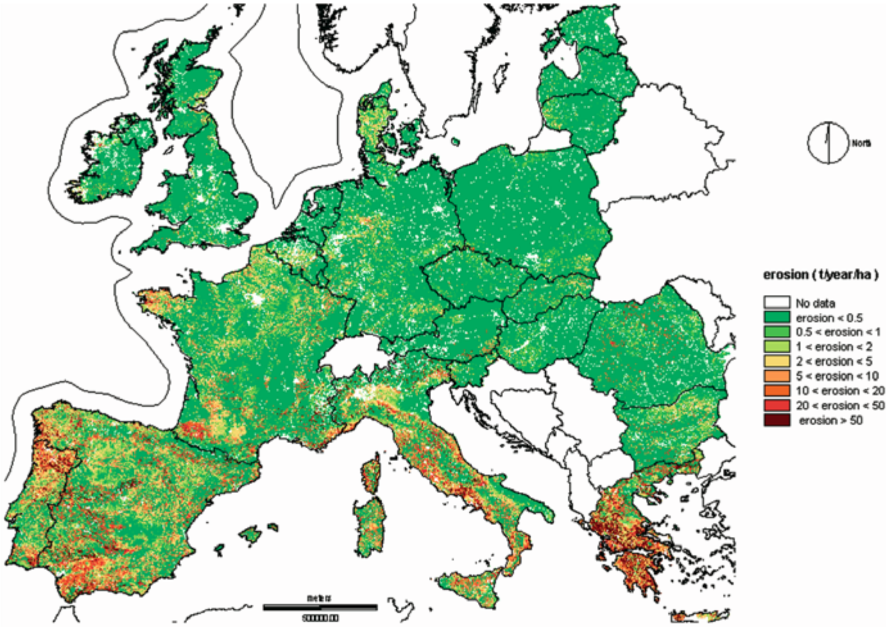


Fig. 5.1. Pan-European Soil Erosion Risk Assessment (PESERA) estimation of soil erosion (t ha^{-1} yr^{-1}) for Europe

million ha) are at risk of losing soil above 1 t ha^{-1}, and 25% of the area (corresponding to 75.5 million ha) is at risk to lose more than 0.5 t of soil ha^{-1} yr^{-1}. The Mediterranean region is the most affected, but there is clear evidence that also other parts of EU25 suffer significant soil erosion. For some weather events, the losses can be much more significant: for instance, in a rainstorm in the South of Spain, 20 t of soil can be washed off just one hectare in a few hours.

It is worth noting that as natural soil formation is extremely slow, losses over 1 or 2 t ha^{-1} yr^{-1} (EEA 1998, ESBN 2005) are therefore considered irreversible. As the soil is practically a non-renewable resource due to the fact that soil formation is extremely slow, the consequences of erosion for soil fertility and soil ecosystems, described below, are significant:

- Loss of soil.
- Loss of soil fertility due to disrupted nutrient cycles.
- Damage to infrastructures due to excessive sediment load.
- Diffuse pollution of surface water.
- Negative effects on aquatic ecosystems and thereby biodiversity.
- Restrictions on land use hindering future redevelopment and reducing the area of productive and valuable soil available for other activities (agricultural and forestry production, recreation etc.).
- Land value depreciation.
- Reduced water retention capacity, hence higher flood risk.
- Human health problems due to dust and particles in the air.

The following costs resulting from these impacts have to be considered:

5.2.1.1
On-site costs (costs basically borne by the owner or the user of the land)

- Yield losses due to eroded fertile land**
- On-site costs due to impact on tourism.

5.2.1.2
Off-site costs (costs borne by third parties and society, such as public administration, private sectors, tax payers and society as a whole)

- Costs of sediment removal, treatment and disposal**.
- Costs due to infrastructure (roads, dams and water supply) and property damage caused by sediments run off and flooding**.
- Costs due to necessary treatment of water (surface, groundwater)**.
- Costs due to damage to recreational functions**.
- Economic effects due to erosion-induced income losses.
- Costs due to increased sediment load for surface waters (e.g. negative effects on aquatic species, difficulties for navigation).
- Costs of healthcare caused by higher exposure to dust and soil particles in the air.

5.2.2
Quantitative analysis

Table 5.1 provides an overview of the sum of the types of costs that could be quantified derived from a review of existing literature and test cases. Comprehensive and comparable information on the extent of erosion needed for the quantitative analysis was only available for 13 countries (equivalent to a surface area of about 150 million ha).

Table 5.1. Estimated total annual cost of soil erosion (million € 2003)

	On-site costs	Off-site costs	Total estimate
Lower bound	40	680	720
Intermediate	588	6,676	7,264
Upper bound	860	13,139	13,999

Note: These estimates relate to the surface affected by erosion in 13 countries and to five land use categories covering a surface area of 150 million ha

In recent years, a number of studies (including some from the FAO) have also tried to assess the costs of erosion, all leading to the same conclusion: off-site costs are much higher than the on-site costs.

Another important remark is that if long term effects (20 years) of soil erosion are taken into account, the estimated on-site costs reportet above for a total of around € 800 million would become € 3.25 billion.

5.3 Decline of soil organic matter

5.3.1 Qualitative analysis

SOM, the organic fraction of soil (not including undecayed plant and animal residues), plays a very important role not only for soil fertility, but also for soil structure, buffering and water retention capacity and is crucial for soil biodiversity. Therefore, in this assessment only the stable fraction of soil organic matter, the fraction that can be transformed into humus, is referred to. Humus means soil organic matter, exclusive of the partial decomposition products of undecayed plant and animal residues, and the soil biomass; its structure is amorphous, specific weight is low and surface area high. The principal constituents are derivatives of lignins, proteins and cellulose combined with inorganic soil constituents. Humus possesses colloidal characteristics which give it the ability to improve soil properties such as structure and porosity, sorption capacity (water, plant nutrients), protection against erosion, buffering capacity and protection of plants from drastic changes in pH, and store for micro-organisms.

SOM plays a major role in the carbon cycle of the soil. Indeed, soil is at the same time an *emitter* of greenhouse gases and also a major *store* of carbon. The global soil carbon pool contains 1,500 gigatons (Gt) of soil organic and inorganic carbon. Furthermore, carbon sequestration in agricultural soils achieved by some land management practices has a potential to contribute to climate change mitigation. Some sources estimate this to be around 2 Gt of carbon annually (Lal 2000). As a part of the European Climate Change Programme (ECCP), the potential of soils for carbon sequestration was estimated to be equivalent to 1.5-1.7% of the EU's anthropogenic CO_2 emissions during the first commitment period of the Kyoto protocol.

At the same time, climate change will likely increase the risk of threats due to more extreme weather events such as floods and heavy rainfall as well as increased temperature. This has severe consequences for soil biodiversity as well as for suitability and possibility to produce certain crops.

Main human-induced driving forces of climate change are:

- Conversion of grassland to arable land.
- Drainage of wetlands.
- Poor crop rotation and plant residue management such as burning crops residues.

- Accelerated mineralization due to management practices such as continued tillage
- Deforestation

Around 45% of soils in Europe have a low or very low organic matter content (0-2% organic carbon) and 45% have a medium content (2-6% organic carbon)(Jones et al. 2005) (Fig. 5.2). Besides climatic reasons, unsustainable practices of human activities are the most relevant driving forces.

Comprehensive and comparable data for EU25 on SOM content are not available, but models exist to estimate it. Such estimations reveal that the problem of soils with very low and low SOM exists in particular in the Southern countries, where 74% of the soils have less than 3.4% organic matter, but also in parts of France, the United Kingdom, Germany and Sweden. The development of a Common Implementation Strategy (CIS) has been discussed with Member States and was generally welcomed. In such a CIS, guidance documents would be produced *inter alia* based on already existing documents to facilitate risk identification. Also, this could be a platform to exchange experience on risk reduction strategies with a view to evaluate the measures undertaken and improve the efficiency of programmes and remediation strategies.

Consequences of decline of SOM for soil fertility and soil ecosystems, as described below are significant.

- Release of greenhouse gases.
- Negative effects on biodiversity, including soil biodiversity.
- Reduced water infiltration due to changes in soil structure, hence higher flood risk.
- Reduced absorption of pollutants and increased water and air pollution.
- Increased erosion with the effects stated above such as:
  - Loss of fertile soil
  - Loss of soil fertility (i.a. due to disrupted nutrient cycles)
  - Damage to infrastructures due to excessive sediment load
  - Diffuse pollution of surface water
  - Negative effects on aquatic ecosystems and thereby biodiversity
  - Restrictions on land use and hindering future redevelopment and reducing the area of productive and valuable soil available for other activities (agricultural and forestry production, recreation etc.).
- Land value depreciation.

As a decline in SOM increases erosion, all costs listed section 5.2.1 are equally relevant here, but will not be repeated. The following list is limited to the costs directly resulting from a decline of SOM. The following costs have then to be considered for a decline of SOM:

5.3.1.1
On-site costs

- Yield losses due to reduced soil fertility**.

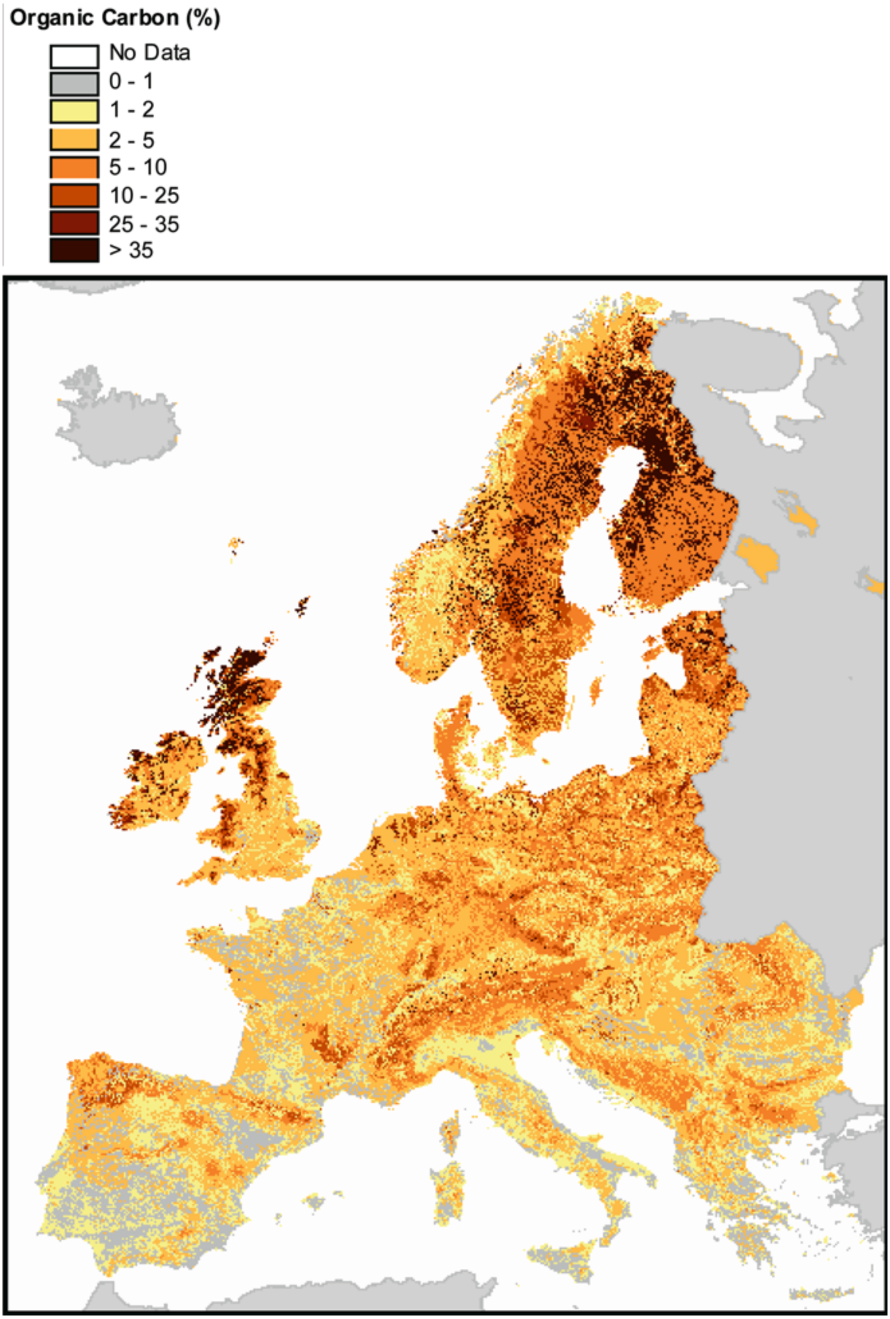


Fig. 5.2. Organic carbon contents of topsoils (0-30cm) in Europe (After Jones et al., 2005)

5.3.1.2
Off-site costs

- Costs related to an increased release of greenhouse gases from soil**.
- Costs due to loss of biodiversity and biological activity in soil (affect ing fertility, nutrient cycles and genetic resources).

5.3.2
Quantitative analysis

As stated earlier, any assessment of SOM loss on a European level is severely limited by the lack of data and of a clear categorisation for different types of organic matter. While some data exists on the organic matter *content* of soils, there is no consistent Europe-wide data on the organic matter *losses*. Indeed, the impact of organic matter loss on the productivity of soils is much less researched than in the case of erosion.

Annual on-site costs (mainly due to lower soil productivity) of SOM decline have been estimated to be around €2 billion.

For the off-site effects of SOM loss, there is evidence that the climate change impact of carbon released from soils is substantial. It has been estimated that the annual costs for society derived from the carbon released annually from soils due to the decline of SOM are between €1.4 and 3.6 billion. From other sources, a result on the same range could be found at least to be €3.1 billion annually.

The total annual costs of non action for SOM decline have thus been estimated to be between €3.4-5.6 billion.

5.4
Compaction

5.4.1
Qualitative analysis

Compaction, an increase in bulk density and a decrease in soil porosity, is a problem mainly of the subsoil.

Estimates of areas at risk of soil compaction vary. While they all demonstrate the importance of soil compaction, enough data were not available on the actual occurrence of compaction, but data were available on the susceptibility of soils to compaction. Some authors (Jones et al. 2003; Romagna 2003; Van-Camp et al. 2004a) classify around 36% of European subsoils as having high or very high susceptibility to compaction (Fig. 5.3). Other sources (Crescimanno et al. 2004) speak of 32% of soils being highly vulnerable and 18% moderately affected, while some other sources (Van Ouwerkerk and Soane 1995) estimate 33 million ha being affected in total, meaning 4% of the European land.

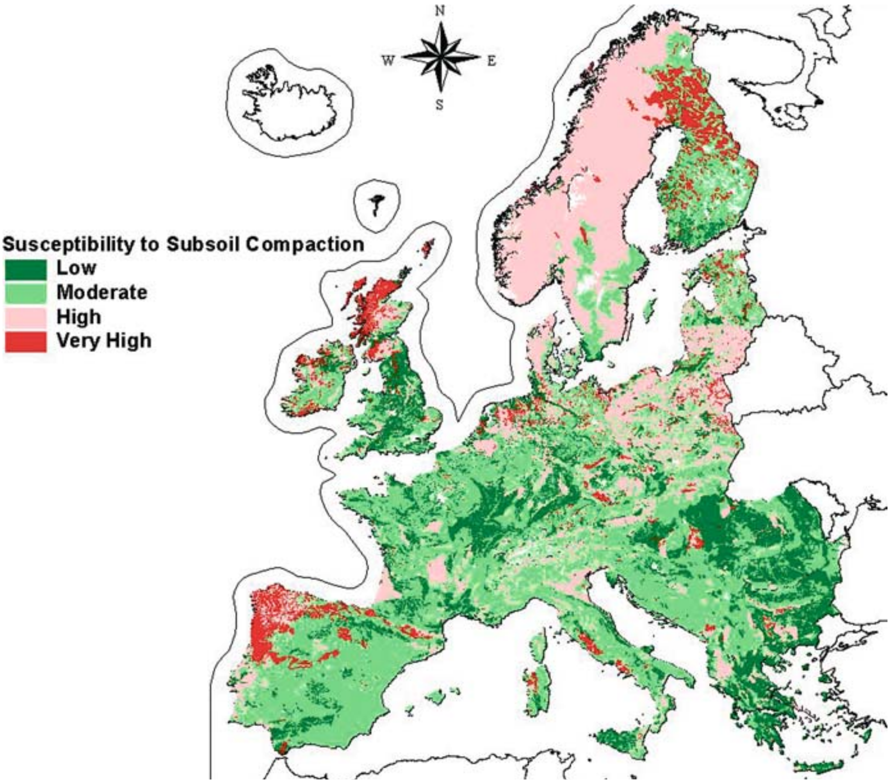


Fig. 5.3. Extent of susceptibility to subsoil compaction in Europe (Jones et al. 2003)

Main human induced driving forces of compaction include:

- Inappropriate use of heavy machinery and increased use of high axle loads due to increased machine power and intensified production.
- High livestock densities, in particular in wet conditions or on wet soils.
- Large constructions works and recreational sites.

The problem is likely to have increased, due to a rise in the use of high-axle loads, which are a consequence of larger machine power and intensified production (Crescimanno et al. 2004).

Consequences of compaction can be described as follows:

- Loss of soil fertility due to changes in soil structure, ie., due to reduced oxygen and water supply to plant roots.
- Reduced water infiltration and retention resulting in increased water run-off
- Higher erosion susceptibility.

- Increased emission of greenhouse gases from the soil due to changes in nutrient cycle.
- Loss of soil biodiversity.
- Land value depreciation.

The following costs have to be considered for soil compaction:

5.4.1.1
On-site costs

- Yield losses due to reduced soil fertility and increased vulnerability of crops to diseases as a consequence of worsened growing conditions.

5.4.1.2
Off-site costs

- Costs due to reduced water infiltration into the soil.
- Costs due to increased leaching of soil nitrogen.
- Costs linked to increased emissions of greenhouse gases due to poor aeration of soil.

5.4.2
Quantitative analysis

No quantitative estimates of the total costs could be produced. Indeed, economic information on the impacts of compaction is very limited.

As regards on site costs, it has been estimated that surface soil compaction may cause yield reductions of up to 13%, whereas subsoil compaction, as a rough indication (Van-Camp et al. 2004b), may reduce agricultural yields by 35% or more in extreme dry or wet periods. On the other hand the off-site costs of compaction could not be estimated at this stage.

5.5
Salinisation

Salinisation, the accumulation in soils of soluble salts mainly of sodium, magnesium, and calcium, can occur naturally in low, poorly drained areas in hot and dry climates, where surface water collects and evaporates, but can be exacerbated by human activities, in particular due to inadequate irrigation of agricultural land.

Main human-induced driving forces for salinisation include:
- Poor irrigation technology.
- Inappropriate drainage.
- Use of saline waters for irrigation and the overexploitation of groundwater.

5.5.1 Qualitative analysis

Salinisation affects around 3.8 million ha in Europe (EEA 1995). Most affected are Campania in Italy, the Ebro Valley in Spain, and the Great Alföld in Hungary, but also areas in Greece, Portugal, France, Slovakia and Austria (Katakouzinos 1968).

The consequences of salinisation for current and future land use are significant.

Consequences of salinisation include:
- Loss of soil fertility due to toxic effects of high salt content.
- Reduced water infiltration and retention resulting in increased water run-off.
- Damage to transport infrastructure from shallow saline groundwater.
- Damage to water supply infrastructure.
- Loss of biodiversity.
- Land value depreciation.

The following costs have to be considered:

5.5.1.1 On-site costs

- Yield losses due to reduce soil fertility**.

Table 5.2. Yearly cost of salinisation in selected countries (million €)

		Spain		Hungary		Bulgaria	
		LB	UB	LB	UB	LB	UB
On-site costs	Agricultural yield losses	42.71	137.64	70.16	133.91	1.08	5.38
Off-site costs	Infrastructure damage	12.08		18.23		1.32	
	Environmental damage	4.83		7.29		0.53	
Total		59.62	154.55	95.68	159.43	2.93	7.23

LB: lower bound; *UB*: upper bound

5.5.1.2
Off-site costs

- Costs due to damage to transport infrastructure (roads and bridges) from shallow saline groundwater**.
- Costs due to damage to water supply infrastructure**.
- Environmental costs, including impacts on native vegetation, riparian ecosystems and wetlands**.
- Costs due to negative effects on tourism.

5.5.2
Quantitative analysis

Data on the economic impact of salinisation is limited. The assessment of the total costs of salinisation had to be based on the three countries for which some information exists: Spain, Hungary and Bulgaria. The above listed yearly costs have been obtained based on the following assumptions:

- For the on-site costs, the extrapolation mainly considers the impacts due to reduced agricultural productivity.
- For the off-site costs in the absence of European estimates, impacts were estimated for these three countries taking into account an Australian study, which estimated off-site costs to be approximately €10/ha.

The total costs, regarding salinisation for these three countries have been estimated to be between €158 and 321 million yr-1.

Extrapolation at EU level was not considered possible. In absence of more detailed information at the appropriate geographical scale, any up scaling of data would be misleading.

5.6
Landslides

5.6.1
Qualitative analysis

Landslides are natural phenomena, which can be exacerbated by human activity or, on the contrary, by lack of human activity. Landslides often occur more frequently in areas with highly erodible soils, clayey sub-soil, steep slopes, intense and abundant precipitation and land abandonment such as the Alpine and the Mediterranean regions.

Main human-induced driving forces for landslides include:

- Rupture of topography such as due to construction works
- Land use changes such as deforestation and land abandonment
- Extractions of materials

There are no sufficient data on the total affected area in the EU. In Italy, more than 50% of the territory has been classified as having a high or very high hydrogeological risk, affecting 60% of the population, i.e. 34 million inhabitants. More than 15% of the territory and 26% of the population are subjected to a very high risk (EEA 2000, MOE 2000) and eight major landslides have been document by the International Disaster Database. The threat of landslides is increasing due to population growth, summer and winter tourism, intensive land use and climate change.

Consequences of landslides are as follows:
- Loss of human lives and well-being.
- Damage to property and infrastructure.
- Indirect negative effects on economic activities due to interruption of transport routes.
- Loss of fertile soil.
- Contamination of soil due to damage to infrastructure such as pipelines and storage facilities.
- Potential contamination of surface waters with associated off-site costs as described already under erosion.

The following costs have to be considered:

5.6.1.1 On-site costs

- The loss of topsoil, leading to a loss of productive soil and hence a decrease in crop yield
- Damage to on-site infrastructures

Table 5.3. Incidences and costs of landslides in Europe

	No. of events	Casualties (total)	(av/event)	Affected people (total)	av/event)	Cost € (total)	(av/event)
Austria	2	43	22	–	–	–	–
Italy	8	1,387	173	10,100	1,263	1,200,000,000	600,000,000*
Sweden	1	13	13	50	50	11,000,000	11,000,000
UK	1	140	140	–	–	–	–
Sum	12	1,583	132	10,150	846	1.211.000,000	403,666,667**

Source: EM-DAT: The OFDA/CRED International Disaster Database www.em-dat.net – Université Catholique de Louvain, Brussels, Belgium.
* Average based on two out of eight cases, for which there is quantified economic data.
** The average figure (average per event) is based on the three cases of landslides where quantitative data on economic impacts was available (Valtelina/Italy, July 1987, €500 M damage; Ancona/Italy, December 1982, €700 M damage; Gothenburg/Sweden, December 1977, €11 M damage)

5.6.1.2
Off-site costs

- Impact on human lives and well-being.
- Damage to property and infrastructure.
- Indirect negative effects on economic activities due to interruption of transport routes.
- Ruptures of underground pipelines, dislocation of storage tanks, release of chemicals stored at ground level and contamination of surface waters with associated off-site costs as described already under erosion.

5.6.2
Quantitative analysis

The International Disaster Database of the Université Catholique de Louvain contains twelve cases of major landslides for EU25, two thirds of which are from Italy. Table 5.3 below presents the quantified evidence on the incidence and costs of landslides that could be inferred from that database.

The extrapolation of the costs of landslides is not possible in the same way as for other soil threats, which occur continuously and are more widely-spread. Table 5.3 demonstrates however the wide range of costs for landslides to be between €11 to 600 million per event (based on information on economic impacts for three events only). Italy is the country for which more data are available. According to the Italian Civil Protection Department, landslides cost between €1 to 2 billion per year to the Italian economy and have resulted in 5,939 deaths during the last century. In a single Italian region (Emilia Romagna), up to 3,300 km of roads and railways are subject to active landslides(http://www.protezionecivile.it/minisite/index.php?dir_pk=251 & cms_pk=1444&n_page=2;http://www.regione.emilia-romagna.it/ geologia/fran3.htm#dterrit)

There is evidence that the off-site social costs constitute the biggest share of the total damage.

With the available data, no extrapolation to EU level was considered possible.

5.7
Contamination

5.7.1
Qualitative analysis

More than two hundred years of industrialisation have left their trace on the status of soil. Europe has a problem of historical contamination of soil due to the use and presence of dangerous substances in many production processes. Moreover, soil contamination is still currently being produced by inadequate practices and accidents.

Main human induced driving forces of contamination include:
- Industrial installations.
- Mining installations.
- Illegal waste dumps and landfill sites not properly managed.
- Storage of chemicals.
- Accidental and provoked spills of chemicals.
- Atmospheric depositions of dangerous substances.
- Military sites.
- Intentional introduction of dangerous substances in the soil.

Soil contamination is a widely spread problem across all Europe. Most experts acknowledge that the data available are insufficient for assessing certain parameters, such as the total surface area contaminated per class of contaminant, the percentage of population exposed to the contamination, the environmental damage caused by contaminated sites, etc. This is partly because the data collected by each Member State are not comparable.

Available information indicates that the extent of contaminated sites across Europe is enormous and there is a very unequal progress among Member States in addressing the issue, some being very advanced in the identification of the extent and localisation of the problem, some others only at very preliminary phases.

The effects of soil contamination are very diverse and far reaching in their consequences. Once contaminated, soil functions may be impaired and human and ecological health and food quality may also be prejudiced. The consequences can be suffered where the contamination occurs but are mostly suffered also in a large surrounding area, including agricultural land, dwellings and/or nature reserves (EEA 1995).

Consequences of soil contamination are as follows:
- Risk to human health for people living on and in the surroundings of a contaminated site (through different exposure paths, e.g. consumption of food grown in from contaminated areas).
- Contamination of surface water, mainly through run off of contaminated sediments.
- Contamination of groundwater and hence drinking water if extracted from groundwater.
- Risk to human health through drinking water extracted underneath of a contaminated site.
- Risk of ecotoxicity for the flora and fauna living in the soil on the site and around a contaminated site causing loss of biodiversity and biological activity.
- Loss of soil fertility due to disrupted nutrient cycles.
- Restrictions on land use and hindering future redevelopment and reducing the area of productive and valuable soil available for other activities (agricultural and forestry production, recreation etc.).
- Land value depreciation.

The costs of contamination depend on the type of contaminant, the spatial extent of the pollution and its intensity, the natural characteristics of the contaminated site and the socio-economic characteristics of the surrounding area. However, while such factors have been addressed in local case studies, the calculation of a Europe-wide figure on contamination is impeded by the fact that much of the data is either unavailable or not comparable.

The different cost categories were estimated as follows:

5.7.1.1
On-site costs

- Costs of monitoring measures and impact assessment studies that must be carried out in order to assess the extent of contamination and the risk of further contamination of other environmental media (water, air) **.
- Costs of exposure protection measures for workers operating on a con taminated industrial site.
- Costs due to land property depreciation if land use restrictions are applied thus representing a loss of economic value of the industrial asset.

5.7.1.2
Off-site costs

These costs are highly site-specific but generally consist of:
- Costs of increased health care needs for people affected by contamination, which include the treatment of patients and the monitoring of their health during long periods to detect the effects of exposure to soil contamination**.
- Costs of treatment of surface water, groundwater or drinking water contaminated through the soil**.
- Costs for insurance companies.
- Costs of dredging and disposing of contaminated sediments down stream borne by water supply companies or public administrations.
- Costs for the depreciation of surrounding land**.
- Costs for increased food safety controls borne by public administrations to detect contaminated food.

Table 5.4. Estimated total annual cost caused by soil contamination for EU25 (M €2003)

	On-site costs	Off-site costs	Total
Lower bound estimate	96	2,283	2,379
Intermediate estimate	192	17,126	17,318
Upper bound estimate	289	207,615	207,904

5.7.2 Quantitative analysis

Estimates for on-site costs are based on a comparison of information from different sources and data available for the case of the MetalEurop site in France. The off-site costs estimates are largely based on available information for the MetalEurop site in France. This is due to the lack of quantified data on off-site costs as regards in particular healthcare costs of neighbouring populations.

These estimates, and in particular the big difference between the lower and the upper bound, show how difficult it is to quantify the costs due to soil contamination and show the disparity between test cases. In order to use a prudent estimate and to the inaccuracy of data, it was considered to be more sound to use the intermediate value of €17.3 billion per year all through out the report.

5.8 Sealing

5.8.1 Qualitative analysis

On average the sealed area, the area of the soil surface covered with an impermeable material, is around 9% of the total area in Member States (EEA 1999). In many European countries the built-up area increased by 25 to 75% in the period 1950-1980. During 1990-2000 the sealed area in EU15 increased by 6% (EEA 2006), and the demand for both new construction due to increased urban sprawl and better transport infrastructures continues to rise.

Main human driving forces for sealing are as follows:
- Urban sprawl.
- Increased transport.
- Movement of population.

Soil sealing through urbanisation dominates in the more densely populated regions and major industrial areas of Western Europe, in particular Belgium, Denmark and the Netherlands, where 16-20% of the surface is built up. Sealing results in the creation of a horizontal barrier between the soil, air and the water and thus has several severe consequences.

Consequences of sealing include:
- Disruption of gas, water and energy fluxes.
- Increased flood risks.
- Reduced groundwater recharge.
- Increases water pollution (due to runoff water from housing and traffic areas being normally unfiltered and potentially contaminated with harmful chemicals)
- Loss in soil and terrestrial biodiversity (due to fragmentation of habitats).

The following costs have to be considered:

5.8.1.1
On-site costs

- Opportunity costs due to restrictions on land use.

5.8.1.2
Off-site costs

- Cost linked to runoff water from housing and traffic areas, which is normally unfiltered and potentially contaminated with harmful chemicals.
- Costs due to fragmentation of habitats and disruption of migration corridors for wildlife.
- Costs due to impacts on landscape and amenity values.
- Costs on biodiversity.

Insufficient data relative to soil-sealing costs is available to provide an assessment of the impacts of soil sealing in economic terms.

5.8.2
Quantitative analysis

There is no sufficient information to estimate the costs derived from sealing of soil. Thus no quantitative assessment could be done.

5.9
Biodiversity

5.9.1
Qualitative analysis

Soil biodiversity means not only the diversity of genes, species, ecosystems and functions, but also the metabolic capacity of the ecosystem (Van-Camp et al. 2004c).

Insufficient data exist on the status of soil biodiversity in Europe, as the biological quality of soil cannot easily be predicted. Although research on soil biodiversity has been carried out in European countries, it is still impossible to reliably quantify the richness, range and different roles played by microbial species.

Soil biodiversity is affected by all the threats listed above, and therefore all driving forces mentioned apply (equally) to the loss of soil biodiversity, changes in land use (agricultural and forestry practices) and soil contamination being the most prominent.

Consequences of biodiversity decline are as follows:

- Reduced food web functioning and consequently crop yield losses.
- Reduced soil formation.
- Reduced nutrient cycling and nitrogen fixation.
- Reduced carbon sequestration.
- Reduced resilience of the soil to endure pressures.
- Reduced recycling of organic waste/litter.
- Increased plant pests and diseases.
- Reduced water infiltration rate and water holding capacity.
- Reduced bioremediation capacity.
- Hampered soil structure (by affecting the stabilisation of organo-mineral complexes).
- Reduced genetic resources present in the soil, including moral and ethical consequences.
- Negative impacts on terrestrial biodiversity outside of soil.

SOM and soil biodiversity decline are closely related and the costs listed above for SOM decline (see section 5.3.1) equally arise for the loss of soil biodiversity. The following additional costs would need to be considered:

5.9.1.1 On-site costs

- Yield losses due to reduce soil fertility

5.9.1.2 Off-site costs

Costs linked to the loss of ecosystem functions and reduced capacity to sequester carbon (see also section 5.3 under organic matter decline)

- Costs related to impacts on landscape and amenity values.
- Costs related to changes in genetic resources.

5.9.2 Quantitative analysis

There was no sufficient information to estimate the costs derived from sealing of soil. Thus no quantitative assessment could be done. Furthermore, the loss of soil biodiversity is not fully understood from a natural science perspective. Therefore, no quantification of these impacts and costs can be given in this report.

5.10 Conclusions

Land degradation in Europe is difficult to quantify due to the lack of updated and comparable data. Nevertheless, on the basis of the available data, extensive land degradation processes can be identified in Europe. These processes are mostly human induced and can be further exacerbated by the influence of extreme climatic events. Main driving force remains the unsustainable economic development that is rapidly depleting the non-renewable soil resources of Europe (Jones et al. 2005).

Effective soil protection policies can only be based on a detailed assessment of the costs of non-action, and the potential economic benefits from enhanced soil protection strategies in Europe.

For the major soil threats the available data allow for the following conclusions:

- *Erosion:* the EEA estimates that 115 million ha, or 12% of Europe's total land area, are affected by water erosion, and that 42 million ha are affected by wind erosion, of which 2% severely affected.
- *Organic matter decline*: soil organic matter (SOM) plays a major role in the carbon cycle of the soil. Indeed, soil is at the same time an *emitter* of greenhouse gases and also a major *store* of carbon containing 1,500 gt of organic and inorganic carbon. Around 45% of soils in Europe have a low or very low organic matter content (0-2% organic carbon) and 45% have a medium content (2-6% organic carbon). The problem exists in particular in the Southern countries, but also in parts of France, the United Kingdom, Germany and Sweden.
- *Compaction:* estimates of areas at risk of soil compaction vary. Some authors classify around 36% of European subsoils as having high or very high susceptibility to compaction. Other sources speak of 32% of soils being highly vulnerable and 18% moderately affected.
- *Salinisation* is the accumulation in soils of soluble salts mainly of sodium, magnesium, and calcium. It affects around 3.8 million ha in Europe. Most affected are Campania in Italy, the Ebro Valley in Spain, and the Great Alföld in Hungary, but also areas in Greece, Portugal, France, Slovakia and Austria.
- *Landslides* often occur more frequently in areas with highly erodible soils, clayey sub-soil, steep slopes, intense and abundant precipitation and land abandonment, such as the Alpine and the Mediterranean regions. There are, to date, no data on the total area affected in the EU, but this problem can be due to population growth, summer and winter tourism, intensive land use and climate change.
- *Contamination:* due to more than two hundred years of industrialisation, Europe has a problem of contamination of soil due to the use and presence of dangerous substances in many production processes. It has been estimated that 3.5 million sites may be potentially contaminated, with 0.5 million sites being really contaminated and needing remediation.
- *Sealing:* on average the sealed area, the area of the soil surface covered with an impermeable material, is around 9% of the total area in Member States. During 1990-2000 the sealed area in EU15 increased by 6%, and the demand for both

new construction due to increased urban sprawl and transport infrastructures continues to rise.
- *Biodiversity decline:* soil biodiversity means not only the diversity of genes, species, ecosystems and functions, but also the metabolic capacity of the ecosystem. Soil biodiversity is affected by all the degradation processes listed above, and all driving forces mentioned apply (equally) to the loss of soil biodiversity.

Though difficult to estimate, several studies demonstrate significant *annual* costs of soil degradation to society in the ranges of:
- erosion: €0.7 – 14.0 billion
- organic matter decline: €3.4 – 5.6 billion
- compaction: no estimate possible
- salinisation: €158 – 321 million
- landslides: up to €1.2 billion per event
- contamination: €0.6 – 17.3 billion
- sealing: no estimate possible
- biodiversity decline: no estimate possible.

No assessments of costs of compaction, soil sealing and biodiversity decline are currently available. The total costs of soil degradation *that could be assessed* for erosion, organic matter decline, salinisation, landslides and contamination on the basis of available data, would be up to €38 billion annually for EU25. These estimates are necessarily wide ranging due to the lack of sufficient quantitative and qualitative data.

These costs do not include the damage to the ecological functions of soil as these were not possible to quantify. Therefore, the real costs for soil degradation are likely to exceed the estimates given above.

On the other hand it must be highlighted that these costs of soil degradation do not take into account the effect of standards adopted in January 2005 under the Common Agriculture Policy cross-compliance scheme, nor the effect of other measures recently taken by Member States. Nevertheless, as changes in soil are very slow, it is likely that the current estimate of the extent of the problem is an appropriate reference.

Evidence shows that the majority of the costs are borne by society in the form of damage to infrastructures due to sediment run off, increased health-care needs for people affected by contamination, treatment of water contaminated through the soil, disposal of sediments, depreciation of land surrounding contaminated sites, increased food safety controls, and also costs related to the ecosystem functions of soil.

The Soil Thematic Strategy of the European Union paves the way towards adequate measures in order to reverse the negative trends in soil and land degradation in Europe and will have also an extensive impact at the global scale by promoting similar actions in the framework of internationally binding agreements related to land degradation, like the UNCCD, UNFCCC and CBD.

References

Crescimanno G, Lane M, Owens P, Rydel B, Jacobsen O, Düwel O, Böken H, Berényi-Üveges Castillo V, Imeson A (2004) Final Report, Working Group on Soil Erosion, Task Group 5: Links with organic matter and contamination working group and secondary soil threats. European Commission, Directorate-General Environment, Brussels.

EEA (1995) Soil. In: Europe's Environment: the Dobris Assessment. Office for Official Publications of the European Communities, Luxembourg.

EEA (1998) Europe's Environment: the second assessment. Office for Official Publications of the European Communities, Luxembourg.

EEA (1999) Soil degradation. In: Environment in the European Union at the turn of the century, Environmental assessment report No 2

EEA (2000) Down to earth: soil degradation and sustainable development in Europe – A challenge for the 21st century, Environmental issue report no 16, European Environment Agency

EEA (2006) Corine Land Cover. Office for Official Publications of the European Communities, Luxembourg.

ESBN (2005) Soil ATLAS of Europe. European Soil Bureau Network, European Commission. pp. 111.

Jones, RJA, Hiederer R, Rusco E, Loveland PJ, Montanarella L (2003). Topsoil organic carbon in Europe. Proceedings of the 4th European Congress on Regional Geoscientific Cartography and Information Systems, 17-20 June 2003, Bologna.

Jones RJA, Hiederer R, Rusco E, Loveland PJ, Montanarella L (2005) Estimating organic carbon in the soils of Europe for policy support. Eur J Soil Sci 56:655-671.

Jones RJA, Houšková B, Bullock P, Montanarella L (Eds) (2005) Soil Resources of Europe, second edition. European Soil Bureau Research Report No.9, EUR 20559 EN, 420pp. Office for Official Publications of the European Communities, Luxembourg.

Katakouzinos, D. (1968). Pedology – Fertilisation. Vol. B: Improvement, fertilisation, classification, mapping of soil. Spiros Spirou & Sons Ltd., Athens, 605 pp. (text in Greek).

Kirkby MJ et al. (2004) Pan-European Soil Erosion Risk Assessment: The PESERA Map, Version 1, October 2003, European Soil Bureau Research No. 16, EUR 21176, OPOCE

Lal R (2000) Soil conversion and restoration to sequester carbon and mitigate the greenhouse effect. III International Congress European Society for Soil Conervation, Valencia, 2000

MOE (2000) Ministry of the Environment, Classificazione dei Comuni italiani in base al livello di attenzione per il rischio idrogeologico, Monography Collana della Relazione sullo Stato dell'Ambiente, Italy

Regione Emilia-Romagna (2003) Direzione Generale Ambiente e Difesa del Suolo e della Costa, Servizio Geologoco, Sismico e dei Suol

Van-Camp L, Bujarrabal B, Gentile A-R, Jones RJA, Montanarella L, Olazábal C, Selvaradjou S-K (2004a). Reports of the Technical Working Groups Established under the Thematic Strategy for Soil Protection, pp. 179

Van-Camp L, Bujarrabal B, Gentile A-R, Jones RJA, Montanarella L, Olazábal C, Selvaradjou S-K (2004b). Reports of the Technical Working Groups Established under the Thematic Strategy for Soil Protection, EUR 21319 EN/1- Working Group on Research

Van-Camp L, Bujarrabal B, Gentile A-R, Jones RJA, Montanarella L, Olazábal C, Selvaradjou S-K (2004c). Reports of the Technical Working Groups Established under the Thematic Strategy for Soil Protection, Vol. III, Organic matter.

Van Ouwerkerk C, Soane BD (eds) (1995) Soil compaction and the environment. Special issue, Soil Till Res 35:1-113.

CHAPTER 6

Climate and Land Degradation – an Overview

Mannava V.K. Sivakumar and Robert Stefanski

Abstract. The definition of land degradation in the United Nations Convention to Combat Desertification (UNCCD) gives explicit recognition to climatic variations as one of the major factors contributing to land degradation. In order to accurately assess sustainable land management practices, the climate resources and the risk of climate-related or induced natural disasters in a region must be known. Land surface is an important part of the climate system and changes of vegetation type can modify the characteristics of the regional atmospheric circulation and the large-scale external moisture fluxes. Following deforestation, surface evapotranspiration and sensible heat flux are related to the dynamic structure of the low-level atmosphere and these changes could influence the regional, and potentially, global-scale atmospheric circulation. Surface parameters such as soil moisture, forest coverage, transpiration and surface roughness may affect the formation of convective clouds and rainfall through their effect on boundary-layer growth. Land use and land cover changes influence carbon fluxes and GHG emissions which directly alter atmospheric composition and radiative forcing properties. Land degradation aggravates CO_2-induced climate change through the release of CO_2 from cleared and dead vegetation and through the reduction of the carbon sequestration potential of degraded land.

Climate exerts a strong influence over dry land vegetation type, biomass and diversity. Precipitation and temperature determine the potential distribution of terrestrial vegetation and constitute principal factors in the genesis and evolution of soil. Precipitation also influences vegetation production, which in turn controls the spatial and temporal occurrence of grazing and favours nomadic lifestyle. The generally high temperatures and low precipitation in the dry lands lead to poor organic matter production and rapid oxidation. Low organic matter leads to poor aggregation and low aggregate stability leading to a high potential for wind and water erosion. The severity, frequency, and extent of erosion are likely to be altered by changes in rainfall amount and intensity and changes in wind. Impacts of extreme events such as droughts, sand and dust storms, floods, heat waves, wild fires etc., on land degradation are explained with suitable examples. Current advances in weather and climate science to deal more effectively with the impacts of different climatic parameters on land degradation are explained with suitable examples. Several activities promoted by WMO's programmes around the world help promote a better understanding of the interactions between climate and land degradation through dedicated observations of the climate system; improvements in the application of agrometeorological methods and the proper assessment and management of water resources; advances in climate science and prediction; and pro-

motion of capacity building in the application of meteorological and hydrological data and information in drought preparedness and management. The definition of land degradation adopted by UNCCD assigns a major importance to climatic factors contributing to land degradation, but there is no concerted effort at the global level to systematically monitor the impacts of different climatic factors on land degradation in different regions and for different classes of land degradation. Hence there is an urgent need to monitor the interactions between climate and land degradation. To better understand these interactions, it is also important to identify the sources and sinks of dryland carbon, aerosols and trace gases in drylands. This can be effectively done through regional climate monitoring networks. Such networks could also help enhance the application of seasonal climate forecasting for more effective dryland management.

6.1 Introduction

Desertification is now defined in the United Nations Convention to Combat Desertification (UNCCD) as "land degradation in the arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities" (UNCCD 1999). Furthermore, UNCCD defines land degradation as a "reduction or loss, in arid, semi-arid, and dry subhumid areas, of the biological or economic productivity and complexity of rain-fed cropland, irrigated cropland, or range, pasture, forest, and woodlands resulting from land uses or from a process or combination of processes, including processes arising from human activities and habitation patterns, such as: (i) soil erosion caused by wind and/or water; (ii) deterioration of the physical, chemical, and biological or economic properties of soil; and (iii) long-term loss of natural vegetation."

According to UNCCD, over 250 million people are directly affected by land degradation. In addition, some one billion people in over one hundred countries are at risk. These people include many of the world's poorest, most marginalized, and politically weak citizens.

Land degradation issue for world food security and the quality of the environment assumes a major significance when one considers that only about 11% of the global land surface can be considered as prime or Class I land, and this must feed the 6.3 billion people today and the 8.2 billion expected in the year 2020 (Reich et al. 2001). Hence land degradation will remain high on the international agenda in the 21st century.

Sustainable land management practices are needed to avoid land degradation. Land degradation typically occurs by land management practices or human development that is not sustainable over a period of time. To accurately assess sustainable land management practices, the climate resources and the risk of climate-related or induced natural disasters in a region must be known. Only when climate resources are paired with potential management or development practices can the land degradation potential be assessed and appropriate mitigation technology considered. The use of climate information must be applied in developing sustainable practices as climatic variation is one of the major factors contributing or even a trigger to land degradation and there is a clear need to consider carefully how climate induces and influences land degradation.

6.2 Extent and Rate of Land Degradation

Global assessment of land degradation is not an easy task, and a wide range of methods are used, including expert judgement, remote sensing and modeling. Because of different definitions and terminology, there also exists a large variation in the available statistics on the extent and rate of land degradation. Further, most statistics refer to the risks of degradation or desertification (based on climatic factors and land use) rather than the actual (present) state of the land.

Different processes of land degradation also confound the available statistics on soil and/or land degradation. Principal processes of land degradation (Lal et al. 1989) include erosion by water and wind, chemical degradation (comprising acidification, salinization, fertility depletion, and decrease in cation retention capacity), physical degradation (comprising crusting, compaction, hard-setting etc.) and biological degradation (reduction in total and biomass carbon, and decline in land biodiversity). The latter comprises important concerns related to eutrophication of surface water, contamination of ground water, and emissions of trace gases (CO_2, CH_4, N_2O, NO_x) from terrestrial/aquatic ecosystems to the atmosphere. Soil structure is the important property that affects all degradative processes. Factors that determine the kind of degradative processes include land quality as affected by its intrinsic properties of climate, terrain and landscape position, climax vegetation and biodiversity, especially soil biodiversity.

In an assessment of population levels in the world's dry lands, the Office to Combat Desertification and Drought (UNSO) of the United Nations Development Programme (UNDP) showed that globally 54 million sq. km or 40% of the land area is occupied by dry lands (UNSO 1997). About 29.7% of this area falls in the arid region, 44.3% in the semi-arid region and 26% in the dry sub-humid region. A large majority of the dry lands are in Asia (34.4%) and Africa (24.1%), followed by the Americas (24%), Australia (15%) and Europe (2.5%).

Figure 6.1 indicates that the areas of the world vulnerable to land degradation cover about 33% of the global land surface. At the global level, it is estimated that the annual income foregone in the areas immediately affected by desertification amounts to approximately US$ 42 billion each year.

The semi-arid to weakly aridic areas of Africa are particularly vulnerable, as they have fragile soils, localized high population densities, and generally a low-input form of agriculture (Lal 1988). About 25% of land in Asian countries is vulnerable.

Long-term food productivity is threatened by soil degradation, which is now severe enough to reduce yields on approximately 16% of the agricultural land, especially cropland in Africa, Central America and pastures in Africa. Sub-Saharan Africa has the highest rate of land degradation. It is estimated that losses in productivity of cropping land in sub-Saharan Africa are in the order of 0.5–1% an-

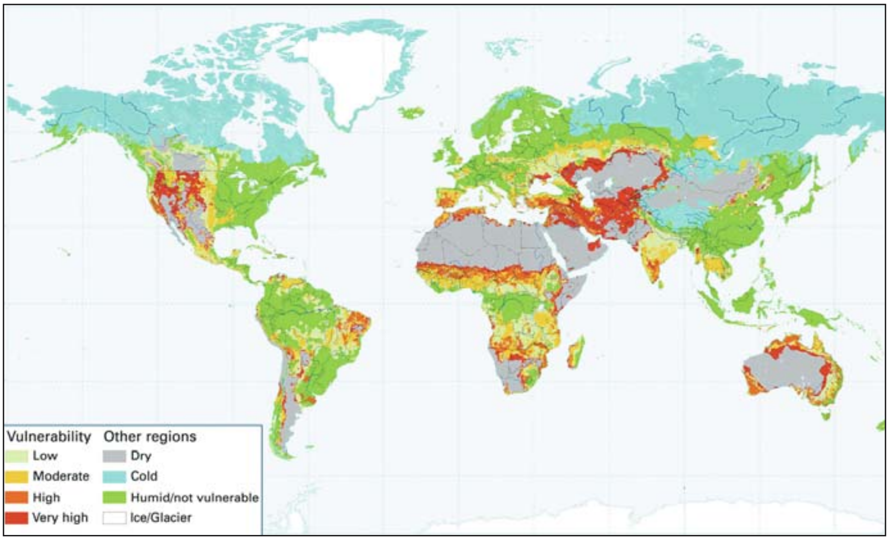


Fig. 6.1. Soil degradation in the world's drylands, 1990s (Source: UNEP)

nually, suggesting productivity loss of at least 20% over the last 40 years (Scherr 1999).

Africa is particularly threatened because the land degradation processes affect about 46% of Africa (Reich et al. 2001) The significance of this large area becomes evident when one considers that about 43% of the continent is characterized as extreme deserts (the desert margins represent the areas with very high vulnerability.) There is only about 11% of the land mass which is humid and which by definition is excluded from desertification processes. There is about 2.5 million km^2 of land under low risk, 3.6 million km^2 under moderate risk, 4.6 million km^2 under high risk, and 2.9 million km^2 under very high risk. The region that has the highest propensity is located along the desert margins and occupies about 5% of the landmass. It is estimated that about 22 million people (2.9% of total population) live in this area (Reich et al. 2001). The low, moderate and high vulnerability classes occupy 14, 16, and 11% respectively and together impact about 485 million people.

Land degradation is also a serious problem in Australia with over 68% of the land estimated to have been degraded (Table 6.1).

According to UNCCD, the consequences of land degradation include undermining of food production, famines, increased social costs, decline in the quantity and quality of fresh water supplies, increased poverty and political instability, reduction in land's resilience to natural climate variability and decreased soil productivity.

Table 6.1. Land degradation on cropland in Australia (Source: Woods, 1983; Mabbutt, 1992).

Type	Area ('000 km^2)
Total	443
Not degraded	142
Degraded	301
i) Water erosion	206
ii) Wind erosion	52
iii) Combined water and wind erosion	42
iv) Salinity and water erosion	0.9
v) Others	0.5

6.3
Land Degradation – causes

Land degradation involves two interlocking, complex systems: the natural ecosystem and the human social system (Barrow 1994). Natural forces, through periodic stresses of extreme and persistent climatic events, and human use and abuse of sensitive and vulnerable dry land ecosystems, often act in unison, creating feedback processes, which are not fully understood. Interactions between the two systems determine the success or failure of resource management programs. Causes of land degradation are not only biophysical, but also socioeconomic (e.g. land tenure, marketing, institutional support, income and human health) and political (e.g. incentives, political stability).

High population density is not necessarily related to land degradation. Rather, it is what a population does to the land that determines the extent of degradation. People can be a major asset in reversing a trend towards degradation. Indeed, mitigation of land degradation can only succeed if land users have control and commitment to maintain the quality of the resources. However, they need to be healthy and politically and economically motivated to care for the land, as subsistence agriculture, poverty and illiteracy can be important causes of land and environmental degradation.

There are many, usually confounding, reasons why land users permit their land to degrade. Many of the reasons are related to societal perceptions of land and the values they place on land. The absence of land tenure and the resulting lack of stewardship is a major constraint in some countries to adequate care for the land. Degradation is also a slow imperceptible process and so many people are not aware that their land is degrading.

Loss of vegetation can propagate further land degradation via land surface-atmosphere feedback. This occurs when a decrease in vegetation reduces evaporation and increases the radiation reflected back to the atmosphere (albedo), consequently reducing cloud formation. Large-scale experiments in which numerical models of the general circulation have been run with artificially high albedo over dry lands have suggested that large increases in the albedo of subtropical areas should reduce rainfall.

6.4 Climatic consequences of land degradation

Land surface is an important part of the climate system. The interaction between land surface and the atmosphere involves multiple processes and feedbacks, all of which may vary simultaneously. It is frequently stressed (Henderson-Sellers et al. 1993; McGuffie et al. 1995; Sud et al. 1996) that the changes of vegetation type can modify the characteristics of the regional atmospheric circulation and the large-scale external moisture fluxes. Changes in surface energy budgets resulting from land surface change can have a profound influence on the earth's climate.

Following deforestation, surface evapotranspiration and sensible heat flux are related to the dynamic structure of the low-level atmosphere. These changes in fluxes within the atmospheric column could influence the regional, and potentially, global-scale atmospheric circulation. For example, changes in forest cover in the Amazon basin affect the flux of moisture to the atmosphere, regional convection, and hence regional rainfall (Lean and Warrilow 1989). More recent work shows that these changes in forest cover have consequences far beyond the Amazon basin (Werth and Avissar 2002). .

Fragmentation of landscape can affect convective flow regimes and rainfall patterns locally and globally. El Niño events and land surface change simulations with climate models suggest that in equatorial regions where towering thunderstorms are frequent, disturbing areas hundreds of kilometres on a side may yield global impacts.

Use of a numerical simulation model by Garrett (1982) to study the interactions between convective clouds, the convective boundary layer and a forested surface showed that surface parameters such as soil moisture, forest coverage, and transpiration and surface roughness may affect the formation of convective clouds and rainfall through their effect on boundary-layer growth.

An atmospheric general circulation model with realistic land-surface properties was employed (Dirmeyer and Shukla 1996) to investigate the climatic effect of doubling the extent of earth's deserts and most regions and it showed a notable correlation between decreases in evapotranspiration and resulting precipitation. It was shown that Northern Africa suffers a strong year-round drought while southern Africa has a somewhat weaker year-round drought. Some regions, particularly the Sahel, showed an increase in surface temperature caused by decreased soil moisture and latent-heat flux.

Land use and land cover changes influence carbon fluxes and GHG emissions (Houghton 1995; Braswell et al. 1997) which directly alter atmospheric composition and radiative forcing properties. They also change land-surface characteristics and, indirectly, climatic processes. Observations during the HAPEX-Sahel project suggested that a large-scale transformation of fallow savannah into arable crops like millet, may lead to a decrease in evaporation (Gash et al. 1997). Land use and land cover change is an important factor in determining the vulnerability of ecosystems and landscapes to environmental change.

Since the industrial revolution, global emissions of carbon (C) are estimated at 270±30 gigatons (Gt) due to fossil fuel combustion and 136±5 Gt due to land use change and soil cultivation. Emissions due to land use change include those by deforestation, biomass burning, conversion of natural to agricultural ecosystems, drainage of wetlands and soil cultivation. Depletion of soil organic C (SOC) pool has contributed 78±12 Gt of C to the atmosphere, of which about one-third is attributed to soil degradation and accelerated erosion and two-thirds to mineralization (Lal 2004).

Land degradation aggravates CO_2-induced climate change through the release of CO_2 from cleared and dead vegetation and through the reduction of the carbon sequestration potential of degraded land.

6.5 Climatic Factors in Land Degradation

Climate exerts a strong influence over dry land vegetation type, biomass and diversity (Williams and Balling 1996). Precipitation and temperature determine the potential distribution of terrestrial vegetation and constitute principal factors in the genesis and evolution of soil. Precipitation also influences vegetation production, which in turn controls the spatial and temporal occurrence of grazing and favours nomadic lifestyle. Vegetation cover becomes progressively thinner and less continuous with decreasing annual rainfall. Dry land plants and animals display a variety of physiological, anatomical and behavioural adaptations to moisture and temperature stresses brought about by large diurnal and seasonal variations in temperature, rainfall and soil moisture.

Williams and Balling (1996) provided a nice description of the nature of dryland soils and vegetation and the manner in which climate affects the soils and vegetation. The generally high temperatures and low precipitation in the dry lands lead to poor organic matter production and rapid oxidation. Low organic matter leads to poor aggregation and low aggregate stability leading to a high potential for wind and water erosion. For example, wind and water erosion is extensive in many parts of Africa. Excluding the current deserts, which occupy about 46% of the landmass, about 25% of the land is prone to water erosion and about 22%, to wind erosion.

Structural crusts/seals formed by raindrop impact which could decrease infiltration, increase runoff and generate overland flow and erosion. The severity, frequency, and extent of erosion are likely to be altered by changes in rainfall amount and intensity and changes in wind.

Land management will continue to be the principal determinant of the soil organic matter (SOM) content and susceptibility to erosion during the next few decades, but changes in vegetation cover resulting from short-term changes in weather and near-term changes in climate are likely to affect SOM dynamics and erosion, especially in semi-arid regions.

From the assessment of the land resource stresses and desertification in Africa which was carried out by the Natural Resources Conservation Service of the United States Department of Agriculture (Reich et al. 2001) utilizing information from the soil and climate resources of Africa, it can be concluded (Table 6.2) that, climatic stresses account for 62.5% of all the stresses on land degradation in Africa. These climatic stresses include high soil temperature, seasonal excess water; short duration low temperatures, seasonal moisture stress and extended moisture stress

Table 6.2. Major land resources stresses and land quality assessment of Africa (Source: Reich, P.F., S.T. Numben, R.A. Almaraz, and H. Eswaran. 2001. Land resource stresses and desertification in Africa. In: Eds. Bridges, E.M., I.D. Hannam, F.W.T. Penning de Vries, S.J. Scherr, and S. Sombatpanit. 2001. Response to Land Degradation. Sci. Publishers, Enfield, USA. 101-114)

Land Stresses			Inherent Land Quality		
Stress Class	Kinds of Stress	Area (1,000 km^2)	Class	Area (1,000 km^2)	Area (%)
1	Few constraints	118.1	I	118.1	0.4
2	High shrink/swell	107.6	II		
3	Low organic matter	310.9	II		
4	High soil temperatures	901.0	II	1,319.6	4.5
5	Seasonal excess water	198.9	III		
6	Minor root restrictions	566.5	III		
7	Short duration low temperatures	.014	III	765.4	2.6
8	Low structural stability	333.7	IV		
9	High anion exchange capacity	43.8	IV		
10	Impeded drainage	520.5	IV	898.0	3.1
11	Seasonal moisture stress	3,814.9	V		
12	High aluminum	1,573.2	V		
13	Calcareous, gypseous	434.2	V		
14	Nutrient leaching	109.9	V	5,932.3	20.2
15	Low nutrient holding capacity	2,141.0	VI		
16	High P, N retention	932.2	VI		
17	Acid sulfate	16.6	VI		
18	Low moisture and nutrient status	0	VI		
19	Low water holding capacity	2,219.5	VI	5,309.3	18.1
20	High organic matter	17.0	VII		
21	Salinity/alkalinity	360.7	VII		
22	Shallow soils	1,016.9	VII	1,394.7	4.8
23	Steep lands	20.3	VIII		
24	Extended low temperatures	0	VIII	20.3	0.1
Land Area		29,309.1			
Water Bodies		216.7			
Total Area		29,525.8			

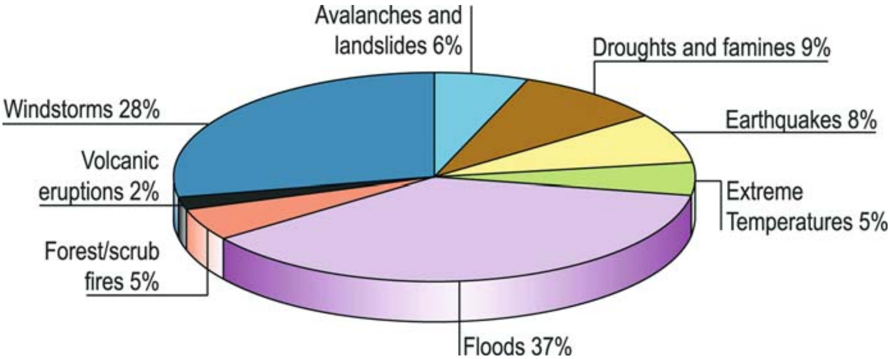


Fig. 6.2. Global distribution of natural disasters (1993-2002)

and affect 18.5 million km^2 of the land in Africa. This study clearly exemplifies the importance of the need to give a more careful consideration of climatic factors in land degradation.

According to the database of CRED, the Belgium Centre for Research on the Epidemiology of Disasters, weather- climate- and water-related hazards that occurred between 1993-2002, were responsible for 63 per cent of the US$ 654 billion damage caused by all natural disasters. These natural hazards are therefore the most frequent and extensively observed ones (Figure 6.2) and they all have a major impact on land degradation.

6.5.1 Rainfall

Rainfall is the most important climatic factor in determining areas at risk of land degradation and potential desertification. Rainfall plays a vital role in the development and distribution of plant life, but the variability and extremes of rainfall can lead to soil erosion and land degradation (Fig. 6.3). If unchecked for a period of time, this land degradation can lead to desertification. The interaction of human activity on the distribution of vegetation though land management practices and seemingly benign rainfall events can make land more vulnerable to degradation. These vulnerabilities become more acute when the prospect of climate change is introduced.

Rainfall and temperature are the prime factors in determining the world's climate and therefore the distribution of vegetation types. There is a strong correlation between rainfall and biomass since water is one of primary inputs to photosynthesis. Climatologists use an "aridity index" (the ratio of annual precipitation to potential evaporation) to help classify desert (arid) or semi-arid areas (UNEP 1992; Williams and Balling 1986; Gringof and Mersha 2006). Drylands exist because the annual water loss (evaporation) exceeds the annual rainfall; therefore these regions have a continual water deficit. Deserts are the ultimate example of a climate where annual evaporation far exceeds the annual rainfall. In cases where the annual water deficits are not so large, some plant life can take hold usually in the form of grasslands or steppes. However, it is these dry lands on the margins of the world's deserts that are most susceptible to desertification, the most extreme example of land degradation. Examples of these regions include the Pampas of South Americas, the Great Russia Steppes, the Great Plains of North America, and the Savannas of Southern Africa and Sahel region of Northern Africa. With normal climatic variability, some years the water deficits can be larger than others but sometimes there can be a several year period of water deficit or long-term drought. During this period, one can see examples of land degradation in the Dust Bowl years of the 1930s in the Great Plains or the nearly two decade long drought in the Sahel in the 1970s and 1980s. It was this period of drought in the Sahel that created the current concern of desertification.

For over a century, soil erosion data has been collected and analyzed from soil scientists, agronomists, geologists, hydrologists, and engineers. From these investigations, scientists have developed a simple soil erosion relationship that incorporates the major soil erosion factors. The Universal Soil Loss Equation (USLE) was developed in the mid-1960s for understanding soil erosion for agricultural applications(Wischmeier and Smith 1978). In the mid-1980's , it was updated and renamed the Revised Universal Soil Loss Equation (RUSLE) to incorporate the large amount of information that had accumulated since the original and to address land use applications besides agriculture such as soil loss from mined lands, constructions sites, and reclaimed lands.The RUSLE is derived from the theory of soil erosion and from more than 10,000 plot-years of data from natural rainfall plots and numerous rainfall simulations.

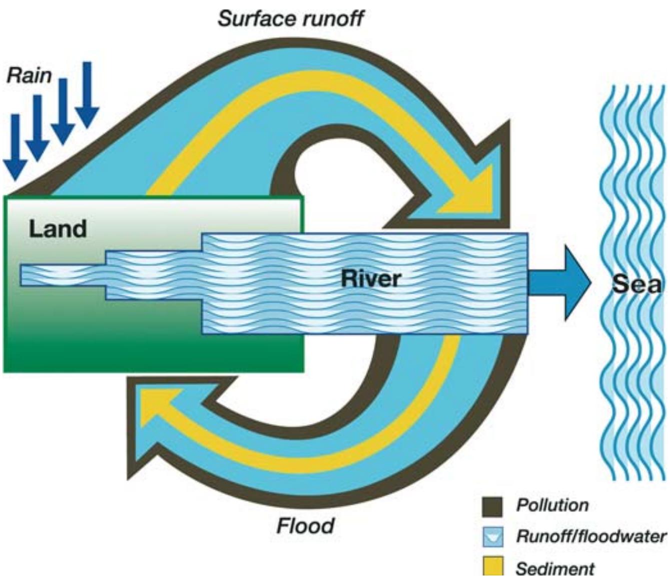


Fig. 6.3. Schematic diagram of rainfall-induced processes involved in land degradation.

The RUSLE is defined as:

$$A = R\,K\,L\,S\,C\,P$$

where A is the soil loss per year (t/ha/year); R represents the rainfall-runoff erosivity factor; K is the soil erodibilty factor; L represents the slope length; S is the slope steepness; C represents the cover management, and P denotes the supporting practices factor (Renard et al. 1997). These factors illustrate the interaction of various climatic, geologic, and human factors and that smart land management practices can minimize soil erosion and hopefully land degradation.

The extremes of either too much or too little rainfall can produce soil erosion that can lead to land degradation. However, soil scientists consider rainfall the most important erosion factor among the many factors that cause soil erosion. Zachar (1982) provides an overview of soil erosion due to rainfall which can erode soil by the force of raindrops, surface and subsurface runoff, and river flooding. The velocity of rain hitting the soil surface produces a large amount of kinetic energy which can dislodge soil particles. Erosion at this micro-scale can also be caused by easily dissoluble soil material made water soluble by weak acids in the rainwater. The breaking apart and splashing of soil particles due to raindrops is only the first stage of the process, being followed by the washing away of soil particles and further erosion caused by flowing water. However, without surface runoff, the amount of soil erosion caused by rainfall is relatively small (Lal 2001).

Once the soil particles have dislodged they become susceptible to runoff. In general, the higher intensity of the rainfall, the greater is the quantity of soil available in runoff water. In the case of a light rain for a long duration, most of the soil dislodgement takes place in the underwater environment and the soil particles are mostly fine. The greater the intensity of rainfall and subsequent surface runoff, the larger the soil particles that are carried away. A critical factor that determines soil erosion by rainfall is the permeability of the soil, which indirectly influences the total amount of soil loss and the pattern of erosion on slopes. One unfortunate by-product of runoff is the corresponding transport of agricultural chemicals and the leaching of these chemicals into the groundwater.

Rainfall intensity is the most important factor governing soil erosion caused by rain (Zachar 1982). Dry land precipitation is inherently variable in amounts and intensities and so is the subsequent runoff. Surface runoff is often higher in dry lands than in more humid regions due to the tendency of dry land soils to form impermeable crusts under the impact of intense thunderstorms and in the absence of significant plant cover or litter. In these cases, soil transport may be an order of magnitude greater per unit momentum of falling raindrops than when the soil surface is well vegetated. The sparser the plant cover, the more vulnerable the topsoil is to dislodgement and removal by raindrop impact and surface runoff. Also, the timing the rainfall can play crucial role in soil erosion leading to land degradation. An erratic start to the rainy season along with heavy rain will have a greater impact since the seasonal vegetation will not be available to intercept the rainfall or stabilize the soil with its root structure.

An ongoing effort of scientists is to try to integrate all these factors into models that can be used to predict soil erosion. The Water Erosion Prediction Project

(WEPP) model is a process-based, distributed parameter, continuous simulation, erosion prediction model for use on personal computers and can be applied at the field scale to simulate hillslope erosion or more complex watershed scale erosion (USDA 2006). It mimics the natural processes that are important in soil erosion. It updates the soil and crop conditions everyday that affect soil erosion. When rainfall occurs, the plant and soil characteristics are used to determine if surface runoff will occur. The WEPP model includes a number of conceptual components that include: climate and weather (rainfall, temperature, solar radiation, wind, freeze – thaw, snow accumulation and melting), irrigation (stationary sprinkler, furrow), hydrology – (infiltration, depressional storage, runoff), water balance (evapotranspiration, percolation, drainage), soils (types and properties) , crop growth – (cropland, rangeland, forestland) , residue management and decomposition, tillage impacts on infiltration and erodibility, erosion – (interrill, rill, channel), deposition (rills, channels, and impoundments), sediment delivery, particle sorting and enrichment.

Of special note is the impact of other forms of precipitation on soil erosion (Zachar 1982). Hail has a severe effect on the soil surface because its kinetic energy is several times that of rain resulting in much more soil surface being destroyed and a greater amount of material being washed away. And if hailstorms are accompanying with heavy rain, as is the case with some thunderstorms, large amounts of soil can be eroded especially on agricultural land before the crops can stabilize the soil surface. Snow thaw erosion occurs when the soil freezes during the cold period and the freezing process dislodges the soil, so that when the spring thaw occurs, fine soil particles are released in the runoff. This kind of erosion can often produce greater erosion losses than by rain. Also, when the soil freezes the infiltration rate is greatly reduced so that when the thaw arrives, relatively intense soil erosion can take place even though the amount of snow thaw is small. In this situation, the erosive processes can be multiplied by a combination of a heavy rain event and sudden influx of warm air. Leeward portions of mountainous areas are susceptible to this since they are typically drier and have less vegetation and are prone to katabatic winds (rapidly descending air from a mountain range warms very quickly).

6.5.2 Floods

Dryland rivers have extremely variable flows and river discharge and the amount of suspended sediments are highly sensitive to fluctuations in rainfall as well as any changes in the vegetation cover in the basins. The loss of vegetation in the headwaters of dryland rivers can increase sediment load and can lead to dramatic change in the character of the river to a less stable, more seasonal river characterised by a rapidly shifting series of channels. However, rainfall can lead to land degradation in other climates, including sub-humid ones. Excessive rainfall events either produced by thunderstorms, hurricanes and typhoons, or mid-latitude low-pressure systems can produce a large amount of water in a short period of time across local areas. This excess of water overwhelms the local watershed and produces river flooding. Of course, this is a natural phenomenon that has occurred for millions of years and continuously shapes the earth. River flooding occurs in all climates, but it is in dryland areas where the problem is most acute.

Flood forecasting is complex process that must take into account many different factors at the same time, depending on the type and nature of the phenomenon that triggers the flooding. For example, widespread flash floods are often started off by heavy rain falling in one area within a larger area of lighter rain, a confusing situation that makes it difficult to forecast where the worst flood will occur. Forecasting floods caused by the heavy rain or storm surges that can sweep inland as part of a tropical cyclone can also be a complex job, as predictions have to include where they will land, the stage of their evolution and the physical characteristics of the coast.

To make predictions as accurate as possible, National Hydrological Services (NHSs) and National Meteorological Services (NMSs) under the auspices of the WMO undertake flood forecasting based on quantitative precipitation forecasts (QPFs), which have become more accurate in recent years, especially for light and moderate amounts of precipitation, although high amounts and rare events are still difficult to predict. So setting up forecasting systems that integrate predictions for weather with those for water-related events is becoming more of a possibility every day, paving the way for a truly integrated approach.

Forecasting also needs to be a cooperative and multidisciplinary effort. With the many issues and the complexity of factors surrounding floods, flood managers have to join forces with meteorologists, hydrologists, town planners, and civil defense authorities using available integrated models. Determining the socioeconomic impacts of floods will mean taking a close look at construction or other activities in and around river channels. Up-to-date and accurate information is essential, through all the available channels: surface observation, remote sensing and satellite technology as well as computer models.

Flood risk assessment and management have been around for decades but recently there has been a shift to Integrated Flood Management. The defining characteristic of Integrated Flood Management is integration, expressed simultaneously in different forms: an appropriate mix of strategies, points of interventions, types of interventions (i.e. structural or non-structural), short or long-term, and a participatory and transparent approach to decision making – particularly in terms of institutional integration and how decisions are made and implemented within the given institutional structure.

Land use planning and water management have to be combined in one synthesized plan through co-ordination between land management and water management authorities to achieve consistency in planning. The rationale for this integration is that the use of land has impacts upon both water quantity and quality. The three main elements of river basin management – water quantity, water quality, and the processes of erosion and deposition – are inherently linked.

Therefore, an integrated flood management plan should address the following five key elements (APFM 2004):

- Manage the water cycle as a whole;
- Integrate land and water management;
- Adopt a best mix of strategies;
- Ensure a participatory approach;
- Adopt integrated hazard management approaches.

6.5.3 Droughts

Drought is a natural hazard originating from a deficiency of precipitation that results in a water shortage for some activities or some groups. It is the consequence of a reduction in the amount of precipitation over an extended period of time, usually a season or more in length, often associated with other climatic factors – such as high temperatures, high winds and low relative humidity – that can aggravate the severity of the event. For example, the 2002-03 El Niño related Australian drought (Coughlan et al. 2003), which lasted from March 2002 to January 2003, was arguably one of, if not the, worst short term droughts in Australia's recorded meteorological history (Nicholls 2004). Analysis of rainfall records for this 11-month period showed that 90% of the country received rainfall below that of the long-term median, with 56% of the country receiving rainfall in the lowest 10% (i.e., decile-1) of recorded totals (Australia-wide rainfall records commenced in 1900). During the 2002-03 drought Australia experienced widespread bushfires, severe dust storms and agricultural impacts that resulted in a drop in Australia's Gross Domestic Product of over 1% (Watkins 2005). The first 5 months of 2005 were exceptionally dry for much of Australia (Figure 6.4), leading many to label this period a truly exception drought.

Extended droughts in certain arid lands have initiated or exacerbated land degradation. Records show that extensive droughts have afflicted Africa, with serious episodes in 1965–1966, 1972–1974, 1981–1984, 1986–1987, 1991–1992, and 1994–1995. The aggregate impact of drought on the economies of Africa can be large: 8–9 per cent of GDP in Zimbabwe and Zambia in 1992, and 4–6 per cent of GDP in Nigeria and Niger in 1984. In the past 25 years, the Sahel has experienced the most substantial and sustained decline in rainfall recorded anywhere in the world within the period of instrumental measurements. The Sahelian droughts in the early 70s were most unique in their severity and were characterized as "the quintessence of a major environmental emergency" and their long term impacts are now becoming clearer (Figure 6.5).

Sea surface temperature (SST) anomalies, often related to the El Niño Southern Oscillation (ENSO) or North Atlantic Oscillation (NAO), contribute to rainfall variability in the Sahel. Droughts in west Africa correlate with warm SST in the tropical south Atlantic. Examination of the oceanographic and meteorological data from the period 1901-1985 showed that persistent wet and dry periods in the Sahel were related to contrasting patterns of SST anomalies on a near-global scale (Sivakumar 2006). From 1982 to 1990, ENSO-cycle SST anomalies and vegetative production in Africa were found to be correlated. Warmer eastern equatorial Pacific waters during ENSO episodes correlated with rainfall of <1,000 mm yr^{-1} over certain African regions.

A coupled surface-atmosphere model indicates that – whether anthropogenic factors or changes in SST initiated the Sahel drought of 1968-1973 – permanent loss of Sahel savannah vegetation would permit drought conditions to persist. The effect of drought, reducing soil moisture and thus evaporation and cloud cover, and increasing surface albedo as plant cover is destroyed, is generally to increase ground and near-surface air temperatures while reducing the surface radia-

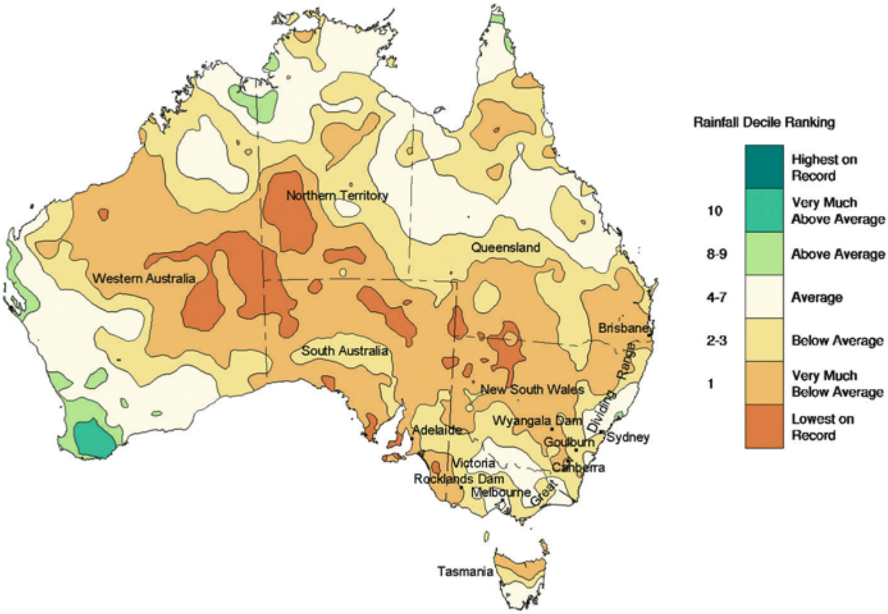
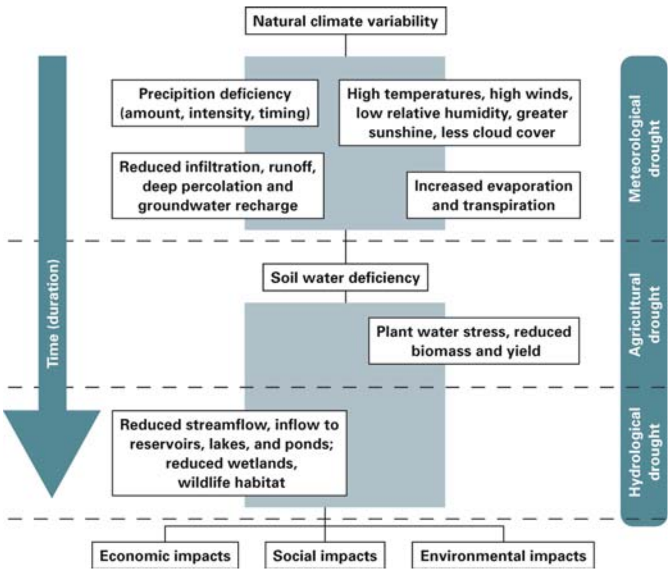


Fig. 6.4. Rainfall deciles for January to May 2005 in Australia (© Commonwealth of Australian 2005, Australian Bureau of Meteorology)

Fig. 6.5. Types and impacts of Droughts



tion balance and exacerbating the deficit in the radiation balance of the local surface-atmosphere system (Williams and Balling 1996). This entails increased atmospheric subsidence and consequently further reduced precipitation.

Early warning systems can reduce impacts by providing timely information about the onset of drought (Wilhite et al. 2000) Conventional surface observation stations within National Meteorological Services are one link in the chain, providing essential benchmark data and time series necessary for improved monitoring of the climate and hydrologic system. Tracking certain indicators such as stream flow or soil moisture can help in formulating drought index values – typically single numbers, far more useful than raw data for decision-making.

Drought plans should contain three basic components: monitoring and early warning, risk assessment, and mitigation and response (Wilhite and Svoboda 2000) . Because of the slow onset characteristics of droughts, monitoring and early warning systems provide the foundation for an effective drought mitigation plan. A plan must rely on accurate and timely assessments to trigger mitigation and emergency response programs.

Various WMO programmes monitor extreme climate events associated with drought, while four monitoring centres – two in Africa, one in China and the Global Information and Early Warning System – provide weather advisories and one and three-month climate summaries. Among other African early warning systems, the Southern Africa Development Community (SADC) monitors the crop and food situation in the region and issues alerts during periods of impending crisis. Such networks can be the backbone of drought contingency planning, coordinated plans for dealing with drought when it comes.

6.5.4 Solar radiation, temperature and evaporation

The only source of energy for the earth is the sun but our world intercepts only a tiny amount of this energy (less than a tenth of 1 percent) to provide the energy for the various biological (photosynthesis) and geophysical (weather and climate) processes for life depends on. The earth system, based on fundamental rules of physics, must emit the same amount of radiation as it receives. Therefore, the complex transfer of energy to satisfy this requirement is the basis for our weather and climate. Solar radiation is highly correlated with cloudiness, and in most dryland climates there are little or no clouds, the solar radiation can be quite intense. In fact, some of the highest known values of solar radiation can be found in places like the Sahara desert. Solar heating of the land surface is the main contribution to the air temperature.

Along with rainfall, temperature is the main factor determining climate and therefore the distribution of vegetation and soil formation. Soil formation is the product of many factors that include: the parent material (rock), topography, climate, biological activity, and time. Temperature and rainfall cause different patterns of weathering and leaching in soils. Seasonal and daily changes in temperature can affect the soil moisture, biological activity, rates of chemical reactions, and the types of vegetation. Important chemical reactions in the soil include the nitrogen and carbon cycles.

In the tropics, surface soil temperatures can exceed 55°C and this intense heat contributes to the cracking of highly-clay soils that expose not only the soil surface but the soil subsurface to water or wind erosion. Of course, these high temperatures will also increase soil evaporation and further reduce available soil moisture for plant growth.

In temperate dry lands, the freeze-thaw cycle can have a direct effect on the composition of the soil by the movement of rocks and stones from various depths to the surface. In high elevations, the freeze-thaw is one factor degrading rock structures, causing cracks and fissures which could lead to landslides and rock avalanches.

Evaporation is the conversion of water from the liquid or solid state into vapour, and its diffusion into the atmosphere. A vapour pressure gradient between the evaporating surface and the atmosphere and a source of energy are necessary for evaporation. Solar radiation is the dominant source of energy and sets the broad limits of evaporation. Solar radiation values in the tropics are high, modified by the cloud cover, which leads to a high evaporative demand of the atmosphere. In the arid and semi-arid regions, considerable energy may be advected from the surrounding dry areas over irrigated zones. Rosenberg et al. (1983) lists several studies that have demostrated the "oasis effect" which is the transfer of energy across an evaporating surface and can cause large evaporative losses in a short period of time.

Climatic factors induce an evaporative demand of the atmosphere, but the actual evaporation resulting will be influenced by the nature of the evaporating surfaces as well as the availability of water. On a degraded land, the land surface itself influences the evaporative demand by the albedo and surface roughness, the latter affecting turbulence. In the arid and semi-arid regions, the high evaporation which greatly exceeds precipitation leads to accumulation of salts on soil surface. Soils with natric horizon are easily dispersed and the low moisture levels lead to limited biological activity.

6.5.5
Wind

The dry lands of the world are affected by moderate to severe land degradation from wind erosion and there is evidence that the frequency of sand storms/dust storms in increasing. It has been estimated that in the arid and semi-arid zones of the world, 24% of the cultivated land and 41% of the pasture land are affected by moderate to severe land degradation from wind erosion (Rozanov 1990).

The world-wide total annual production of dust by deflation of soils and sediments was estimated to be 61 to 366 million tonnes (Middleton 1986). Losses of desert soil due to wind erosion are globally significant. The upper limit for global estimates of the long-range transport of desert dust is approximately 1×10^{16} g year^{-1}.

For Africa, it is estimated that more than 100 million tonnes of dust per annum is blown westward over the Atlantic. The amount of dust arising from the Sahel zone has been reported to be around or above 270 million tons per year which corresponds to a loss of 30 mm per m² per year or a layer of 20 mm over the entire area (Stahr et al. 1996)

Every year desert encroachment caused by wind erosion buries 210,000 hectares of productive land in China (PRC 1994). It was shown that the annual changes of the frequency of strong and extremely strong sandstorms in China are as follows: 5 times in the 1950s, 8 times in the 1960s, 13 times in the 1970s, 14 times in the 1980s, and 20 times in the 1990s (Ci 1998).

Sand and dust storms are hazardous weather and cause major agricultural and environmental problems in many parts of the world. There is a high on-site as well as off-site cost due to the sand and dust storms. They can move forward like an overwhelming tide and strong winds take along drifting sands to bury farmlands, blow out top soil, denude steppe, hurt animals, attack human settlements, reduce the temperature, fill up irrigation canals and road ditches with sediments, cover the railroads and roads, cause household dust damages, affect the quality of water in rivers and streams, affect air quality, pollute the atmosphere and destroy mining and communication facilities. They accelerate the process of land degradation and cause serious environment pollution and huge destruction to ecology and living environment (Wang Shigong et al. 2001). Atmospheric loading of dust caused by wind erosion also affects human health and environmental air quality.

Wind erosion-induced damage includes direct damage to crops through the loss of plant tissue and reduced photosynthetic activity as a result of sandblasting, burial of seedlings under sand deposits, and loss of topsoil (Fryrear 1971; Amburst 1984; Fryrear 1990). The last process is particularly worrying since it potentially affects the soil resource base and hence crop productivity on a long-term basis, by removing the layer of soil that is inherently rich in nutrients and organic matter. Wind erosion on light sandy soils can provoke severe land degradation and sand deposits on young seedlings can affect crop establishment (Fig 6.6).

Calculations based on visibility and wind speed records for 100 km wide dust plumes, centered on eight climate stations around South Australia, indicated that

Fig. 6.6. Sand and dust storms move forward like an overwhelming tide and strong winds take along drifting sands to bury crops

dust transport mass was as high as 10 million tonnes (Butler et al. 1994). Thus dust entrainment during dust events leads to long-term soil degradation, which is essentially irreversible. The cost to productivity is difficult to measure but is likely to be quite substantial.

6.5.5.1
Causes of wind erosion

The occurrence of wind erosion at any place is a function of weather events interacting with soil and land management through its effects on soil structure, tilth and vegetation cover. In regions where long dry periods associated with strong seasonal winds occur regularly, the vegetative cover of the land does not sufficiently protect the soil, and the soil surface is disturbed due to inappropriate management practices, wind erosion usually is a serious problem.

At the southern fringe of the Sahara Desert, a special dry and hot wind, locally termed *Harmattan,* occurs. These NE or E winds normally occur in the winter season under a high atmospheric pressure system. When the wind force of *Harmattan* is beyond the threshold value, sand particles and dust particles will be blown away from the land surface and transported for several hundreds kilometres to the Atlantic Ocean.

In the Northwest region of India, the convection sand-dust storm that occurs in the season preceding the monsoon is named *Andhi* (Joseph et al. 1980). It is called *Haboob* in Africa and Arabic countries. It is titled *"phantom" or "devil"* in some regions.

In general, two indicators, wind velocity and visibility, are adopted to classify the grade of intensity of sand-dust storms. For instance, the sand-dust storms occurring in the Northwest part of India are classified into three grades. The feeble sand-dust storm develops when wind velocity is at force 6 (Beaufort) degree and visibility varies between 500-1,000 m. The secondary strong sand-dust storm will occur when wind velocity is at force 8 and visibility varies 200-500 m. Strong sand-dust storms will take place when wind velocity is at force 9 and visibility is <200 metres.

In China, a sand-dust storm is defined similarly to the above. The only difference is that the category of strong sand-dust storms is defined again into two grades, namely strong sand-dust storms and serious-strong sand-dust storms. When wind velocity is 50 metres per second (m/s) and visibility is <200 metres, the sandstorm is called a strong sand-dust storm. When wind velocity is 25 m/s and visibility is 0-50 metres, the sandstorm is termed a serious sand-dust storm (some regions name it Black windstorm or Black Devil) (Xu Guochang et al. 1979).

Four definitions of the dust phenomena are the same as used by the Australian Bureau of Meteorology, which conforms to the worldwide standards of the World Meteorological Organization (WMO). SYNOP present weather [WW] codes are included:

1. *Dust storms* (SYNOP WW code: 09) are the result of turbulent winds raising large quantities of dust into the air and reducing visibility to less than 1,000 m.

2. *Blowing dust* (SYNOP WW code: 07) is raised by winds to moderate heights above the ground reducing visibility at eye level (1.8 m), but not to less than 1,000 m.
3. *Dust haze* (SYNOP WW code: 06) is produced by dust particles in suspended transport which have been raised from the ground by a dust storm prior to the time of observation.
4. *Dust swirls* (or dust devils) (SYNOP WW code: 08) are whirling columns of dust moving with the wind and usually less than 30 m high (but may extend to 300 m or more). They usually dissipate after travelling a short distance.

Wind erosivity is the main factor controlling the broad pattern of wind erosion. It has been defined as “that property of the wind which determines its ability to entrain and move bare, dry soil in fine tilth” (Painter 1978). It can be estimated from daily or hourly records of wind speed above a threshold related to the lowest speed at which soil particles are entrained (Skidmore and Woodruff 1968). Chepil and Woodruff (1963) developed an index of wind erosion capacity (C) defined as:

$$C = \frac{V^3}{2.9(P-E_2)}$$

where V = wind speed at standard observing levels (~ 10 m), m s^{-1}; P = precipitation (mm); and E_p is potential evapotranspiration (mm). Table 6.3 gives a classification of the wind erosion capacity as per the different values of the index of wind erosion capacity.

When soil movement is sustained, the quantity of soil that can be transported by the wind varies as the cube of the velocity. Models demonstrate that wind erosion increases sharply above a threshold wind speed. In the U.S. corn belt, a 20% increase in mean wind speed greatly increases the frequency with which the threshold is exceeded and thus the frequency of erosion events.

There have been several efforts to integrate all these wind erosion factors into a computer model. One such effort is the Wind Erosion Prediction System (WEPS) which is a process-based, daily time-step model that predicts soil erosion by simulation of the fundamental processes controlling wind erosion (Wagner 1996). The WEPS model is able to calculate soil movement, estimate plant damage, and predict PM-10 emissions when wind speeds exceed the erosion threshold. It

Table 6.3. Wind erosion capacity (Source: W.S. Chepil and N.P. Woodruff. 1963. Physics of wind erosion and its control. Advances in Agronomy, 15)

Index value	Wind erision capacity
0-20	Insignificant or zero
20-50	Moderate
50-100	High
> 150	Very high

also provides users with spatial information regarding soil flux, deposition, and loss from specific regions of a field over time. The structure of WEPS is modular and consists of seven submodels and four databases. Most of the WEPS submodels use daily weather as the natural driving force for the physical processes that change field conditions. The other submodels focus on hydrology including the changes in temperature and water status of the soil; soil properties; growth of crop plants; crop plant decomposition; typical management practices such as tillage, planting, harvesting, and irrigation; finally the power of the wind on a subhourly basis.

6.5.5.2
Climatic implications of dust storms

The very fine fraction of soil-derived dust has significant forcing effects on the radiative budget. Dust particles are thought to exert a radiative influence on climate directly through reflection and absorption of solar radiation and indirectly through modifying the optical properties and longevity of clouds. Depending on their properties and in what part of the atmosphere they are found, dust particles can reflect sunlight back into space and cause cooling in two ways. Directly, they reflect sunlight back into space, thus reducing the amount of energy reaching the surface. Indirectly, they act as condensation nuclei, resulting in cloud formation (Pease et al. 1998). Clouds act as an *"atmospheric blanket,"* trapping long wave radiation within the atmosphere that is emitted from the earth. Thus, dust storms have local, national and international implications concerning global warming. Climatic changes in turn can modify the location and strength of dust sources.

6.6
Wild Fires, Land Degradation and Atmospheric Emissions

Uncontrolled wildfires occur in all vegetation zones of the world. It is estimated that fires annually affect 1015 million hectares (m ha) of boreal and temperate forest and other lands, 2040 m ha of tropical rain forests due to forest conversion activities and escaped agricultural fires, and up to 500 m ha of tropical and subtropical savannas, woodlands, and open forests. The extent of the soil organic carbon pool doubles that present in the atmosphere and is about two to three times greater than that accumulated in living organisms in all Earth's terrestrial ecosystems. In such a scenario, one of the several ecological and environmental impacts of fires is that they are a significant source of greenhouse gases responsible for global warming.

Globally, biomass burning, which includes wild fires, is estimated to produce 40 percent of the carbon dioxide, 32 percent of the carbon monoxide, 20 percent of the particulates, and 50 percent of the highly carcinogenic poly-aromatic hydrocarbons produced by all sources (Levine 1990). Current approaches for estimating global emissions are limited by accurate information on area burned and fuel available for burning.

Emissions from fires are considerable and contribute significantly to gross global emissions of trace gases and particulates from all sources to atmosphere. Natural emissions are responsible for a major portion of the compounds, including non-methane volatile organic compounds (NMVOC), carbon monoxide (CO) and nitric oxide (NO), which determine tropospheric oxidant concentrations. The total NMVOC flux is estimated to be about 84×10^{12} g of carbon (Tg C) which is comprised primarily of isoprene (35%), 19 other terpenoid compounds (25%) and 17 non-terpenoid compounds (40%).

The influence of fire on soil characteristics (soil-water content, soil compaction, soil temperature, infiltration ability, soil properties especially organic matter, pH, exchangeable Ca, Mg, K, Na and extractable P) of a semi-arid southern African rangeland was quantified over two growing seasons (2000/01–2001/02) following an accidental fire (Snyman 2003). The decrease in basal cover due to fire (head fires)exposed the soil more to the natural elements and therefore to higher soil temperatures and soil compaction in turn leading to lower soil-water content and a decline in soil infiltrability.

6.7 Climate change and land degradation

Human activities – primarily burning of fossil fuels and changes in land cover – are modifying the concentration of atmospheric constituents or properties of the Earth's surface that absorb or scatter radiant energy. In particular, increases in the concentrations of greenhouse gases (GHGs) and aerosols are strongly implicated as contributors to climatic changes observed during the 20th century and are expected to contribute to further changes in climate in the 21st century and beyond. These changes in atmospheric composition are likely to alter temperatures, precipitation patterns, sea level, extreme events, and other aspects of climate on which the natural environment and human systems depend.

According to IPCC(2003), established by WMO and UNEP, ecosystems are subject to many pressures (e.g., land-use change, resource demands, population changes); their extent and pattern of distribution is changing, and landscapes are becoming more fragmented. Climate change constitutes an additional pressure that could change or endanger ecosystems and the many goods and services they provide. Soil properties and processes – including organic matter decomposition, leaching, and soil water regimes – will be influenced by temperature increase. Soil erosion and degradation are likely to aggravate the detrimental effects of a rise in air temperature on crop yields. Climate change may increase erosion in some regions, through heavy rainfall and through increased wind speed.

CO_2-induced climate change and land degradation remain inextricably linked because of feedbacks between land degradation and precipitation. Climate change might exacerbate land degradation through alteration of spatial and temporal patterns in temperature, rainfall, solar radiation, and winds. Several climate models suggest that future global warming may reduce soil moisture over large areas of semiarid grassland in North America and Asia (Manabe and Wetherald 1986). This climate change is likely to exacerbate the degradation of semiarid lands that will be caused by rapidly expanding human populations during the next decade. Emmanuel (1987) predicted that there will be a 17% increase in the world area of desert land due to the climate change expected with a doubling of atmospheric CO_2 content.

Water resources are inextricably linked with climate, so the prospect of global climate change has serious implications for water resources and regional development (Riebsame et al. 1995). Climate change – especially changes in climate variability through droughts and flooding – will make addressing these problems more complex. The greatest impact will continue to be felt by the poor, who have the most limited access to water resources. The impact of changes in precipitation and enhanced evaporation could have profound effects in some lakes and reservoirs. Studies show that, in the paleoclimate of Africa and in the present climate, lakes and reservoirs respond to climate variability via pronounced changes in storage, leading to complete drying up in many cases. Furthermore, these studies also show that under the present climate regime several large lakes and wetlands show a delicate balance between inflow and outflow, such that evaporative increases of 40%, for example, could result in much reduced outflow.

The frequency of episodic transport by wind and water from arid lands is also likely to increase in response to anticipated changes in global climate (Manabe and Wetherlad 1986). Lower soil moisture and sparser vegetative cover would leave soil more susceptible to wind erosion. Reduction of organic matter inputs and increased oxidation of SOM could reduce the long-term water-retention capacity of soil, exacerbating desertification. Moreover, increased wind erosion increases wind-blown mineral dust, which may increase absorption of radiation in the atmosphere (Nicholson and Kim 1997).

6.7.1 Carbon sequestration to mitigate climate change and combat land degradation

The soil organic carbon (SOC) pool to 1-m depth ranges from 30 tons ha^{-1} in the arid climates to 800 tons ha^{-1} in organic soils in cold regions (Lal 2007). Conversion of natural to agricultural ecosystems causes depletion of SOC pool by as much as 60% in soils of temperate regions and 75% or more in the cultivated soils of the tropics. The depletion is exacerbated when the output of carbon (C) exceeds the input and when soil degradation is severe.

Carbon sequestration implies transferring atmospheric CO_2 into long-lived pools and storing it securely so it is not immediately reemitted. Thus, soil C sequestration means increasing SOC and soil inorganic carbon stocks through judicious land use and recommended management practices. Some of these practices include mulch farming, conservation tillage, agroforestry and diverse cropping systems, cover crops and integrated nutrient management, including the use of manure, compost, biosolids, improved grazing, and forest management.

The potential carbon sink capacity of managed ecosystems approximately equals the cumulative historic C loss estimated at 55 to 78 gigatons (Gt). Offsetting fossil-fuel emissions by achievable SOC potential provides multiple biophysical and societal benefits. An increase of 1 ton of soil carbon of degraded cropland soils may increase crop yield by 20 to 40 kg ha^{-1} for wheat, 10 to 20 kg ha^{-1} for maize, and 0.5 to 1 kg ha^{-1} for cowpeas and could enhance world food security (Lal 2007).

6.8 Understanding the Interactions between Climate and Land Degradation – Role of WMO

WMO is the United Nations specialized agency responsible for meteorology and operational hydrology. WMO provides support to the National Meteorological and Hydrological Services (NMHSs) of its 188 Member States and Territories in their respective missions of observing and understanding weather and climate and providing meteorological and related services in support of national needs. These needs especially relate to protection of life and property, safeguarding the environment and contributing to sustainable development.

The scientific programmes of WMO have been vital in expanding knowledge of the climate system. The systematic observations carried out using standardized methods have provided worldwide data for analysis, research and modelling of the atmosphere and its changing patterns of weather systems. WMO coordinates a global network for the acquisition and exchange of observational data under the Global Observing System of its World Weather Watch Programme. The system comprises some 10 000 stations on land, 1 000 upper-air stations, 7 000 ships, some 3 000 aircraft providing over 150 000 observations daily and a constellation of 16 meteorological, environmental, operational and research satellites. WMO also coordinates a network of three World Meteorological Centres, 35 Regional Specialized Meteorological Centres and 187 National Meteorological Centres. Specialized programmes of observations, including those for chemical constituents of the atmosphere and characteristics of the oceans and their circulations, have led to a better understanding of interactions between the domains of the climate system (the atmosphere, the oceans, the land surface and the cryosphere) and of climate variability and change.

Specifically, WMO contributes to understanding the interactions between climate and land degradation through dedicated observations of the climate system; improvements in the application of agrometeorological methods and the proper assessment and management of water resources; advances in climate science and prediction; and promotion of capacity building in the application of meteorological and hydrological data and information in drought preparedness and management. In this context, WMO will continue to address the issue of land degradation through its Agricultural Meteorology Programme, Hydrology and Water Resources Programme, and other scientific and technical programmes by:

6.8.1 Advocating for enhanced observing systems at national, regional and international levels

WMO is committed to work with the Parties to the UNCCD to improve the observing systems for weather, climate and water resources in order to meet the needs of the Convention, and to assist developing countries to strengthen their participation in the collection and use of these observations to meet their commitments to the Convention. In this regard, it is quite relevant to examine the Decisions of the Conference of Parties of the United Nations Framework Convention on Climate Change (UNFCCC) which address the issue of climate observing systems, and the regional workshop programme that has been developed and is being implemented in different parts of the world by the Global Climate Observing System (GCOS) Secretariat co-sponsored by WMO.

6.8.2 Promoting effective early warning systems

Early warning systems serve as an essential and important alert mechanism for combating land degradation. As meteorological and hydrological hazards are linked with climate variability, regular assessments and authoritative statements on the interpretation and applicability of observational data are needed for the study of climate variability and the implementation of a climate alert system to allow NMHSs to make early warnings on pending significant climate anomalies. Warnings of climate-related disasters are becoming feasible from weeks to seasons in advance. WMO's World Climate Programme will continue to issue routine statements on the state of El Niño or La Niña, which, through the NMHSs, can alert Governments to ensure preparedness against the impacts of El Niño-related anomalies, which can trigger various disasters. WMO played an active role in the activities of the *ad hoc* Panel on early warning systems established by the Committee on Science and Technology (CST) of the UNCCD. High on the recommendations of the Panel is the need to undertake a critical analysis of the performance of early warning, monitoring and assessment systems; the improvement of methods for and approaches to the prediction of drought and monitoring of desertification; and the development of mechanisms to facilitate an exchange of information focusing in particular on national and subregional networks. WMO's new major programme on Natural Disaster Prevention and Mitigation will provide the focus for the consolidation of its efforts in the area of early warnings and for taking new initiatives in this area in collaboration with other organizations.

6.8.3
Further enhancing climate prediction capability

Climate prediction capabilities are being enhanced through the Climate Variability (CLIVAR) project of the World Climate Research Programme (WCRP). The prediction of El Niño and the associated impacts are becoming possible, with reasonable skill, up to few seasons in advance. Related to this, WMO is broadening the implementation of the WMO Climate Information and Prediction Services (CLIPS) project, which is designed to promote the use of climate information and prediction services, capacity building, multi-disciplinary research and the development of new applications. Consensus long-range forecasts on droughts, which were issued at several Regional Climate Outlook Fora, organized in different parts of the world with active support from WMO, provide good early warning information to national authorities.

6.8.4
Assessing vulnerability and analyzing hazards

It is important to analyze vulnerability at the local, national and regional levels which is an important factor in evaluating the adequacy of early warnings. A good tool to assess those different vulnerabilities is the linkage between weather, climate and disaster databases to the different type of meteorological or hydrological disasters. In this regard, a pilot project is ongoing in Chile linking climate with flood disaster databases with the support of WMO through the World Climate Programme, as part of the activities of the Inter-Agency Task Force for Disaster Reduction (IATF's) Working Groups on Climate and Disasters and on Risk Vulnerability and Impact Assessment. This is an important tool for risk communication among policy makers and communities. WMO will continue to assist in developing and managing the relevant climate databases through data rescue and climate database management projects.

6.8.5
Implementing risk management applications

Risk management approaches need to be employed in combatting droughts and mitigating floods. In this context, hazard mapping, suitable agroclimatic zoning and the establishment of partnerships are essential tools for land use and preparedness planning. Several expert teams established by the Commission for Agricultural Meteorology (CAgM) of WMO are examining these issues critically and are issuing guidance reports for the users. In the area of flood forecasting and management, WMO's Hydrology and Water Resources Programme is implementing the Associated Programme for Flood Management (APFM) in collaboration with the Global Water Partnership, in the context of integrated water resources management. Several related projects are being developed in different parts of the world in order to provide guidance on the development of support systems for sustainable land management and agroclimatic zoning.

6.8.6 Contributing actively to the implementation of the UN system's International Strategy for Disaster Reduction (ISDR)

It is to be noted that society's ability to cope with and adapt to, climate change will depend heavily on its ability to assess how and where weather and climate patterns are likely to change, to predict the continuous fluctuations in risk and vulnerability to communities, and to develop adaptive strategies that will increase the community's resilience when the next potential disaster strikes. WMO leads the ISDR Working Group on Climate and Disasters.

6.8.7 Supporting the strengthening of the capabilities of the Parties and regional institutions with drought-related programmes

The capabilities of Parties and regional institutions with drought-related programmes will be strengthened and collaboration will be promoted with other institutions in drought- and desertification-prone regions, with emphasis on Africa, Asia, Latin America and the Caribbean, and the northern Mediterranean region, which are all referred to in the Regional Annexes to the Convention. Examples of such institutions in Africa are the AGRHYMET Centre and the African Centre of Meteorological Applications for Development (ACMAD), both located in Niamey, Niger, the IGAD Climate Prediction and Applications Centre in Nairobi, Kenya and the SADC Drought Monitoring Centre in Gaborone, Botswana. In order to enhance capacity building in the development of National Action Plans within the framework of the Convention, WMO organized Roving Seminars on the Application of Climatic Data for Desertification Control, Drought Preparedness and Management of Sustainable Agriculture in Beijing, China in May 2001 and in Antigua and Barbuda in April 2004.

6.9 Future perspectives

The definition of land degradation adopted by UNCCD assigns a major importance to climatic factors contributing to land degradation, but there is no concerted effort at the global level to systematically monitor the impacts of different climatic factors on land degradation in different regions and for different classes of land degradation. Hence there is an urgent need to monitor the interactions between climate and land degradation. To better understand these interactions, it is also important to identify the sources and sinks of dryland carbon, aerosols and trace gases in drylands. This can be effectively done through regional climate monitoring networks. Such networks could also help enhance the application of seasonal climate forecasting for more effective dryland management.

There are serious gaps in the basic meteorological network and observational facilities in many areas, some of them in regions with severe land degradation problems. The most serious single and geographically widespread shortcoming is the lack of information on rainfall intensity. WMO is taking steps to facilitate the development of early warning systems by organizing the development of suitable instruments and statistical processing. Furthermore, WMO is coordinating efforts on the part of its Members to further investigations of using data from meteorological satellites to supplement knowledge of meteorological conditions influencing land degradation, especially over areas inadequately covered by ground-level observations. WMO, through its 188 Members, is pleased to be part of the effort to better understand the role of climate in land degradation and work with various national, regional and international organizations and the civil society in combating and arresting land degradation.

References

Armbrust DV (1984) Wind and sandblast injury to field crops: Effects of plant age. Agron J 76:991-993

Associated Programme on Flood Management (APFM) (2004) Integrated Flood Management: Concept paper. APFM Technical Document No. 1. Geneva, Switzerland. http://www.apfm.info/ publications.htm

Barrow CJ (1994) Land degradation. Development and breakdown of terrestrial environments. Cambridge University Press, New York, NY, USA

Braswell BH, Schimel DS, Linder E, Moore B III (1997) The response of global terrestrial ecosystems to interannual temperature variability. Science 278:870-872.

Butler PR, Davies WJ, Leys JF (1994) Dust Storms in South Australia on 24-25th May, 1994. Technical Report Number 243. Primary Industries, South Australia

Chepil WS, Woodruff NP (1963) Physics of wind erosion and its control. Adv Agron 15:211-302

Ci Longjun (1998) Mechanism of Desertification and sustainable Strategies to Combat Desertification in China. Quatern Sci 5:31-44

Coughlan M, Jones D, Plummer N, Watkins A, Trewin B, Dawkins S (2003) Impacts of 2002/2003 El Niño on Australian climate. In: (Plummer N, Flannery M, Mullen C, Trewin B, Watkins A, Wright W, Powell T, Power S (eds.) Proceedings of Droughtcom workshop: Improving the communication of climate information, pp. 7-12

Dirmeyer PA, Shukla J (1996) The effect on regional and global climate of expansion of the world's deserts. Quart J Roy Meteorol Soc 122:451-482.

Emanuel KA (1987) The dependence of hurricane intensity on climate. Nature 326:483-485

Fryrear DW (1971) Survival and growth of cotton plants damaged by windblown sand. Agron J 63:638-642

Fryrear DW (1990) Wind Erosion: Mechanics, Prediction, and Control. Adv Soil Sci 13:187-199

Garrett AJ (1982) A parameter study of interactions between convective clouds, the convective boundary layer and a forested surface. Mon Weather Rev 110:1041-1059

Gash JHC, Kabat P, Monteny BA, Amadou M, Bessemoulin P, Billing H, Blyth EM, deBruin HAR, Elbers JA, Friborg T, Harrison G, Holwill CJ, Lloyd CR, Lhomme J-P, Moncrieff JB, Puech D, Sogaard H, Taupin JD, Tuzet A, Verhoef A (1997) The variability of evaporation during the HAPEX-Sahel intensive observation period. J Hydrol 52:188-189

Gringof I, Mersha E (2006) Assessment of desertification, drought and other extreme meteorological events. In: Impacts of Desertification and Drought and Other Extreme Meteorological Events, World Meteorological Organization, WMO/TD No. 1343, Geneva, Switzerland, pp. 12-29.

Henderson-Sellers A, Durbidge TB, Pitman AJ, Dickinson RE, Kennedy PJ, McGuffie K (1993) Tropical deforestation: modelling local to regional-scale climate change. J Geophys Res 98: 7289-7315

Houghton RA (1995) Land-use change and the carbon-cycle. Global Change Biol 1:275-287

Joseph PV, Raipal DK, Deka SN (1980) "Andhi," the convective dust storms of Northwest India. Mausam 31:431-442

IPCC (2003) Climate Change 2001: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Third Assessment. Published for the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK.

Lal R (1988) Soil degradation and the future of agriculture in sub-Saharan Africa. J Soil Water Conserv 43:444-451

Lal R (2001) Soil degradation by erosion. Land Degrad Dev 12:519-539

Lal R (2004) Soil carbon sequestration impacts on global climate change and food security. Science 304 :1623-1627.

Lal R (2007) Soil science in a changing climate. CSA News 52:3-10

Lal R, Hall GF, Miller FP (1989) Soil degradation: I. Basic processes. Land Degrad Rehabil 1:51-69

Lean J, Warrilow DA (1989) Simulation of the regional climate impact of Amazon deforestation. Nature 342:411-413.

Levine J (1990) Convener of Chapman Conference on Global Biomass Burning March 19-23, 1990. Williamsburg, Virginia.

Mabbutt JA (1994) Climate change: some likely multiple impacts in Southern Africa. Food Policy 19:165-191

Manabe S, Wetherald RT (1986) Reduction in summer soil wetness induced by an increase in atmospheric carbon dioxide. Science 232:626-628

McGuffie KA, Henderson-Sellers A, Zhang H, Durbidge TB, Pitman AJ (1995) Global climate sensitivity to tropical deforestation. Global Planet Change 10:97-128

Middleton NJ (1986) Dust storms in the Middle East. Jour Arid Env 10:83-96

Nicholls N (2004) The changing nature of Australian droughts. Clim Chang 63:323-336

Nicholson SE, Kim J (1997) The relationship of the El Niño Southern Oscillation to African rainfall. Int J Climatol 17:117-135

Painter DJ (1978) Wind erosiveness in New Zealand. New Zealand J Sci 21:137-148

Pease P, Vatche P, Tchakerian N, Tindale N (1998) Aerosols over the Arabian Sea: geochemistry and source areas for aeolian desert dust. J Arid Environ 39: 477-496

People's Republic of China (PRC) (1994) China 21st Agenda, China Environmental Science Press, Beijing, China

Reich PF, Numben ST, Almaraz RA, Eswaran H (2001) Land resource stresses and desertification in Africa. In: (Bridges EM, Hannam ID, Oldeman LR,. Pening de Vries FWT, Scherr SJ, Sompatpanit (eds.). Responses to Land Degradation. Proc. 2nd. International Conference on Land Degradation and Desertification, Khon Kaen, Thailand. Oxford Press, New Delhi, India.

Renard KG, Foster GR, Weesies GA, McCool DK, Yoders CD (1997) Predicting Soil Erosion by Water: A guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE). U.S. Department of Agriculture, Agriculture Handbook No. 703, 404 pp.

Riebsame WE, Strzepek KM, Wescoat JL Jr, Perrit R, Graile GL, Jacobs J, Leichenko R, Magadza C, Phien H, Urbiztondo BJ, Restrepo P, Rose WR, Saleh M, Ti LH, Tucci C, Yates D (1995) Complex river basins. In: (Strzepek KM, Smith JB ed.) As Climate Changes, International Impacts and Implications. Cambridge University Press, Cambridge, United Kingdom, pp. 57-91.

Rosenberg NJ, Blad BL, Verma SB (1983) Microclimate: The Biological Environment. 2nd Edition. John Wiley and Sons, New York, New York. p. 232-233.

Rozanov BG (1990) Global assessment of desertification: status and methodologies. In: Desertification revisited: Proceedings of an ad hoc consultative meeting on the assessment of desertification. UNEP-DC/PAC, Nairobi. pp. 45-122

Scherr S (1999) Soil Degradation: a threat to developing-country food security by 2020? International Food Policy Research Institute (IFPRI), Washington

Sivakumar MVK (2006) Climate prediction and agriculture: current status and future challenges. Clim Res 33:3-17

Skidmore EL, Woodruff NP (1968) Wind erosion forces in the United States and their use in predicting soil loss. Agriculture Handbook No. 346, United States Department of Agriculture Agricultural Research Service

Snyman HA (2003) Short-term response of rangeland following an unplanned fire in terms of soil characteristics in a semi-arid climate of South Africa. J Arid Env 55:160-180

Stahr K, Hermann L, Jahn R (1996) Long distance sand transport in the Sudano –sahelian zone and the consequences of sahel Soil properties. In: Buerkert B, Allison BE, von Oppen M (ed.). Proceedings of International symposium. " Wind erosion" in West Africa. The problem and its control. University of Hohenheim, 5-7th December 1994. Margraf Verlag, Welkersheim, Germany

Sud YC, Walker GK, Kim J-H, Liston GE, Sellers PJ, Lau K.-M. (1996) Biogeophysical effects of a tropical deforestation scenario: A GCM simulation study. J Clim 16:135-178

UNEP (1992) World Atlas of Desertification, United Nations Environment Programme, Nairobi, Kenya, 69 pp.

UNCCD (1999) United Nations Convention to Combat Desertification in those countries experiencing serious drought and/or desertification, particularly in Africa. Text with Annexes. Secretariat of the Convention to Combat Desertification. Bonn, Germany.

UNSO (1997) Aridity zones and dryland populations. An assessment of population levels in the World's drylands. Office to Combat Desertification and Drought (UNSO/UNDP).

USDA (2006) Water Erosion Prediction Project Website of the Agricultural Research Service of the United States Department of Agriculture.
http://www.ars.usda.gov/Research/docs.htm?docid=10621

Wagner LE (1996) An overview of the wind erosion prediction system. Proc. of International Conference on air Pollution from Agricultural Operations, February 7-9, 1996, Kansas City, MO, pp.73-75. http://www.weru.ksu.edu/weps/docs/wepsoverview.pdf

Wang Shi-gong, Dong Guangrong, Shang Kezheng, Chen Huizhong (2001) Progress of research on understanding sand and dust storms in the world. In: Yang Youlin, Squires V, Lu Qi (ed.) Global alarm: dust and sandstorms from the World's Drylands. RCU of the United Nations Convention to Combat Desertification (UNCCD), Bangkok

Watkins A (2005) The Australian drought of 2005. WMO Bull 54:156-162

Werth D, Avissar R (2002) The local and global effects of Amazon defor estation. J Geophys Res 107 (D20), LBA 55-1 to LBA 55-8.

Wilhite DA, Sivakumar MVK, Wood DA (2000) Early warning systems for drought preparedness and drought management. World Meteoro logical Organization, Geneva, Switzerland. AGM-2, WMO/TD No. 1037, 185 pp.

Wilhite DA and Svoboda MD (2000) Drought early warning systems in the context of drought preparedness and mitigation. In: Wilhite DA, Sivakumar MVK, Wood DA (2000) Early warning systems for drought preparedness and drought management. World Meteorological Organization, Geneva, Switzerland. AGM-2, WMO/TD No. 1037, pp 1-16

Williams MAJ, Balling RC Jr. (1996) Interaction of Desertification and Climate. WMO, UNEP, Arnold London, 270 pp.

Wischmeier WH, Smith DD (1978) Predicting rainfall erosion losses – a guide to conservation planning. Agriculture Handbook No. 537. U.S. Department of Agriculture, Washington, DC.

Woods LE (1983) Land Degradation in Australia. AGPS, Canberra, Australia.
Xu Guochang, Cheng Minlian, Wu Guoxiong (1979) On an extraordinary heavy sandstorm on April 22nd in Gansu Province. Acta Meteorologica Sinica, 37 (4): 26-35 (in Chinese)
Zachar D (1982) Soil Erosion. Chapter 4: Erosion factors and conditions governing soil erosion and erosion processes. Elservier Scientific Publishing Company, Amsterdam, Netherlands.

CHAPTER 7

Climate, Extreme Events and Land Degradation

Michèle L. Clarke and Helen M. Rendell

Abstract. The frequency of occurrence of climate extremes in temperature and precipitation is expected to increase during the next century (Easterling et al. 2000). Here we examine the impact of the climate extremes of heavy rainfall, drought, and high winds, on processes of land degradation, including floods, mass movements, soil erosion by both water and wind, and salinisation. Case studies are used to explore the impacts of individual events on land degradation, as well as the role of decadal-scale temporal and spatial variability in climate systems in driving extreme events. Predictions of future trends in the frequency and magnitude of extreme events, based on an ensemble of general circulation models and on regional climate models, are examined

7.1 Introduction

The frequency of occurrence of climate extremes is expected to change during the next century, with increases in the frequency of heat waves and heavy precipitation events, and decreases in the frequency of frost days, as a consequence of anthropogenically-forced climate change (Easterling et al. 2000). Changes in the frequencies of extreme events will have an impact on land degradation processes such as floods and mass movements, soil erosion by both water and wind, and on soil salinisation. Studies of climate extremes in the second half of the 20th century reveal significant trends in both temperature and rainfall at the global level (Frich et al. 2002). Projected future changes in climate extremes to the end of the 21st century show considerable spatial and temporal variability (Tebaldi et al. 2006), with the uncertainties surrounding future precipitation changes greater than those for temperature (Arblaster and Alexander 2005).

Climate extremes encompass both extreme weather, with durations of minutes to days (the synoptic timescale), and extreme climate events with durations of months, in the case of periods of wet/stormy weather, or years, in the case of drought (McGregor et al. 2005). In all cases, the frequency of extreme events may be affected by seasonal to inter-annual fluctuations of large scale climate variations such as El Niño/Southern Oscillation (ENSO) and the North Atlantic Oscillation (NAO) (Schweirz et al. 2006). Distinguishing between natural climate variability and anthropogenically-driven climate change remains a significant challenge.

In contrast to the record of extreme climate events, the land degradation impacts of such events have lacked systematic study. Case studies of particular events and their impacts on society are relatively common, but examples which combine daily meteorological records, spanning decades, with individual event impact records are relatively rare. In this paper we examine the challenges involved in establishing records of both extreme events and their impacts. Case studies are used to explore the impacts of individual events on land degradation and their decadal-scale temporal and spatial variability. Future trends in the frequency of extreme events, based on an ensemble of general circulation models and on regional climate models, are examined.

7.2 Classification of climate extremes

Extreme events are distinguished by their magnitude (e.g. extremely high or low temperatures, heavy rainfall or periods with no rainfall). All types of extreme event require a length of record before a frequency distribution can be determined (Katz and Brown 1992); we need to know, for example, whether the frequency of extreme rainfall events per decade has changed. In the case of daily rainfall or temperature data, a minimum of 40 years of continuous record is required (Frich et al. 2002). The length and continuity of record are important as these facilitate authoritative statements, such as the recent announcement by the UK Meteorological Office that autumn 2006 was the warmest in a 347 year record (UK Meteorological Office, 2006).

Changes in temperature extremes can result from changes in the mean and the variance of the probability distribution of daily temperatures (McGregor et al. 2005). Small increases in the values of mean daily precipitation may result in proportionally much larger increases in the probability of extreme daily rainfall events (Groisman et al. 1999), and one way of representing such changes is in terms of the magnitude and frequency (or recurrence interval) of these daily rainfall events, as illustrated schematically in Fig. 7.1.

Many indicators of extreme climate events have been proposed (Trenberth and Owen 1999; Nicholls and Murray 1999; Frich et al. 2002) and a selection of these indicators is given in Table 7.1. In most cases the definitions specify particular thresholds beyond which events are considered extreme.

The requirement for appropriate lengths of record raises problems as it is clear from the global distribution of meteorological stations that some localities, particularly in Africa, the Middle East, South Asia and South America have sparse coverage of stations (Frich et al. 2002). In other places many stations may no longer be active (Brunetti et al. 2002). In arid, semi-arid and sub-humid areas rainfall may be highly variable both spatially and temporally so that, in the case of extreme rainfall events, the use of regional averaging of station data may result in these events going undetected (Brunetti et al. 2002).

Extreme events with a slow rate of onset such as heatwaves or droughts are harder to define. Some analyses use simple measures such as the maximum number of consecutive dry days or the sustained exceedance of particular temperatures (Frich et al. 2002) but, in the case of drought, definitions present particular difficulty. Drought can be 'meteorological', 'agricultural' or 'hydrological' based on the

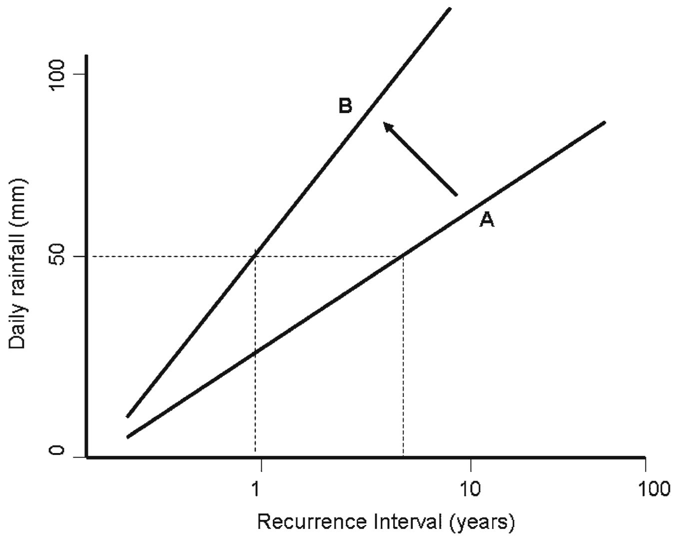


Fig. 7.1. Schematic view of the impact on the magnitude and recurrence interval for daily rainfall data if the rainfall distribution in southern Britain (line A) was to become more like that for central and southern Italy (line B). The frequency of 50mm events, for example, would increase substan-tially.

number of days below a particular rainfall threshold, soil moisture deficits or on the levels of surface and groundwater storage, respectively (Pielke et al. 2005). Empirically-based indices allow the comparative severity of a particular drought event to be established, and allow the spatial and temporal variability of drought to be evaluated (Edwards and McKee 1997). The Palmer Drought Severity Index (PDSI) (Palmer 1965) has been widely used, particularly in the USA, but requires both temperature and precipitation data, as well as empirical relationships to define a climate weighting factor. The Standardised Precipitation Index (SPI) (McKee et al. 1993, 1995; Edwards and McKee 1997), is simpler to calculate, and is based on the analysis of monthly rainfall series and provides results at the multiple timescales relevant to soil moisture, streamflow and groundwater conditions (Lloyd-Hughes and Saunders 2002). An additional advantage of the SPI approach is that it provides the means of identifying extremely wet periods as well as extremely dry ones.

Tropical storms and extra-tropical depressions can also provide extremes in terms of wind speeds, rainfall and associated storm surges. Storminess is defined in terms of the number of days with strong winds reaching Beaufort Wind Scale/World Meteorological Organisation wind speeds in the range 7 (13.9–17.1 ms^{-1}) to 11 (> 28.4 ms^{-1}) for any one of four 6-hourly data records for that day (Qian and Saunders 2003). Tropical storms are defined as Categories 1 to 5 on the Saffir-Simpson scale, with Category 1 storms having sustained wind speeds in the range 74-95 miles hr^{-1} (33.1–42.5 ms^{-1}) and/or storm surges 4-5 ft (1.2–1.6m) above normal, to Category 5 storms with wind speeds > 155 miles hr^{-1} (>69.2 ms^{-1}) and/or storm surges > 18 ft (> 5.6m) above normal (Neumann et al. 1993).

Table 7.1. Examples of selected indicators for a range of different extreme climate events

Extreme event	Indicator Definition	Source of reference
High temperatures	Heat wave duration index: maximum period > 5 consecutive days with $T_{max} > 5^{\circ}C$ above the 1961-1990 daily T_{max} normal	Frich et al. 2002
	Percentage of time $T_{min} > 90^{th}$ percentile of daily minimum temperature	Frich et al. 2002
Heavy precipitation	Number of days with precipitation ≥ 10 mm. day^{-1}	Frich et al. 2002
	Maximum 5 day precipitation total	Frich et al. 2002
	Percentage of annual total precipitation due to events exceeding the 1961-1990 95^{th} percentile	Frich et al. 2002
	5 day precipitation total exceeding 10% of the regional mean annual rainfall	Brunetti et al. 2002
	Daily Precipitation exceeds 95^{th} or 99^{th} percentile	Nicholls and Murray 1999
Dry Periods Drought	Maximum number of consecutive dry days ($R_{day} < 1$mm)	Frich et al. 2002
	Percentage of region with precipitation in the lowest 5 or 10%	Nicholls and Murray 1999
	Standardised precipitation index (SPI) less than -1.0 (extreme drought SPI < -2.0)	McKee et al. 1995
High Winds	Wind speeds exceeding Beaufort thresholds	Trenberth and Owen 1999
	Number of 'gale days' per month	Trenberth and Owen 1999
	Gust factors exceeding threshold values	Trenberth and Owen 1999

Longer term trends in extreme weather, such as seasons dominated by sequences of storms or floods, or by drought, may also be related to inter-annual fluctuations of large scale climate variations such as El Niño/Southern Oscillation (ENSO) and the North Atlantic Oscillation (NAO) (Hurrell and Van Loon 1997).

7.3 Land Degradation

Whilst there are various methods of classifying extreme events, not every extreme event will have a similar impact on land degradation. Some individual land degradation processes like landsliding or gully incision may involve a particular threshold being crossed and subsequent events, of lower magnitude, may reactivate the landslide or develop/enlarge the gully. In addition, some land degradation processes may be enhanced by human activity, particularly land use changes and land management practices, while others may be effectively mitigated by anthropogenic intervention measures. The main land degradation processes considered below include floods, and associated channel erosion and deposition, mass movements, principally landslides and debris flows, and the more diffuse processes of soil erosion by water and wind and salinisation.

The coupling of meteorological data and land degradation processes poses some significant challenges for monitoring. Long records are required for the estimation of return periods and probabilities of occurrence. The impacts of extreme events on land degradation may not be recorded in the same systematic way as the meteorological data. The impacts of extreme events tend only to be recorded if they affect human populations and societies, and events relating to urban areas or infrastructure are also more likely to be recorded than those affecting rural areas. The impacts of extreme events can be also be established independently by monitoring other variables in the natural environment such as water and sediment fluxes.

While the study of the impacts of individual extreme events, such as rainfall events in southeast Spain (Hooke and Mant 2000) and Italy (Guzzetti et al. 2004) are relatively common, longer term data sets are rare. Data on gully development, for example, are frequently based on the analysis of repeated remotely sensed images (Poesen et al. 2003) while the actual timings of incision and development of gully systems remain unknown and are therefore not tied into the meteorological record (Morgan and Mngomezulu 2003).

7.4 Extreme rainfall events and their impacts

In this section we explore the information that can be gained from studying coupled records of extreme climate events and their impacts on land degradation using a series of case studies.

7.4.1 Landslides, debris flows and floods in the northern Mediterranean

A combination of climate, relative relief, and geology make some areas of the northern Mediterranean vulnerable to floods, mass movements and soil erosion by water (Luino 2005). Below we examine two case studies from southern Italy for which both daily meteorological and land degradation records were available.

A total of 46 extreme rainfall events, defined as 5-day periods in which rainfall exceeded 10% of the mean annual value, were identified for the period 1951-2000 for southeast Basilicata in southern Italy (Clarke and Rendell 2006a). Documentary records of landslides and floods were analysed and the antecedent rainfall for each event was recorded in terms of P_2 (rainfall 2 days prior to the event) and P_{30} (rainfall 30 days prior to the event). The landslide events range in magnitude from single landslides blocking minor roads to multiple events affecting different settlements simultaneously. All events recorded had P_{30} > 50mm, 73% of landslides and floods had P_{30} > 100mm and 16% had P_2 >100mm. However, only 59% of the extreme rainfall events identified were associated with a land surface impact (Clarke and Rendell 2006a). This discrepancy may reflect lack of reporting or the positive effects of mitigation over the time period studied.

A comparable study in the Benevento area of Campania, in southern Italy, used a Rainfall Hazard Index (RHI) approach to define extreme events (Diodato 2004). In this case the 24-h antecedent rainfall was used, and 33 rainfall events were identified as exceeding a critical threshold over the period 1926-2002, and data on hydrogeomorphological events (floods, mass movements, soil erosion) were collected independently for the same time period. Of the 33 extreme rainfall events analysed, 22 (67%) were associated with floods, landslides and/or erosion events while 11 (33%) were not (Diodato 2004). Just as in the Basilicata study there is a discrepancy between the extreme events and their impacts within the long term daily record. Irrespective of how the extreme events were defined, in the case of both of these records not every meteorologically-defined extreme rainfall event resulted in a recorded land surface impact.

Taking the 50 yr or 76 yr records for Basilicata and the Benevento area, respectively, the pattern of extreme rainfall events show a change in frequency with time reflecting changes in the winter cyclonic activity in the Mediterranean driven by decadal scale variability in the North Atlantic Oscillation (Hurrell and Van Loon 1997). Positive values of the NAO index are associated with intense low pressure over Iceland and high pressure over the Azores, driving Atlantic storm tracks over northwest Europe (Britain and Scandinavia). Negative values of the NAO index reflect weakened Icelandic low and Azores high pressure and Atlantic storm tracks move across the Iberian Peninsula and into the Mediterranean (Hurrell and Van Loon 1997). Trigo et al. (2005) analysed the inventory of 19 landslides in the Lisbon area of Portugal, occurring between 1958 and 2001, in terms of both antecedent rainfall and the status of the NAO. All of the landslide events were associated with negative values of the NAO index.

7.4.2 Floods, gully incision and development in the Southwest USA

Now we examine the problems that can arise when both meteorological records and the documentary records of land degradation are more fragmentary. A phase of gully incision and development occurred in the late 19th and early 20th centuries along the courses of ephemeral rivers and streams in the southwest USA (Cooke and Reeves 1976). Explanations for this widespread, apparently more or less simultaneous gully incision have included secular climate changes, anthropogenically-induced changes in vegetation following the introduction of cattle ranching, and the construction of dams, flood control channels within the drainage networks (Cooke and Reeves 1976; Bull 1997). Episodes of gully incision and channel erosion during flood events have been related to increases in winter precipitation during El Niño–related circulation patterns (Waters and Haynes 2001) (see Fig. 7.2). One problem in relating precipitation and land degradation episodes is that considerable uncertainty surrounds the timing of many of the gully entrenchment events in Arizona and New Mexico. Cooke and Reeves (1976), for example, narrow down the timing of incision of gullies in the Aravaipa valley to between 1886 and 1914. In only a few examples is gully incision pinned down to a particular year or month (eg. Greens Canal in 1916, Tucson in August 1890) (Cooke and Reeves 1976). More data are available for damaging floods within the Gila River catchment (Dobyns 1981) and we have compared these data with the El Niño/La Niña reconstruction for 1868-1920 (Japan Meteorological Agency 1991; Meyers et al. 1997) in Table 7.2.

Although the 'large floods' of 1868, 1891 and 1905 (Dobyns 1981) all occurred during El Niño events, it is clear that relationship between rainfall-driven flood events and El Niño/La Niña conditions is complex. A similar conclusion is reached by Ely (1997) for an analysis of ≥10 yr floods in Arizona and southern Utah over the period 1900-1995, particularly with respect to summer floods which are generally the result of convective thunderstorms which show little or no relationship with a 5 yr running mean of the ENSO Index. On a much longer timescale, detailed investigations of the alluvial sediments within many of the valleys in the southwest USA reveal a series of phases of gully incision and aggradation spanning the last 11,500 years (Bull 1997; Waters and Haynes 2001). Thus while recent gully incision may be partly related to anthropogenic disturbance, the longer term record favours a climate-driven interpretation.

Fig. 7.2. Gully near Tucson, Arizona (left) in Spring 1999 and (right) during El Niño related rains in Winter/Spring 1992/3

Table 7.2. Details of damaging flood events in the Gila River catchment from Dobyns (1981) compared with reconstructed ENSO data (using Japan Meteorological Agency 1991 SST-based index extended by Meyers et al. 1997).

Year	Description	ENSO data
1868	Gila River floods in August and September, dams destroyed	El Niño
1874	Gila River entrenchment of channel at Phoenix in January (127mm of rain Phoenix Jan 18th/19th)	La Niña
1874	Gila River Flood in February	La Niña
1880	Summer storms "erosion during a drought year"	
1881	Flood in Upper Santa Cruz River 24th/25th July	El Niño
1883	Flood in headwaters of Queen Creek, August	Weak El Niño
1884	Floods in the whole of the Gila River system, March	El Niño
1887	Santa Cruz River Tucson 7th/8th September	Start of El Niño
1890	Gila River Flood, February (including failure of earth dam in the Hassayampa Creek) San Pedro River flood August	La Niña
1891	Upper Gila River, February 17th/18th February 21st-24th	El Niño
1905	Gila River floods in January, February and November	El Niño
1906	San Francisco River, December	La Niña
1916	San Francisco River, January	La Niña

Note: no records of floods/erosion for El Niño events in 1877-8, 1896-7, 1899-1900 or 1902-03.

7.4.3 Drought

Droughts are a normal part of annual climate cycles. Mediterranean climates, for example, are characterised by summer droughts (Conacher and Sala 1998). Longer term droughts in the Mediterranean and the Near East are associated with low precipitation in what would otherwise be the winter rainfall season (Brunetti et al. 2002; Inbar and Bruins 2004). Drought impacts include loss of vegetation and biodiversity, loss of feed and drinking water for farm animals and wildlife, lower water levels in lakes and ponds, reduced springflow and streamflow, reductions in water quality and salinisation. Although some soils are naturally saline, processes of salinisation may be driven by inappropriate irrigation methods. A combination of lack of precipitation and high evapotranspiration may lead to increases in soil salinity and consequent limitations on crop production (Amezketa 2006). Inbar and Bruins (2004), for example, demonstrate that the main land degradation impact of the 1998-2001 drought in the Jordan valley was soil degradation as a result of using partly recycled brackish wastewater for irrigation.

Since the 1980s the availability of remotely sensed images has allowed the systematic study of the interactions between rainfall, drought, landuse and surface vegetation cover over large areas (Nicolson et al. 1998). Given the diffuse nature of drought, attempts to characterise drought-driven changes in the land surface have tended to focus on comparisons of normalised difference vegetation indices (NDVI). The NDVI provides a good correlation with percent vegetation cover but, as Nicholson et al. (1998) point out, it does not provide an indication of land degradation processes involving changes in soil fertility or species diversity.

The Standardised Precipitation Index (SPI) provides a way of establishing the comparative severity of drought episodes for any particular location over a range of different time periods. Droughts become classified as severe when SPI values are between -1.5 and -2.0 and extreme when SPI values of -2.0 or less are reached (McKee et al. 1995). A number of studies have combined monthly NDVI data with SPI data derived from long term monthly rainfall records to try to resolve the impacts of drought on surface vegetation cover. Ji and Peters (2003) used NDVI and SPI data for the period 1989-2000 from the Great Plains area of the USA to study drought impacts during the growing season (May to October). They concluded that the 3-month SPI had the highest correlation with the surface vegetation cover, while noting that the highest correlations occurred in the middle of the growing season. A similar study by Vicente-Serrano (2007) focused on drought impact on vegetation over the period 1987-2000 in the middle Ebro Basin of north-eastern Spain. In this case a vegetation condition index (VCI) was derived from the NDVI data and then compared to SPI values computed over timescales of 3-, 6- and 12-months. Although the VCI-SPI correlations reveal a complex pattern, the clearest relationships are seen in summer for the 3- and 6-month SPI values and the areas occupied by dry farming of cereals, and by shrubs and pasturelands.

Where prolonged drought produces a reduction in surface vegetation cover either naturally or enhanced by tillage practices (Al-Kaisi 2003) then surfaces may become vulnerable to erosion by both wind and water (Sterk 2003).

7.4.4
High Winds

High winds are a climate extreme generated by atmospheric pressure differences. The strong persistent north-east Trade Winds blowing over the Sahara in winter are driven by the presence of a high pressure system (anticyclone) over the Azores in the North Atlantic (Sterk 2003). High wind velocities are also associated with the passage of deep depressions including tropical storms. The impact of storms in coastal zones can be considerable, damaging structures (Dorland et al. 1999) and vegetation and driving sand invasion. In this section we examine the relationships between wind erosion and dust storms, and then storm impacts in coastal areas.

7.4.4.1
Wind erosion and dust storms

Wind erosion has the potential to remove topsoil and sediments and transport the material over long distances. Extreme events in this context are synoptic conditions driving persistent strong turbulent winds. In order for surface materials to be entrained by wind, the wind speed must exceed threshold values, the materials must be dry and unprotected by vegetation cover (Okin et al. 2006). Cohesive materials, like clays, require high wind velocities or disturbance of surfaces for entrainment to take place (Sterk 2003). Dust plumes were generated from the dry surface of the Owens Lake playa, for example, by sand grains saltating over a surface disturbed by salt crystallisation (Reheis 1997). In arid and semi-arid areas surface disturbance may also happen as a result of the passage of vehicles or tillage for agriculture.

The Sahara Desert probably accounts for almost half of the dust supplied to the oceans (Goudie and Middleton 2001). The analysis of satellite images has identified two source areas for dust within the Sahara; the Bodélé Depression, and a large area including Mauritania, Mali and southern Algeria (Goudie and Middleton 2001). Plumes of Saharan dust travel far out over the Atlantic Ocean with the extent of plumes enhanced by strong Trade Winds (Harmattan winds) during periods of positive NAO (Hurrell and Van Loon 1997). The dust fallout over the Atlantic Ocean and the Caribbean Sea has impacts on ocean nutrients (Jickells et al. 2005) and on the mortality of corals (Shinn et al. 2000).

Several studies have investigated the frequency of dust storms over varying lengths of record. The 40-year record of dust storms in Australia appears to be closely related to the development of drought conditions which are in turn associated with El Niño events (McTainsh et al. 2005). The annual frequency of dust storms from 1960-2002 shows a strong peak in 1964 with >200 storms, peaks in 1961 and 1962 with >150 storms, while 1960, 1994 and 2002 all had > 100 storms (McTainsh et al. 2005), and all of these years were drought years. Okin and Reheis (2002) also demonstrate a significant relationship between strong La Niña and El Niño events and subsequent dust storm activity in the southwestern USA over the period 1973-1999.

Increases in dust storm frequencies in the Sahara since the mid 1960's have also been linked to drought (Goudie and Middleton 2001). The mean May-September concentrations of Saharan dust in Barbados were inversely related to the rainfall in West Africa in the previous year ($r = -0.75$ $p < 0.001$) (Prospero and Lamb 2003). Many, but not all, of the peaks in monthly mean dust concentrations on Barbados were also associated with the years in which major El Niño events occurred (Prospero and Lamb 2003). Lui et al. (2004) demonstrate that dust storm frequency in March-May in northern China over the period 1982-2001 is most negatively correlated with the antecedent summer and annual rainfall and soil moisture anomalies which influence the vegetation cover conditions the following spring. Dust storm frequencies in Inner Mongolia declined between 1961 and 1997, but have shown an increase since then with a succession of major storms in spring 2000 and 2001 which are related to a combination of higher than average temperatures and anomalously low antecedent rainfall conditions (Gao et al. 2003). Dust storms in

2000 and 2001 caused substantial disruption to transport networks in north China and dramatically reduced air quality in Bejing and the Korean peninsula (Gao et al. 2003). Chen et al. (2003) note that while the frequency of all dust storms has declined, the frequency of severe dust storms (visibility <200m) has increased. The asian dust storms of April 2001, for example, had an impact on air quality in North America (Jaffe et al. 2003).

Dust storms impacts are generally reported in terms of the downwind effects of the dust on urban air quality (Jaffe et al. 2003), for example, rather than impacts in the deflation areas. The exception to this is when deflation involved the loss of fertility of agricultural land through loss of organic and minerogenic components of topsoil such as in the 'Dust Bowl' of the American Midwest in the 1930's (Goudie and Middleton 1992) or on farmland in Inner Mongolia (Zhao et al. 2006). Sterk (2002) also identified three types of agricultural damage in the Sahel region associated with wind erosion: sedimentation in undesired locations, crop damage and soil degradation.

7.4.4.2
Storm impacts in coastal areas

The impact of storms on coastal zones is often greater than over land owing to the lower wind shear and surface roughness as the storms move over the sea. The impacts of the high winds can result in the destruction of structures, damage to or felling of trees, and sand invasion of coastal settlements and agricultural land. Where the storms are accompanied by a storm surge then flooding can also occur with consequent salinisation of inland surface and groundwater (Michener et al. 1997).

Tropical storm flooding, as a result of the associated storm surge rather than the rainfall, is a relatively frequent occurrence along the lowlying coastal plain of south-eastern USA. Between 1899 and 1992 a total of 178 hurricanes and tropical storms made landfall along the Atlantic and Gulf of Mexico coasts (Neumann et al. 1993). The land degradation associated with storm surges is reflected primarily in damage to ecological communities, with the die back of plants unable to tolerate the sudden influx of saline water (Hook et al. 1991; Lodge and McDowell 1991). Plant communities are also subject to wind damage. In September 1989 Hurricane Hugo, a category 4 storm, damaged an estimated 1.8 million hectares of forest in South Carolina (Hook et al. 1991; Putz and Sharitz 1991) and in August 1992 Hurricane Andrew damaged up to 90% of the mangroves in Everglades National Park (Smith et al. 1994). Studies of storm damage tend to be driven by single events and Michener et al. (1997) argue that more detailed analyses of types of disturbance and the timing of tropical storms are required.

Processes of sand invasion are found in coastal zones exposed to strong turbulent winds where sand supply is abundant and vegetation cover patchy or minimal. Sand invasion along the coasts of western Europe has been combatted by planting of forest cover as in the Landes of southwest France and the Atlantic coast of Portugal (Clarke et al. 2002; Clarke and Rendell 2006b). The more recent episodes of sand invasion have been related to the state of the NAO during the 18th and 19th

centuries and the persistence of periods of relative storminess in the North Atlantic (Clarke and Rendell 2006b).

Just as in the previous sections, it is clear that the decadal-scale inter-annual variability in the climate system represented by ENSO and NAO can have a substantial impact on the frequency of occurrence of climate extremes.

7.5 Future trends in extreme events

Studies of future trends in extreme events, based on the application of an ensemble of general circulation models (Tebaldi et al. 2006; Arblaster and Alexander 2005) or downscaled results using regional climate models (Sánchez et al. 2004) point to an increase in frequency of both 5-day precipitation totals and in the duration of periods of consecutive dry days. Tebaldi et al (2006) argue that little or no change in mean precipitation could still involve a decrease in the frequency coupled with an increase in the intensity of rainfall events (and possibly increased seasonality), although the modelling results tend to show considerable spatial and inter-annual variability.

Given the linkages between the climate extremes, expressed in terms of heavy rainfall, droughts, and high winds, and the variability of inter-annual indices, particularly ENSO, the prediction of future trends in these indices is also important in the context of land degradation. Meehl et al. (2006) address the issue of future changes in ENSO using two coupled climate models and forcings based on stabilised doubled and quadrupled atmospheric concentrations of CO_2. and conclude that there is no clear indication of how the frequency and intensity of ENSO events will change in the future.

7.6 Conclusions

Studies of long-term, decadal-scale, extreme event impacts on land degradation, as opposed to individual events, are relatively rare. Although the coupling of archival and meteorological records for modelling land degradation impacts has real potential, it is likely to be limited by the quality of the available records. The case studies presented above illustrate some of the issues associated with the spatial and temporal variability of extreme events and their land degradation impacts. Only by coupling the extreme climate events with their land degradation impacts can we make useful predictions for the future. The systematic monitoring of extreme event impacts presents a major challenge for future work.

References

Al-Kaisi M (2003) Managing soils under dry conditions. Integ Crop Manage 490:161-162.
Amezketa E (2006) An integrated methodology for assessing soil salinization, a pre-condition for land desertification. J Arid Environ 67:594-606
Arblaster J, Alexander L (2005) Extreme change: an analysis of past, present and future changes in global temperature and precipitation indices. Bull Aus Met Ocean Soc 18: 125-130
Balling RCJr, Wells SG (1990) Historical rainfall patterns and arroyo activity within the Zuni river drainage basin, New Mexico. Annals Assoc Amer Geog 80:603-617
Brunetti M, Maugeri M, Nanni T, Navarra A (2002) Droughts and extreme events in regional daily Italian precipitation series. Int J Climatol 22:543-558
Bull WB (1997) Discontinuous ephemeral streams. Geomorph 19:227-276
Chen Y, Cai Q, Tang H (2003) Dust storm as an environmental problem in north China. Environ Manage 4:413-417
Clarke ML, Rendell HM (2006a) Hindcasting extreme events: the occurrence and expression of damaging floods and landslides in southern Italy. Land Degrad Devel 17:365-380
Clarke ML, Rendell HM (2006b) The effects of storminess, sand supply and the North Atlantic Oscillation on sand invasion and coastal dune accretion in western Portugal. The Holocene 16:341-355
Clarke ML, Rendell HM, Tastet J-P, Clavé B, Massé L (2002) Late Holocene sand invasion and North Atlantic storminess along the Aquitaine Coast, southwest France. The Holocene 12:231-238
Conacher A, Sala M (eds) (1998) Land degradation in Mediterranean environments of the world. Wiley, Chichester 491pp
Cooke RU, Reeves RW (1976) Arroyos and environmental change in the American south-west. Clarendon Press, Oxford. 213pp
Diodato N (2004) Local models for rainstorm-induced hazard analysis on Mediterranean river-torrential geomorphological systems. Nat Hazards Earth Sys 4:389-397
Dobyns HF (1981) From fire to flood: historic human destruction of Sonoran Desert riverine oases. Ballena Press Anthropological Papers No. 20, Ballena Press, Socorro NM, 221pp.
Dorland C, Tol RSJ, Palutikof JP (1999) Vulnerability of the Netherlands and Northwest Europe to storm damage under climate change. Clim Chang 43:513-535.
Easterling DR, Meehl GA, Parmesan C, Changnon SA, Karl TR, Mearns LO (2000) Climate extremes: observations, modelling, and impacts. Science 289:2068-2074
Edwards DC, McKee TB (1997) Characteristics of the 20th century drought in the United States at multiple timescales. Department of Atmospheric Science, Colorado State University, Fort Collins, CO. Atmospheric Science Paper No. 634, Climatology Report No. 97-2, 174pp
Ely LL (1997) Response of extreme floods in the southwestern United States to climatic variations in the late Holocene. Geomorph 19:175-201
Enzel Y, Wells SG (1997) Extracting Holocene paleohydrology and paleoclimatology information from modern extreme flood events: an example from southern California. Geomorph 19:203-226.
Frich P, Alexander LV, Della-Marta P, Gleason B, Haylock M, Klein Tank AMG, Peterson T (2002) Observed coherent changes in climatic extremes during the second half of the twentieth century. Clim Res 19:193-212.
Gao T, Su L, Ma Q, Li H, Li X, Yu X (2003) Climatic analysis on increasing dust storm frequency in the springs of 2000 and 2001 in Inner Mongolia. Int J Clim 23:1743-1755
Goudie AS, Middleton NJ (2001) Saharan dust storms: nature and consequences. Earth-Sci Rev 56:179-204
Goudie AS, Middleton NJ (1992) The changing frequency of dust storms through time. Clim Chang 20:197-225

Groisman PYA, Karl TR, Easterling DR, Knight RW, Jamason PF, Hennessy KJ, Suppiah R, Page CM, Wibig J, Fortuniak K, Razuvaev VN, Douglas A, Førland E, Zhai P-M (1999) Changes in the probability of heavy precipitation: important indicators of climatic change. Clim Chang 42:243-283

Guzzetti F, Cardinali M, Reichenbach P, Cipolla F, Sebastiani C, Galli M, Salvati P (2004) Landslides triggered by the 23 November 2000 rainfall event in Imperia Province, Western Liguria, Italy. Eng Geol 73:229-245

Hook DD, Burford MA, Williams TM (1991) Impact of hurricane Hugo on the South Carolina coastal plain forest. J Coast Res 8:291-300

Hooke JM, Mant JM (2000) Geomorphological impacts of a flood event on ephemeral channels in SE Spain. Geomorph 34:163-180

Hurrell JW, Van Loon H (1997) Decadal variations in climate associated with the North Atlantic Oscillation. Clim Chang 36:301-326

Inbar M, Bruins HJ (2004) Environmental impact of multi-annual drought in the Jordan Kinneret watershed, Israel. Land Degrad Develop 15:243-256.

Jaffe D, Snow J, Cooper O (2003) The 2001 Asian dust events: transport and impact on surface aerosol concentrations in the US. EOS 84:501-504

Japan Meteorological Agency (1991) Marine department Report.

Ji L, Peters AJ (2003) Assessing vegetation response to drought indices in the northern Great Plains using vegetation and drought indices. Remote Sens Environ 87:85-98

Jickells TD, An ZS, Andersen KK, Baker AR, Bergametti G, Brooks N, Cao JJ, Boyd PW, Duce RA, Hunter KA, Kawahata H, Kubilay N, laRoche J, Liss PS, Mahowald N, Prospero JM, Ridgwell AJ, Tegen I, Torres R (2005) Global iron connections between desert dust, ocean biogeochemistry, and climate. Science 308:67-71

Katz RW, Brown BG (1992) Extreme events in a changing climate: variability is more important than averages. Clim Chang 21:289-302

Liu X, Yin Z-Y, Zhang X, Yang X (2004) Analyses of the spring dust storm frequency of northern China in relation to antecedent and concurrent wind, precipitation, vegetation, and soil moisture conditions. J Geophys Res 109: D16210, doi:10.1029/2004JD004615.

Lloyd-Hughes B, Saunders MA (2002) A drought climatology for Europe. Intl J Climatol 22: 1571-1592.

Lodge DJ, McDowell WH (1991) Summary of ecosystem-level effects of Caribbean hurricanes. Biotropic 23:373-378

Luino F (2005) Sequence of instability processes triggered by heavy rainfall in northern Italy. Geomorph 66:13-39

Mazzarella A, Diodato, N (2002) The alluvial events in the last two centuries at Sarno, southern Italy: their classification and power-law time-occurrence. Theor Appl Climatol 72: 75-84.

McGregor GR, Ferro CAT, Stephenson DB (2005) Projected changes in extreme weather and climate events in Europe. In: Kirch W, Menne B, Bertollini R (eds) Extreme weather and climate events and public health responses. Dresden, Springer, pp. 13-23

McKee TB, Doesken NJ, Kleist J (1993) The relationship of drought frequency and duration to time scales. Eighth Conference on Applied Climatology, 17-22 January 2003, Anaheim, California, Preprints pp.179-184

McKee TB, Doesken NJ, Kleist J (1995) Drought monitoring with multiple time scales. 9th AMS Conference on Applied Climatology, 15-20 January 1995, Dallas Texas, Preprints pp.233-236

McTainsh G, Chan Y-C, McGowan H, Leys J, Tews K (2005) The 23rd October 2002 dust storm in eastern Australia: characteristics and meteorological conditions. Atmos Environ 39:1227-1236

Meehl GA, Teng H, Branstator G (2006) Future changes of El Niño in two global coupled climate models. Clim Dynam 26:549-566.

Meyers SD, O'Brien JJ, Thelin E (1999) Reconstruction of monthly SST in the tropical Pacific ocean during 1868-1933 using adaptive climate basis functions. Mon Wea Rev 127: 1599-1612

Michener WK, Blood ER, Bildstein KL, Brinson MM, Gardner LR (1997) Climate change, hurricanes and tropical storms, and rising sea level in coastal wetlands. Ecol Appl 7:770-801

Morgan RPC, Mngomezulu D (2003) Threshold conditions for initiation of valley-side gullies in the Middle Veld of Swaziland. Catena 50:401-414

Neumann CJ, Jarvinen BR, McAdie CJ, Elms JD (1993) Tropical cyclones of the North Atlantic Ocean 1871-1992. National Climatic Center, Asheville, NC, USA.

Nicholls N, Murray W (1999) Workshop on indices and indicators for climate extremes: Ashville, NC, USA, 3-6 June 1997 breakout group B: precipitation. Clim Chang 42:23-29.

Nicholson SE, Tucker CJ, Ba MB (1998) Desertification, drought, and surface vegetation; an example from the West African Sahel. Bull Amer Met Soc 79:815-829

Okin GS, Reheis MC (2002) An ENSO predictor of dust emission in the southwestern United States. Geophys Res Lett 29(9), 10.1029/2001GL014494.

Okin GS, Gillette DA, Herrick JE (2006) Multi-scale controls on and consequences of Aeolian processes in landscape change in arid and semi-arid environments. J Arid Environ 65:253-275

Palmer WC (1965) Meteorological drought. Research Paper No. 45, U.S. Department of Commerce Weather Bureau, Washington, D.C

Pielke RA, Doesken N, Bliss O, Green T, Chaffin C, Salas JD, Woodhouse CA, Lukas JJ, Wolter K (2005) Drought 2002 in Colorado: an unprecedented drought or a routine drought? Pure Appl Geophys 162:1455-1479

Poesen J, Nachtergaele J, Verstraeten G, Valentin C (2003) Gully erosion and environmental change: importance and research needs. Catena 50:91-133

Prospero JM, Lamb PJ (2003) African droughts and dust transport to the Caribbean: climate change implications. Science 302:1024-1027

Putz FE, Sharitz RR (1991) Hurricane damage to old-growth forest in Congaree Swamp National Monument, South Carolina USA. Can J For Res 21:1765-1770

Qian B, Saunders MA (2003) Seasonal predictability of wintertime storminess over the North Atlantic. Geophys Res Lett 30:1698-1701

Reheis MC (1997) Dust deposition downwind of Owens (dry) Lake, 1991-1994: preliminary findings. J Geophys Res 102:25999-26008.

Reheis MC (2006) A 16-year record of eolian dust in southern Nevada and California: controls on dust generation and accumulation. J Arid Envts 67: 487-520.

Sánchez E, Gallardo C, Gaertner MA, Arribas A, Castro M (2004) Future climate extreme events in the Mediterranean simulated by a regional climate model: a first approach. Global Planet Ch 44:163-180

Schwierz C, Appenzeller C, Davies HC, Liniger MA, Müller W, Stocker T, Yoshimori M (2006) Challenges posed by and approaches to the study of seasonal-to-decadal climate variability. Clim Chang 79: 31-63.

Shinn EA, Smith GW, Prospero JM, Betzer P, Hayes ML, Garrison V, Barber RT (2000) African dust and the demise of Caribbean coral reefs. Geophys Res Lett 27:3029-3032

Smith TJIII, Robblee MB, Wanless HR, Doyle TW (1994) Mangroves, hurricanes and lightning strikes. BioScience 44:256-262

Sterk G (2003) Causes, consequences and control of wind erosion in Sahelian Africa: a review. Land Degrad Develop 14:95-108.

Tebaldi C, Hayhoe K, Arblaster JM, Meel GA (2006) Going to extremes: an intercomparison of model-simulated historical and future changes in extreme events. Clim Chang 79:185-211.

Trenberth KE, Owen TW (1999) Workshop on indices and indicators for climate extremes: Ashville, NC, USA, 3-6 June 1997 breakout group A: storms. Clim Chang 42:9-21

Trigo RM, Zêzere JL, Rodrigues ML, Trigo IF (2005) The influence of the North Atlantic Oscillation on rainfall triggering of landslides near Lisbon. Nat Hazards 36:331-354.

UK Meteorological Office (2006) News release- warmest autumn on record confirmed. URL http://www.metoffice.gov.uk/corporate/pressoffice/2006/pr20061201.html, last accessed 15th January 2007.

Vicente-Serrano SM (2007) Evaluating the impact of drought using remote sensing in a Mediterranean, semi-arid region. Nat Hazards 40:173-208

Waters MR, Haynes CV (2001) Late Quaternary arroyo formation and climate change in the American Southwest. Geology 29:399-402.

Zhao H-L, Y X-Y, Zhou R-L, Zhao X-Y, Zhang T-H, Drake S (2006) Wind erosion and sand accumulation effects on soil properties in Horqin sandy farmland, Inner Mongolia. Catena 65: 71-79

Effects of Some Meteorological Parameters on Land Degradation in Tanzania

E. Matari

Abstract. The impact of some meteorological parameters on land degradation in Tanzania is analysed. Rainfall is responsible for floods in case if it is in excess and drought in case of deficit. In recent years, parts of Tanzania have experienced recurring droughts. The most devastating droughts were those of 1983-1984 and 1993-1994. According to Tanzania historical data, droughts occur every four years which affect over 3.6 million people. The most frequently hit areas are, central areas of Dodoma, Singida and some parts of Pwani, Shinyanga, Mwanza and Mara. Experience over the twenty-year period from 1980 to 2000 has shown that floods occurred 15 times, killing 54 people and affecting 800,000 people. Flood prone regions are Tanga, Mbeya, Pwani, Morogoro, Arusha, Rukwa, Iringa, Kigoma and Lindi. The impact of El-Niño rains is discussed and the probability of rainfall exceeding specific thresholds is analysed. Wind erosion is discussed. The impact of climate change and its relationship to land degradation is analysed. Finally the impact of solar radiation, temperature and evaporation is discussed. The paper concludes that climate and weather contribute significantly to land degradation in Tanzania. The paper recommends that there is a need to: make an inventory of national land resources; assess potentials and constraints in dryland farming; identify agricultural options to safely increase cropping intensity and yields; adopt more sustainable forms of land use, including contingency crop planning in the case of droughts; study the reasons behind poor land use; encourage pastoralists to reduce their herds of stocks and finally encourage the use of indigenous knowledge in land preservation.

8.1 Introduction

Soil degradation is on the increase worldwide, especially in countries within the tropics. According to historical data in Tanzania, droughts occur every four years, which affect 3.63 million people. The most frequently hit areas include the central areas of Dodoma, Singida and some parts of Pwani, Shinyanga, Mwanza and Mara. These regions receive 200 to 600 mm of annual rainfall.

In recent years, parts of Tanzania have experienced recurring droughts. The most devastating were those of 1983-1984 and 1993-1994 (Mhita and Venalainen 1992). These droughts necessitated the rationing of hydroelectric power, resulting in negative economic growth.

Land use activities have contributed to soil degradation in the marginal zones to the extent it can no longer adequately support living communities. The human population and livestock in these marginal areas have grown enormously in recent decades resulting in a need for increased food and fiber production as well as other resources.

In many areas the demands made on soils, vegetation and climate now greatly exceed their capacity to yield. The carrying capacity of the land has been exceeded. Drought in some areas has driven the pastoralists into the zone of cultivation resulting in serious conflicts.

Rainfall in Tanzania is a crucial factor in the ability of farmers and pastoralists to produce the foodstuffs needed for consumption by the people.

Rainfed agriculture is the main stay of the economy, consequently severe droughts have disastrous impacts on the socio-economic development of the country.

Experience during 1980-2000 has shown that floods occurred 15 times, killing 54 people and affecting 800,270 people. Flood prone regions are Tanga, Mbeya, Pwani, Morogoro, Arusha, Rukwa, Iringa, Kigoma and Lindi (Fig. 8.1a and 8.1b).

Management of arable areas by farmers and grazing areas by livestock owners is one of the major causes of soil degradation. More sustainable management of lands would reduce environmental pressures. Conservation tillage, i.e. reduced or no tillage, is the key to sustainable arable land management as it protects the soil resources, increases the efficiency of water use and, is of special importance in semi-arid areas since it can reduces the effects of droughts.

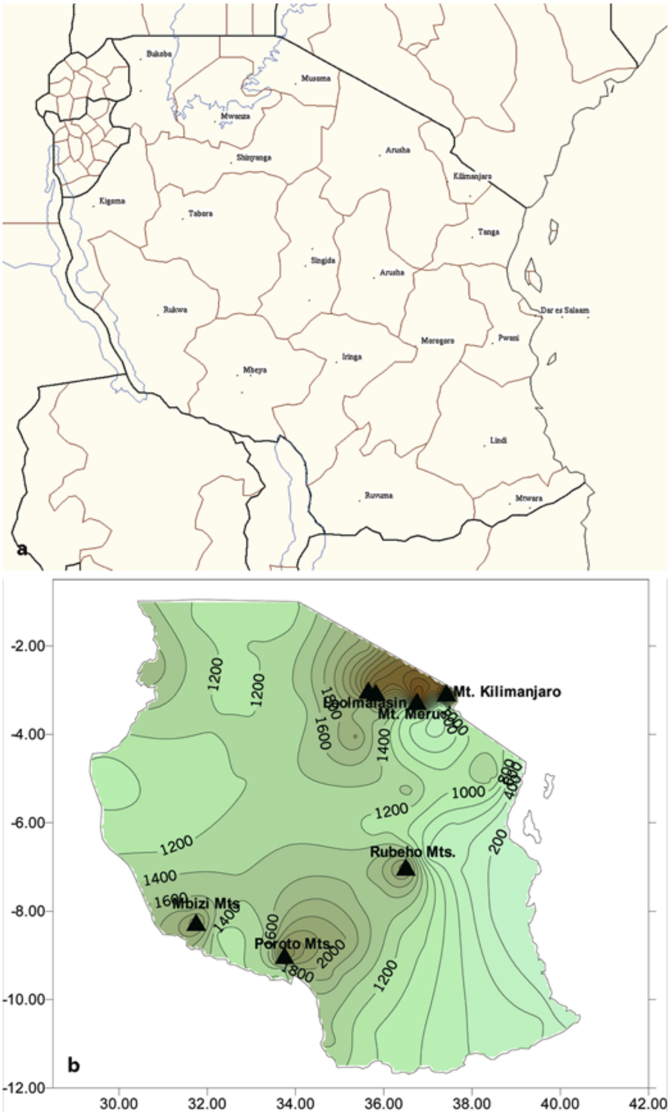
Land/soil degradation can either be as a result of natural hazards or due to unsuitable land use and inappropriate land management practices. Natural hazards include frequent floods on steep slopes, tornadoes, high velocity winds, high intensity rains, strong leaching in humid regions and drought conditions in dry regions. Anthropogenic activities such as deforestation of fragile lands, removal of vegetation, shifting cultivation, overgrazing, unbalanced fertilizer use, non-adoption of soil conservation management practices and over-pumping of ground water result in soil erosion.

Desertification is now defined in the UNCCD as "land degradation in the arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities". According to UNCCD, over 250 million people are directly affected by land degradation. In addition, some one billion people in over 100 countries are at risk. These people include many of the world's poorest, most marginalized, and politically weak citizens.

8.2 Impact of rainfall on land degradation in Tanzania

Rainfall is the most important climatic factor in determining areas at risk of land degradation and potential desertification. Rainfall plays a vital role in the development and distribution of plant life, but the variability and extremes of rainfall can lead to soil erosion and land degradation. If unchecked for a period of time, this land degradation can lead to desertification. The interaction of human activity on

Fig 8.1 a, b. **a** Location of flood-prone regions in Tanzania, **b** Topography of Tanzania



the distribution of vegetation through land management practices and seemingly due to rainfall events can make land more vulnerable to degradation. These vulnerabilities become more acute when the prospect of climate change is introduced.

Rainfall and temperature are the prime factors in determining the world's climate and therefore the distribution of vegetation types. There is a strong correlation between rainfall and biomass since water is one of primary inputs to photosynthesis. Climatologists use the "aridity index" (the ratio of annual precipitation to potential evaporation) to help classify desert (arid) or semi-arid areas. Dry lands exist because the annual water loss (evaporation) exceeds the annual rainfall; therefore these regions have a continual water deficit. Deserts are the ultimate example of a climate where annual evaporation far exceeds the annual rainfall. In cases where the annual water deficits are not so large, some plant life can take hold usually in the form of grasslands or steppes.

Rainfall intensity is the most important factor governing soil erosion caused by rain. Dryland precipitation is inherently variable in amounts and intensities and so is the subsequent runoff. Surface runoff is often higher in drylands than in more humid regions due to the tendency of dry land soils to form impermeable crusts under the impact of intense thunderstorms and in the absence of significant plant cover or litter. In these cases, soil transport may be an order of magnitude greater per unit momentum of falling raindrops than when the soil surface is well vegetated. The sparser the plant covers, the more vulnerable the topsoil is to dispersal and removal due to raindrop impact and surface runoff. Also, the timing of the rainfall can play a crucial role in soil erosion leading to land degradation. An erratic start to the rainy season along with heavy rain will have a greater impact since the seasonal vegetation will not be available to intercept the rainfall or stabilize the soil with its root structure.

Of special note is the impact of other forms of precipitation on soil erosion. Hail has a severe effect on the soil surface because its kinetic energy is several times more than that of rain, resulting in much more soil surface being destroyed and a greater amount of material being washed away. And if hailstorms are accompanied by heavy rain, as is the case with some thunderstorms, large amounts of soil can be eroded, especially on agricultural land before the crops can stabilize the soil surface.

8.2.1 Loss of topsoil through water erosion

Loss of top soil through water erosion is the most common type of human-induced soil degradation. It is generally known as surface wash or sheet erosion. It occurs in almost every country, under a great variety of climatic and physical conditions and land use. As the topsoil is normally rich in nutrients, a relatively large amount of nutrients is lost together with the topsoil. Loss of topsoil itself is often preceded by compaction and/or crusting, causing a decrease in infiltration capacity of the soil, and leading to accelerated run-off and soil erosion.

8.2.2 Terrain deformation/mass movement through water erosion.

The most common phenomena of this degradation type are rill and gully formation. Rapid incision of gullies, eating away valuable soil is well known and dramatic in many countries. Other phenomena of this degradation type are riverbank destruction and mass movement (landslides), and off-site deposition of the eroded material (Fig. 8.2a) in a negative way (choking of river beds; smothering of riverside crops).

The degradation of the above-ground vegetation and animal populations is prevalent in many areas, through direct human influence and aggravated by droughts of a more or less cyclic nature (Sahel, Southeastern Africa, Northeastern Brazil). By and large this biotic degradation is proving to be reversible in a few years time after return of the rains and the "resting" of the land from excessive human or animal occupation.

Fig. 8.2 a,b. a Example of a flood and landslide during the 1997/98 ENSO event in Tanzania, **b** Flooding scenario during 1997/98 El-Niño year in Tanzania

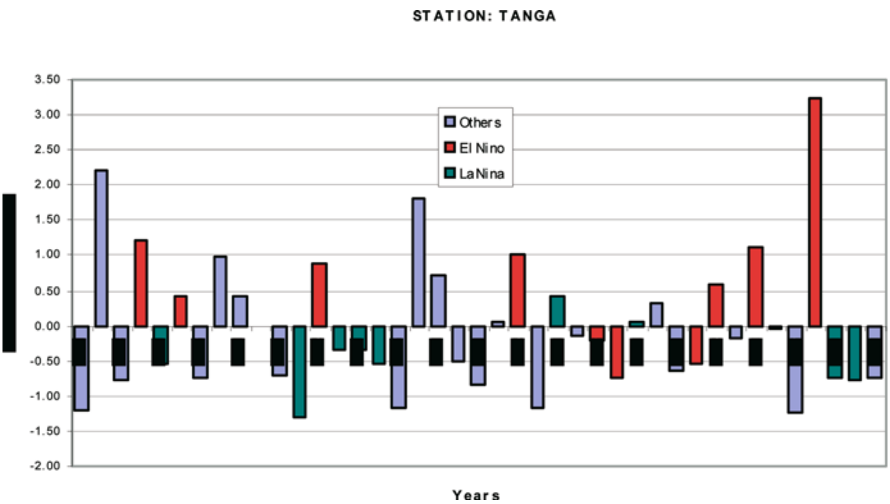


Fig. 8.3. Rainfall analysis for Tanga during the 1997/98 El Niño year

8.3 Floods

Dryland rivers have extremely variable flows (as can be seen from the rainfall variability in Fig. 8.3) and river discharge (Fig. 8.2b), and the amount of suspended sediments are highly sensitive to fluctuations in rainfall as well as any changes in the vegetation cover in the basins. In Tanzania flood prone areas are characterized by high probability of rainfall greater than 1000 mm (Fig. 8.4). This is a scenario during 1997/98 El-Niño year whereby many farms with crops were washed out by the floods which were caused by the heavy rains (WMO 2004). The loss of vegetation in the head-waters of dryland rivers can increase sediment load and can lead to dramatic change in the character of the river to a less stable, more seasonal river characterized by a rapidly shifting series of channels. However, rainfall can lead to land degradation in other climates, including sub-humid regions due to excessive rainfall events either produced by thunderstorms, hurricanes and typhoons.

8.4 Drought

Agriculturalists conceive drought as a shortage of moisture within the root zone for plant growth and development. On the other hand, hydrologists see droughts resulting in a severe reduction in stream, lake and reservoir levels. Economists view droughts as a serious water shortage that adversely affects the economy. However, meteorologists regard droughts as simply a prolonged period of precipitation deficiency that causes serious hydrological imbalance.

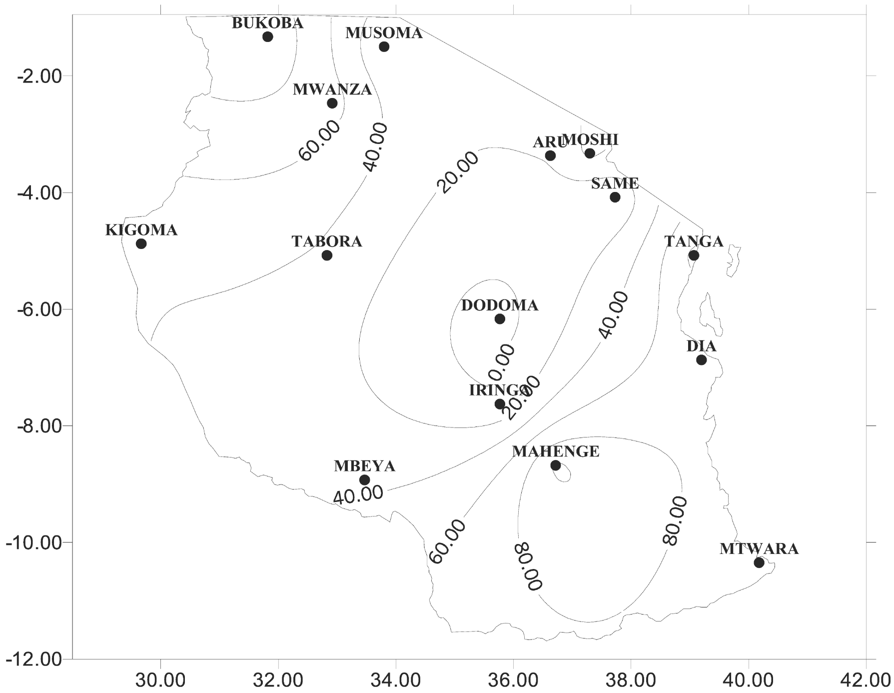


Fig. 8.4. Probability of rainfall exceeding 1000 mm in Tanzania

According to Mutoni (2000), the central part of Tanzania extending to the north eastern parts have a high probability of drought (Fig. 8.5). It is the consequence of a reduction in the amount of precipitation over an extended period of time, usually a season or more in length, often associated with other climatic factors such as high temperatures, high winds and low relative humidity that can aggravate the severity of the event.

Drought can be characterized as a normal, recurring feature of climate and it occurs in almost all climatic regimes, in areas of high as well as low rainfall. It is a temporary anomaly, in contrast to aridity, which is a permanent feature of the climate and is restricted to areas of low rainfall. Drought is the consequence of a natural reduction in the amount of precipitation received over an extended period of time, usually a season or more in length. Drought is also related to the timing (i.e. main season of occurrence, delays in the start of the rainy season, occurrence of rains in relation to primary crop growth stages) and to the intensity and number of rainfall events. Thus, each drought is unique in its climatic characteristics and impacts (Nyenzi et al. 1997)

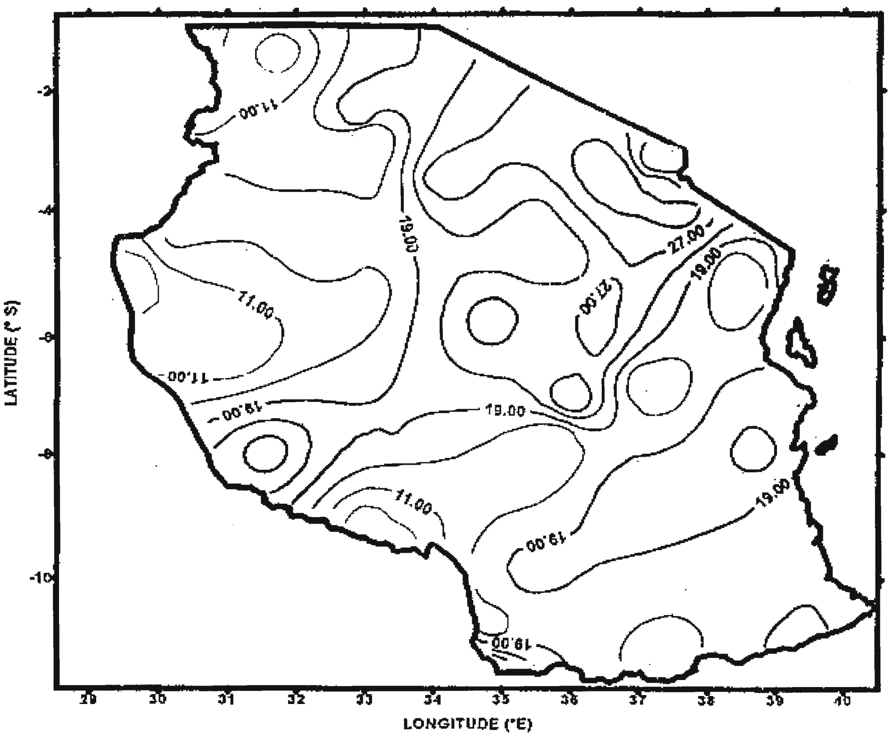


Fig 8.5. Annual probability of droughts in Tanzania

8.5 Wind Erosion

For Africa, it is estimated that more than 100 million tones of dust per annum is blown westward over the Atlantic. The amount of dust arising from the Sahel zone has been reported to be around or above 270 million tons yr^{-1}. In Tanzania wind erosion is maximum over those areas with a high probability of drought (Fig. 8.5).

Wind erosion-induced damage includes direct damage to crops through the loss of plant tissue and reduced photosynthetic activity as a result of sandblasting, burial of seedlings under sand deposits, and loss of topsoil. The last process is particularly worrying since it potentially affects the soil resource base and hence crop productivity on a long-term basis, by removing the layer of soil that is inherently rich in nutrients and organic matter. Wind erosion on light sandy soils can provoke severe land degradation and sand deposits on young seedlings can affect crop establishment

Calculations based on visibility and wind speed records for 100 km-wide dust plumes, centred on eight climate stations around South Australia, indicated that dust transport mass was as high as ten million tons. Thus dust entrainment during dust events leads to long-term soil degradation, which is essentially irreversible. The cost to productivity is difficult to measure but is likely to be quite substantial.

8.5.1 Causes of wind erosion

The occurrence of wind erosion at any place is a function of weather events interacting with soil and land management through its effects on soil structure, tilth and vegetation cover. In regions where long dry periods associated with strong seasonal winds occur regularly, wind erosion usually is a serious problem, as the vegetative cover of the land does not sufficiently protect the soil, and the soil surface is disturbed due to inappropriate management practices.

Wind erosivity is the main factor controlling the broad pattern of wind erosion. It has been defined as "that property of the wind which determines its ability to entrain and move bare, dry soil in fine tilth". It can be estimated from daily or hourly records of wind speed above a threshold related to the lowest speed which soil particles are entrained

8.5.2 Climatic Implications of dust storms

The very fine fraction of soil-derived dust has signification forcing effects on the radiation budget. Dust particles are thought to exert a radiation and indirectly through modifying the optical properties and longevity of clouds depending on their properties and in what part of the atmosphere they are found, dust particles can reflect sunlight back into space and cause cooling in two ways. Directly, they reflect sunlight back into space, thus reducing the amount of energy reaching the surface.

Wind erosion is possible when the wind velocity at the soil surface exceeds the threshold velocity required to move the least stable soil particle. The detached particle may move a few millimeters before finding a more protected site on the landscape. The wind velocity required to move this lest stable particle is called the static threshold. If the wind velocity increases, soil movement begins and if the velocity is sufficient, soil movement is sustained. This velocity is called the dynamic threshold.

Loss of topsoil through wind erosion is the uniform displacement of topsoil and selective removal of fine particles by wind action. It is widespread, particularly in arid and semi-arid climates.

Terrain deformation by wind erosion is much less widespread than loss of topsoil. It is defined as the uneven displacement of soil material by wind action and leads to deflation hollows and dunes.

Overblowing, which is defined as the coverage of the land surface by wind-carried particles, is an off-site effect of the wind erosion types mentioned above. Overblowing may occur in the same mapped unit or in adjacent units. It may affect structures like roads, buildings and waterways, but it can also cause damage to agricultural land.

Loss of nutrients is a form of chemical soil degradation which occurs if agriculture is practiced on poor or moderately fertile soils, without sufficient application of manure or fertilizer ie., nutrient mining. It causes a general depletion of the soil fertility and leads to decreased productivity. Loss of organic matter by clearing the natural vegetation is also included in this type of chemical soil degradation, although it often has a negative influence on the soil physical properties as well. The loss of nutrients by erosion of fertile topsoil is considered to be a side-effect of wind or water erosion, and not distinguished separately.

8.6 Climate change as cause and result of degradation of dryland areas

Human activities – primarily burning of fossil fuels and changes in land cover – are modifying the concentration of atmospheric constituents or properties of the earth's surface that absorb or scatter radiant energy. Overgrazing in the Masailand creates land degradation by leaving the bare soil without vegetation (Fig. 8.6). In particular, increases in the concentrations of greenhouse gases (GHGs) and aerosols are strongly implicated as contributors to climatic changes and are expected

Fig. 8.6. Overgrazing in the Masailand of Tanzania

to contribute to further changes in climate in the 21st century and beyond. These changes in atmospheric composition are likely to alter temperatures precipitation patterns, seal level, extreme events, and other aspects of climate on which the natural environment and human systems depend.

According to WMO (2006), meteorological and hydrological hazards are linked with climate variability. Regular assessments and authoritative statements on the interpretation and applicability of observational data are needed for the study of climate variability and the implementation of a climate alert system to allow NMHSs to make early warnings on pending significant climate anomalies. Warnings of climate related disasters are becoming feasible from weeks to seasons in advance.

Human-induced global climate change may, or may not negatively affect the climatic conditions of drylands, and hence their degradation. The current Global Circulation Models are yet too rough to come to unequivocal conclusions for regions or local areas. The implications of a coupling between terrestrial and ocean models, and of the direct effect of increased atmospheric CO_2 on plant growth are not yet known. In contrast to the situation with methane and nitrous oxide, the increase in the concentration of atmospheric carbon dioxide has a direct positive effect on plant growth through the so-called “CO_2-fertilization” and the “CO_2-antitranspiration” phenomena. Also, a slight increase of the surface temperature of open waters because of any global warming would result in a strong intensification of the global hydrological cycle. This implies more rainfall in many parts, and thus more transpiration-cum-growth of plants, or more run-off to be used on-site or downstream for extra irrigation if stored adequately. These factors have a potentially positive aspects of human-induced climate change in the field of agriculture and rural development, while also concentrating on how to deal with the potential negative consequences. Among the latter are the potential increase in the frequency and severity of extreme weather events (droughts, floods, hurricanes) because of an intensification of the hydrological cycle. According to a study by Hyera and Matari (1996), in Tanzania the temperature will increase by 2-3 °C due to climate change (Fig. 8.7) and rainfall is likely to vary from -3 to 4% (Fig. 8.8).

8.7 Conclusions

Sustainable land management practices in Tanzania are needed to avoid land degradation. Land degradation typically occurs because of land management practices or human development that is not sustainable over a period of time. To accurately assess sustainable land management practices, the climate resources and the risk of climate-related or induced natural disaster in a region must be known. Only when climate resources are paired with potential management or development practices can the land degradation potential be assessed and appropriate mitigation technology considered. The use of climate information must be applied in developing sustainable practices as climatic variations contributes to land degradation and there is a clear need to consider carefully how climate induces and influences land degradation.

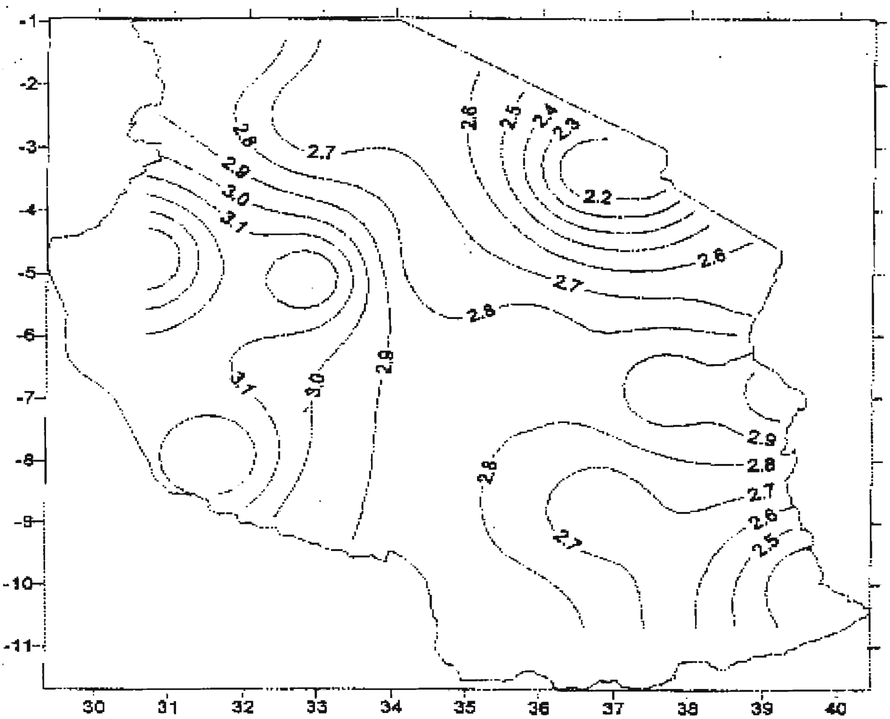


Fig. 8.7. Projected temperature change due to climate change in Tanzania

In this context, the following recommendations are made to address the interactions between climate and land degradation in Tanzania:

- Making an inventory of national land resources.
- Assessing potentials and constraints in dryland farming and identifying agricultural options to safely increase cropping intensity and yields, decrease risks and offering other advantages while reducing land degradation.
- Studying the reasons behind poor land use, including land tenure-based problems, pricing of agricultural goods, subsidies, taxes, laws and social customs.
- Encouraging farmers to adopt more sustainable forms of land use, including contingency crop planning in the case of droughts.
- Encouraging pastorists to reduce their herds of stocks and looking for alternative means for them.
- Encouraging the use of indigenous knowledge in land preservation such as 'Ngoro' farming system used for farming over southern highlands of Tanzania (Fig. 8.9).

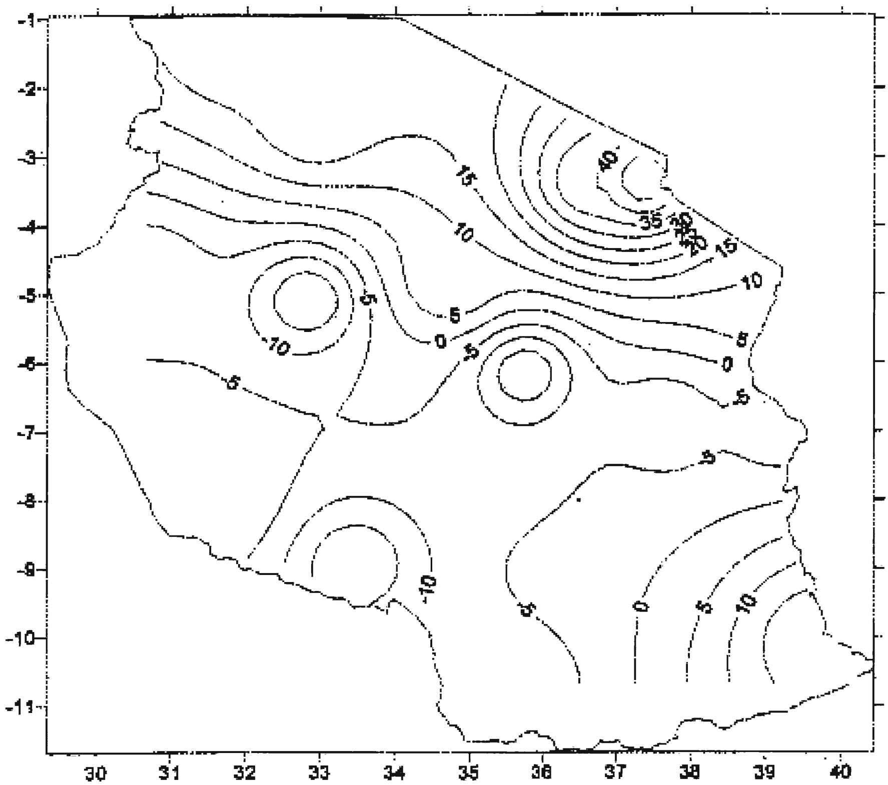


Fig. 8.8. Projected change in annual rainfall (%) due to climate change in Tanzania

Fig. 8.9. Local 'Ngoro' farming system used for soil conservation on steep slopes.

References

Hyera T, Matari E (1996) The development of climate change scenarios in Tanzania. In: The assessment of vulnerability and adaptation to climate change impacts in Tanzania. Associates of CEEST (Centre for Energy Environment Scientific Technolgy) from the Directorate of Meteorology.
Mhita MS, Venalainen A (1992) The Variability of Rainfall in Tanzania. FINNIDA/SATCC/WMO Meteorology project doc., Helsinki, Finnish Meteorological Institute.
Mutoni EJ (2000) Climatological Atlas of Tanzania. Directorate of Meteorology P. O. Box 3056 Dar es Salaam, Tanzania.
Nyenzi B, Kavishe MM, Nassib IR, Tilya FF (1997). Analysis of meteorological droughts in Tanzania. Directorate of Meteorology, P. O. Box 3056 Dar es Salaam, Tanzania.
WMO (2006) Climate and land degradation. Report no. 989, World Meteorological Organization, Geneva.
WMO (2004) The application of climate information prediction and early warning products in disaster management for sustainable development in Tanzania.

Rainfall and Land Degradation

Leo Stroosnijder

Abstract. The complexity of the notion 'land' and its scale features leads to many different definitions of land and land degradation. Among the components of land degradation are desertification, soil degradation and erosion. There is a wealth of literature claiming that land degradation is serious. These so-called doom papers are based on 'hard' facts from remote sensing, computer models and measurements. However, other papers have raised the question 'how serious is land degradation?' In any discussion of land degradation there are four spatial-temporal scales that should be distinguished: regional, watershed, field and point. At each scale, one may use different proxies for land degradation. When assessing land degradation, 'experts' tend to overestimate the phenomenon; they should take better account of its spatial and temporal dimensions. One of the main reasons they currently overestimate land degradation is that they underestimate the abilities of local farmers, many of whom have been able to modify their land management. In order to study land degradation at multiple scales it is also necessary to study rainfall at multiple scales. Rainfall can be analysed for land degradation at four different scales: from the 'small' annual scale to the 'large' minute scale. Besides scales one may also distinguish between average values and temporal and spatial variations. In this paper, one or more examples of rainfall data are presented for each scale and interpreted with respect to land degradation. At the annual scale, trend analysis and rainfall probabilities are important. The decadal (10-day) scale is especially suitable for calculating the varying lengths of the growing season. At the scale of one day, the size classes of showers, return period (design storm), hydrological and agronomic modelling and dry spell analysis are discussed. At the minute scale, erosivity in El Niño and La Niña years is important.

Rainfall meets land at the soil surface. Rainfall is divided over several pedohydrological components. Green water is that part of rainfall that is stored in the soil and available to plants. Land degradation decreases infiltration, waterholding capacity and transpiration, but enhances runoff and soil evaporation. These agrophysical processes decrease the Green Water Use Efficiency (GWUE; the ratio of transpiration to precipitation). Special attention is given to estimating the effects of land degradation on 'computing available soil moisture' in order to understand what farmers perceive as drought. Rain falling on the land may be intercepted by vegetation, run off the ground surface, or infiltrate into the soil; this is reflected in the rainwater balance. Infiltrating water may be stored in the root zone or drain below the root zone to groundwater and stream base flow, contributing what is nowadays called 'blue water'. These processes are reflected in the infiltration water balance. The maximum amount of water stored in the root zone available for plant

growth is a very important soil characteristic because it determines the potential survival of plants in a dry spell. Water stored in the root zone may be lost as evaporation from the soil surface into the atmosphere, or taken up by plants and lost as transpiration. This is reflected in the soil water balance. In drylands in sub-Saharan Africa the GWUE ranges from 5–15%, which is very low. In East Africa it may reach 20%, but in comparable climates in the USA the GWUE may be above 50%.

The concepts of land degradation mitigation are derived from the rainwater balance. After drawing a number of conclusions, it is suggested how we could improve our understanding of land degradation by improving the availability of rainfall data at multiple scales.

9.1 Introduction

Land is the complex of soil, water and the natural flora and fauna in a landscape, above and below the soil surface. Land degradation is the decline in the extent to which land yields products useful to local livelihoods (Scoones and Toulmin 1999) or, in more recent terminology, in the decline in 'ecosystem services' (MEA 2005). The complexity of the notions 'land' and 'land degradation' and their scale features lead to many different definitions.

A special form of land degradation is desertification, i.e. land degradation in the arid, semi-arid and dry sub-humid areas most vulnerable to land degradation. The previous UN Secretary-General Kofi Annan has called desertification one of the world's most alarming processes of environmental degradation. Under the scenario of climate change it is often claimed that the droughts, flash floods, dust storms, famine, migration and forest fires associated with desertification are bound to increase, leading to loss in human well-being and bringing high socio-economic costs. That long-term food productivity is threatened by land degradation is of major significance and concern, since this has serious impact on global food security.

According to the United Nations Convention to Combat Desertification (UNCCD 1997), over 250 million people are directly affected by land degradation. In addition, some one billion people in over one hundred countries are at risk. These people include many of the world's poorest and most marginalised, who tend to lack strong political leverage.

In this paper, land degradation will be discussed mainly in relation to sub-Saharan Africa. There are four spatial-temporal scales that should be distinguished in a discussion on land degradation: regional, watershed, field and point scales. At each scale one may use different proxies for land degradation, as will be discussed in section 9.2, with examples. There are many links between land and rainfall – direct and indirect: rainfall affects vegetation (productivity, cover and biodiversity), the soil water status and the soil characteristics. In order to link land degradation at multiple scales to rainfall, it is also necessary to study rainfall at multiple scales. Rainfall can be analysed for land degradation at four different scales, each of which has its specific application(s). Besides scales, one must also distinguish between average values and temporal and spatial variations. In section 9.3, one or more examples of rainfall data for each scale are presented and interpreted with respect to land degradation. An overview of scales used for the analysis of land degradation and rainfall is given in Table 9.1.

Farmers often experience land degradation as 'drought'. Their notion of drought refers to the occurrence of dry spells (Stroosnijder 2007). However, several recent studies have presented little evidence for an increase in the length and/or frequency of dry spells. So, when farmers talk of 'drought', they must be referring to the amount of water that can be stored in the root zone soil profile (Green Water) and the use of this Green Water. In scientific terms, they are referring to the Green Water Use Efficiency (GWUE), i.e. the fraction of rain that is used for plant transpiration. In dryland systems in sub-Saharan Africa the GWUE ranges from 5–15%, which is very low compared to similar agro-climatic zones in the world. Land degradation (of which soil erosion is the major cause) deteriorates soil physical characteristics that affect a number of pedo-hydrological processes: it decreases infiltration, waterholding capacity and plant transpiration, but increases runoff and soil evaporation (Stroosnijder 2003). This is the subject of section 9.4.

Understanding that there is a link between productivity and the rainwater balance clarifies the term 'desertification' and provides useful concepts for the mitigation of droughts at the farm level. The goal of GWUE improvement is to maximise the productive flow of water as plant transpiration and to minimise the non-productive water flows, including soil evaporation, runoff and percolation beyond the root zone. The concepts of land degradation mitigation are derived from the rainwater balance: they are elaborated in section 9.5. Finally conclusions and recom-

Table 9.1. Useful scales for studying the relationship between land degradation and rainfall

Land Degradation Scale	Land Degradation proxy
Regional	Vegetation cover Productivity
Watershed	Landuse changes
Field	Soil fertility
Point	Erosion Soil organic matter Physical soil qualities
Rainfall scale	**Application**
Year	Trend Probability
Decade	Length of growing season
Day	Shower size classes Return period Hydrological and agronomic modelling Dry spell analysis
Minute	Rainfall erosivity

mendations are presented as to how our understanding of land degradation could be enhanced through improving the availability of rainfall data at multiple scales.

9.2 Land degradation

9.2.1 Defining land degradation

All current land degradation definitions refer to a loss in productivity of the land (Blaikie and Brookfield 1987). This implies that one of the possible proxies for land degradation is a decline in productivity of the land (Mazzucato and Niemeijer 2000a). Soil degradation, being a component of land degradation, comprises erosion and the decline in soil qualities: chemical changes due to leaching or salinisation, physical changes due to compaction or crusting, and biological changes due to the loss of soil organic matter or micro-organisms. With respect to erosion, it is useful to distinguish between on-site and off-site erosion.

Recently a new definition has been proposed, based on the concept of ecosystem services (MEA 2005). Furthermore, many have taken on board the notion expressed by Warren (2002) that land degradation is contextual and cannot be judged independently of its spatial, temporal, economic, environmental and cultural context.

So, at present there are too many definitions for land degradation. In fact it may be questioned whether changes in land or land qualities that result from deliberate changes in land use, for instance due to economic development, may be called land degradation. Since humans have influenced the land since the origin of mankind, it may be better to call such changes ‘land development’ to distinguish them from undesired changes in ecosystem services.

9.2.2 The land degradation debate

There is a wealth of literature claiming that land degradation is serious. These so-called doom papers are based on ‘hard’ facts from remote sensing, computer models and measurements. Examples are: Stoorvogel and Smaling (1990); Oldeman et al. (1991); Some et al. (1992); VandePol (1992); Pimentel et al. (1995); UNEP (1997); Smaling et al. (1997); Scherr (1999); FAO (2000); Pimentel (2006). In these papers, land degradation is expressed either in terms of the state of degradation (ha affected), or of the rate of degradation (soil loss in t ha^{-1}) or of the impact (abandoned land or decline in productivity).

Many other papers, however, raise the question ‘how serious is land degradation?’. Examples are: Tiffen et al. (1994); Biot et al. (1995); Leach and Mearns (1996); Fairhead and Leach (1996); Crosson (1997); Scoones and Toulmin (1998); Fairhead and Leach (1998); Mazzucato and Niemeijer (2000b); Lomborg (2001); Mortimore and Adam (1999); Benjaminsen (2001); Rasmussen et al. (2001); Warren et al. (2001); Niemeijer and Mazzucato (2002); Lambin et al. (2001); Lal (2001); Woldeamlak and Stroosnijder (2003); and Fleskens and Stroosnijder (2007).

The extent, severity, and economic and environmental impacts of soil degradation by accelerated erosion are debatable (Lal 2001). Estimates of the global and regional land area affected are tentative and subjective. The impact of erosion on soil qualities and productivity is also uncertain (Stocking and Murnaghan 2001), and field measurements are scale- and technique-dependent (Stroosnijder 2005). Although considerable progress has been made in modelling soil erosion, the validation of the models remains poor.

Many of the authors mentioned above have concluded that there appears to be little evidence of widespread land degradation, though this does not preclude severe local degradation in sub-Saharan Africa. It seems that when assessing land degradation the 'experts' may very well be overestimating it. The discrepancies found between more empirical assessment of land degradation (based on productivity indicators and land properties) and the expert assessments and models that form the basis of most land degradation studies suggest that the methodology of the studies needs to be improved in several ways; most notably, they need to deal better with the spatial and temporal dimensions of the problems they observe (Fresco and Kroonenberg 1992). In an attempt to explain this controversy in the literature several spatial scales will be distinguished, each with its appropriate proxies for land degradation.

9.2.3
Useful scales and proxies for land degradation

In a discussion of land degradation there are four spatial-temporal scales that should be distinguished: regional, watershed, field and point. These scales partly overlap those used in erosion measurements (Stroosnijder 2005). At each scale, one may use different proxies for land degradation, some of which will be briefly discussed below.

9.2.3.1
Proxies at the regional scale: vegetation cover and productivity

Nicholson (2000) reports little evidence for the Sahel of large-scale denudation of soils, increase in surface albedo, or reduction of the productivity of the land, although degradation has probably occurred in some areas. There has, however, been a steady build-up of dust in the region over the last half a century which has probably influenced large-scale climate.

Many studies use the ratio of net primary production (NPP) to precipitation, i.e. the rain use efficiency (RUE). This can be calculated from remotely sensed data and rain measurements on the ground. Prince et al. (1998) found RUE to be very resilient, i.e. little variation between 1882–1990 for the Sahel, which implies that NPP is in step with rainfall, recovering rapidly from drought and not supporting the fears of widespread, large scale desertification. Their results even showed a small but systematic increase in RUE. Hein and DeRidder (2006) found evidence in the same direction.

Kakembo (2001) found no relation between rainfall variation and the observed trends in vegetation degradation for South Africa. He attributed the observed degradation to injudicious land use practices.

Mazzucato and Niemeijer (2001) examined the correlations between agricultural productivity (Fig. 9.1) and long-term rainfall (1956–1998), rural population density and animal traction index (as a proxy for technology) for Burkina Faso. From a stepwise regression analysis it became obvious that agricultural productivity per unit of cultivated area was mainly correlated with long-term average annual rainfall (environment) and barely related to rural population density (pressure on resources) or animal traction (technology). There was no indication whatsoever that pressure on resources in the form of rural population density or livestock density had affected land productivity. As such, the spatial analysis of agricultural productivity of cultivated land did not provide any evidence of soil degradation being the result of pressure on soil resources.

9.2.3.2
Proxy for the watershed scale: landuse changes

The watershed scale is a popular research scale. Integrated watershed management is a new field of applied science and the 'catchment approach' has been practised for over 15 years in East Africa (Okoba 2005; Tenge 2005).

Woldeamlak Bewket (2003) studied land cover dynamics since the 1950s in the Chemoga watershed of the Blue Nile basin in Ethiopia. The results show that in the 40-year period examined, forest cover increased at a rate of about 11 ha per annum

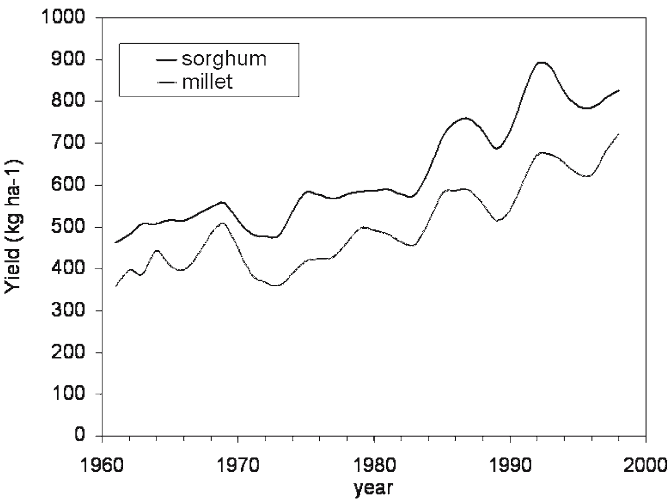


Fig. 9.1. Sorghum and millet productivity (kg ha^{-1}) in Burkina Faso over about 40 years (1962–1998), after Niemeijer and Mazzucato (2002)

Table 9.2. Landuse changes in Beressa watershed (Ethiopia) between 1957 and 2000 (after Aklilu Amsalu et al. 2006)

Land use	1957	1984	2000
Natural forest	14.8	6.8	2.4
Cropland	54.8	56.6	60.6
Grazing land	8.5	18.7	11.6
Forest plantation	1.8	1.2	10.6
Bare	16.3	12.8	8.0

in the 36,400 ha watershed, which is evidence that the deforestation trend has been reduced and even partly reversed in the area.

Selamyihun Kidanu and Tekalign Mamo (2005) studied changes in land use and the associated incidence of gully erosion in the past 35 years at Ginchi watershed in the central highlands of Ethiopia. Their results reveal that 81 % of cropland in the base year was still cropland in 1994, while 17 % had been reconverted to grassland. Of the total grassland in the base year, only 33 % was still under grass in 1994, while 63 % had been converted into cropland.

Aklilu Amsalu et al. (2006) studied the dynamics of land resource use in the Beressa watershed (Ethiopia) in a 40–year period in the second half of the 20th century. The natural vegetation cover here has been extensively cleared, although most of the cleared areas have since been replaced with forest plantations (Table 9.2). Grazing land has expanded remarkably at the expense of cropland and bare land. In response to perceived soil degradation, water shortage, socio-economic and policy changes, the farmers have gradually changed from annual cropping to tree planting and livestock production.

9.2.3.4
Proxy at the farm level: soil fertility

Applying a General Linear Model to 124 topsoil samples for several villages in eastern Burkina Faso and correcting for factors such as local soil type, soil texture and land use, Mazzucato and Niemeijer (2000b) found no significant differences between the villages in terms of organic matter, total nitrogen, total phosphorus and available potassium. This suggests that there is no relationship between chemical soil fertility and pressure on natural resources (Table 9.3).

DeRidder et al. (2004) re-examined soil fertility in the West African Sahel, concluding that although nutrient budgets show negative trends in nutrient reserves, these are probably overestimated because lateral inflows and outflows are scale-dependent, difficult to estimate and often ignored: 'Under farming conditions, decline in soil fertility can hardly be measured. Factors involved are inherent low soil fertility, heterogeneity of soils and highly variable soil fertility management in

Table 9.3. Changes in soil fertility between 1969 and 1996 in eastern Burkina Faso (after Mazzucato and Niemeijer 2000a)

Changes in soil fertility	C(%)	N(%)	P2O5(%)	K(meq. 100 g^{-1})
According to soil type				
– Slightly weathered soils (Entisols)	0	-	0	0
– Leached ferruginous soils (Alfisols)	+	0	0	+
– Brown tropical soils (Eutropepts)	+	0	0	0
According to land use				
– Uncultivated	0	-	0	+
– Cultivated	0	0	0	0

0 = no notable or significant change, + = higher fertility in 1996 and – = lower fertility in 1996

space and in time. However, at coarser scales, gradients in soil fertility are detected being a result of centripetal transport of organic material'.

9.2.3.5
Proxies at the point scale: erosion, soil organic matter and physical soil qualities

One drawback of using erosion as a proxy is the difficulty of determining its magnitude (Stroosnijder 2005). Four causes are often mentioned in the literature: the large temporal and spatial variation of erosion, the paucity of accurate erosion measurements, the problem of extrapolating data from small plots to higher scales, and the conversion of erosion into production and monetary units (impact). Measurement techniques differ in their accuracy, equipment and personnel costs. The most accurate (and often most expensive) techniques do not always serve the purpose. It is an illusion to think that the role of measurements can be taken over by the application of erosion prediction technology. Measurements are needed to develop, calibrate and validate that technology.

There seems to be less controversy with respect to the slow but continuous decrease in soil organic matter (SOM). Through several stages, such as shifting cultivation, fallow rotation and permanent use, humans have taken much of the land *in cultura*, i.e. into cultivation, and so the natural landscape has changed into a cultural landscape. This development (very rapid on the geological time scale), has changed the vegetation cover. In a 'cultural landscape' there is less above-ground (or 'plant') organic carbon (POC) than in a 'natural landscape'. Since POC and SOC (soil organic carbon) are correlated, when the natural landscape is transformed into a cultural landscape, the SOC will start to decrease. This gradual process will continue until SOC and POC have attained a new equilibrium.

Agricultural production in sub-Saharan Africa typically takes place in a low-input farming system: rainfed agriculture with little or no fertilisation – at best a limited input of manure from livestock, or compost from household waste. On the other hand, the consumption and utilisation of the agricultural products nowadays is virtually 100%. The grain, pulses, etc. grown are consumed by the farmers and

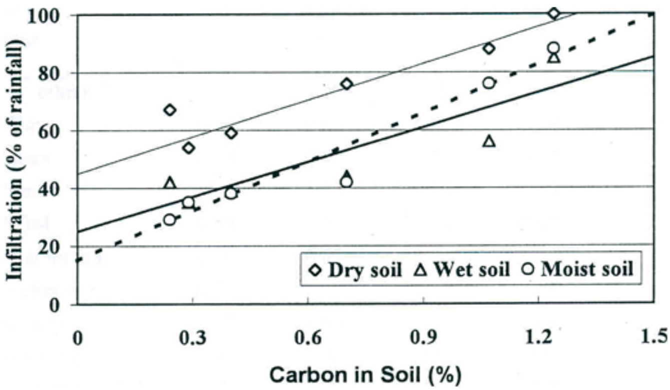


Fig. 9.2. Infiltration as percentage of rainfall for dry, moist and wet soil conditions and various carbon percentages of sandy soils in the Sahel (after Hoogmoed et al. 2000)

their families, and the straw is either used for fodder (throughout the dry season the animals browse on the fields) or as building material for roofs, fences, etc. Due to the lack of replenishment of organic material, many agro-ecological systems lose SOM at an annual rate of 2% of their reserves of SOM (Pieri 1989).

A decrease in SOM adversely affects many physical, chemical and biological soil characteristics. Figure 9.2 shows an example: the decrease in infiltration resulting from decreasing SOM.

9.2.4 Two conundrums

The above presents us with two interesting conundrums: (1) How is it possible that at the larger scale, soil physicists show proof of soil degradation while at lower scales there is no proof of land degradation? and (2) If, inspite of significant scientific evidence, land degradation has been ongoing for decades, how could the people living off that land have survived?

An explanation of the first conundrum lies in the way the natural mosaic of soil surface states is aggregated into land, catena and the landscape. In addition to degraded spots, there are always less degraded places, yet these are often less measured in degradation studies, causing an inherent bias. These latter points gain from runon of water and nutrients, seeds and organic debris, creating so-called islands of fertility. If we aggregate point information into higher scales we generalise the mosaic of such points. Thus, averaging or compensation leads to less and less convincing evidence of land degradation at higher scales. In fact, this is similar to what is already known from scaling runoff and sediment generation (e.g. the sediment delivery ratio). The runoff from a 1 m^2 plot may be 50% of rainfall, but at the bottom of a hill slope one may measure only half of this amount and at the watershed outlet the runoff may have fallen to only one-tenth of its original value. In other words, the severity of erosion is reduced when going from the point to the watershed scale. Our remote sensing tool with its pixel size well above the point scale does a kind of automatic averaging whose consequences we do not fully comprehend: are they real or artificial? In addition, our models are not suited for aggregating mosaic information that has high variation at scales of 1 m. Besides, the data is lacking for such models (Fleskens and Stroosnijder 2007). This makes it difficult to upscale and downscale !

The answer to the second conundrum was formulated by Mazzucato and Niemeijer (2001,) who state that a major reason for the overestimation of land degradation has been the underestimation of the abilities of local farmers. It is clear that farmers in sub-Saharan Africa have not survived by following a capital-intensive development route. This suggests that they have somehow been able to adjust their land management practices to the increased population density in an environmentally sustainable way. There is much more to soil and water conservation and technological intensification than agricultural statistics reveal. The sub-Saharan farmers have a large repertoire of technologies to draw from. They have developed flexible, efficient, and effective land management strategies to deal with the limited availability of labour and external inputs, as well as the harsh environment in which they work. What is more, they have been able to adapt. The indifference of many Sahelian farmers to high rates of soil loss may reflect their awareness that erosion does not seriously damage productivity in the short term.

9.3 Rainfall analysis for land degradation assessment

In order to study land degradation at multiple scales it is necessary to study rainfall at multiple scales too. Rainfall can be analysed for land degradation at four different scales: from the 'small' annual scale to the 'large' minute scale. Each scale has its specific application(s). Besides scales, one may also distinguish between average values and temporal and spatial variations. A few examples of rainfall data for each of the scales are presented below and interpreted with respect to land degradation.

9.3.1 Applications of the annual scale: trends and probabilities

Trends of annual rainfall are used to assess changes in rainfall that affect land degradation mainly through changes in vegetation cover. Conway et al. (2004), analysing 100 years of rainfall in Addis Ababa, conclude that there was no major shift or trend in annual and seasonal rainfall during the period 1898–2002. Well-known drought years in northern and northeastern Ethiopia are not picked out in the Addis Ababa rainfall record, suggesting that the series should not be used as a proxy for inter-annual rainfall variability in these parts of the Ethiopian highlands.

Niemeijer and Mazzucato (2001) averaged the annual rainfall of the 16 major stations in Burkina Faso with a long-term record. The result is shown in Figure 9.3. There is no trend if a period of 80 years (1920–2000) is considered. Within this period, however, there is a period of almost 40 years (1950–1990) with a steady downward trend. Annual rainfall decreased by about 400 mm over this period: from

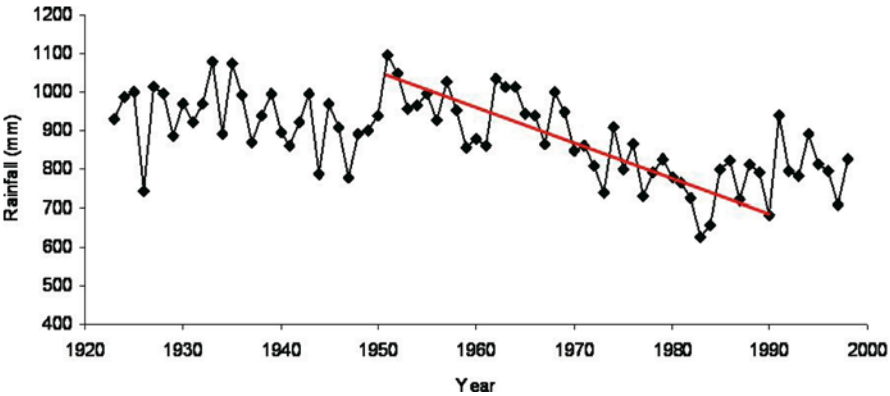


Fig. 9.3. Average annual rainfall for 16 major rain stations in Burkina Faso (1923–1998)

1100 to 700 mm, a decrease of almost 40% (regression line in Figure 9.3). For local farmers and pastoralists such a decline is very real and affects their daily livelihoods significantly.

The mean annual rainfall at Sakarani Mission (West Usambara Mountains, Tanzania) from 1928 to 2000) was 1070 mm and ranged from 441 mm y^{-1} to 1772 mm y^{-1} (Vigiak, pers. com.). The median value was 1035 mm y^{-1}, whereas a dry year (10% probability of non-exceedance) was 760 mm y^{-1} and a wet year (90% probability of non-exceedance) was 1420 mm y^{-1}. During the period of observation, a trend towards a reduction of total rainfall was visible, notwithstanding the high scatter among the years: the mean annual rainfall from 1928 to 1948 was 1270 mm, whereas from 1980 to 2000 it was 931 mm.

A similar pattern was observed by Ayoub (1999) studying long-term rainfall in Sudan: he found a decline of 30–40 %. Aklilu Amsalu et al. (2006), however, studied rainfall dynamics in the Beressa watershed, Ethiopia from 1954–2003 and found that though contrary to farmers' perceptions, the long-term rainfall pattern there has improved.

Another application of data on annual rainfall is to perform a statistical analysis to find rainfall probabilities, as done by Hoogmoed and Stroosnijder (1984). Variation in annual rainfall can be analysed to identify 'normal' (50% probability), 'dry' (90% probability of exceedance) and 'wet' (10% probability of exceedance) years: this approach is used for modelling land use scenarios (Stroosnijder 1996).

9.3.2 Application of the decadal scale: length of the growing season

The decadal (10-day) scale is mainly used by agronomists for plant growth, e.g. to calculate the length of the growing season(s). Hoogmoed and Stroosnijder (1984) give averages for decadal rainfall for a 'normal' and a 'dry' year for Niono in Mali (14^0 15' N) at the southern edge of the millet-growing area of the Sahel (Figure 9.4). The 50% and 90% probability values for Niono are respectively 470 and 290 mm y^{-1}.

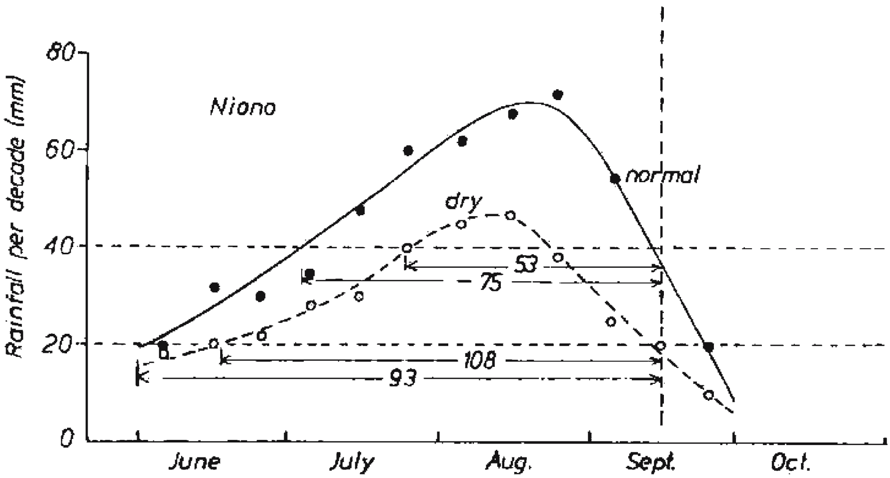


Fig. 9.4. Decadal rainfall at Niono (Mali) for a normal (p=50%) and a dry (p=90%) year

The 'normal' year curve is the average over 1957, 1959, 1962 and 1975. These years had their total rainfall in the period July–September closest to the 50% probability value of a series of 30 years (1950–1980). In the 'dry' years 1966, 1972, 1973 and 1974 the rainfall in the same period was closest to the 90% probability values.

Figure 9.4 shows how long the growing season will be if a minimum precipitation is set per 10-day period. For instance, if the lower limit is set at 40 mm $10d^{-1}$, the amount necessary to trigger growth if one accounts for 50% runoff (Stroosnijder and Hoogmoed 1984), the period up to 15 September (general flowering date due to photoperiod) will be 75 days for a 'normal' year and 53 days for a 'dry' year. However, if a lower limit of 20 mm $10d^{-1}$ is set, an amount sufficient for growth if runoff is nil, this period will be 108 days for a 'normal' year and 93 days for a 'dry' year.

In that study, it was demonstrated that rainfall distribution over the growing season in the southern part of the Sahel is such that millet cropping should be possible. However, given that the growing cycle of millet must be of a minimum length in order to obtain a reasonable grain harvest, it is important that crop growth starts as early as possible. Often, sowing is possible only in wet soil, since dry soil is too hard to till. Moreover, rainfall may be so erratic that there is a considerable risk that insufficient water will be stored in the soil to keep the young plants alive in the early season and therefore fields have to be resown. If runoff losses could be decreased or avoided, the risk of the young crop exhausting the water reserves in the soil would also decrease.

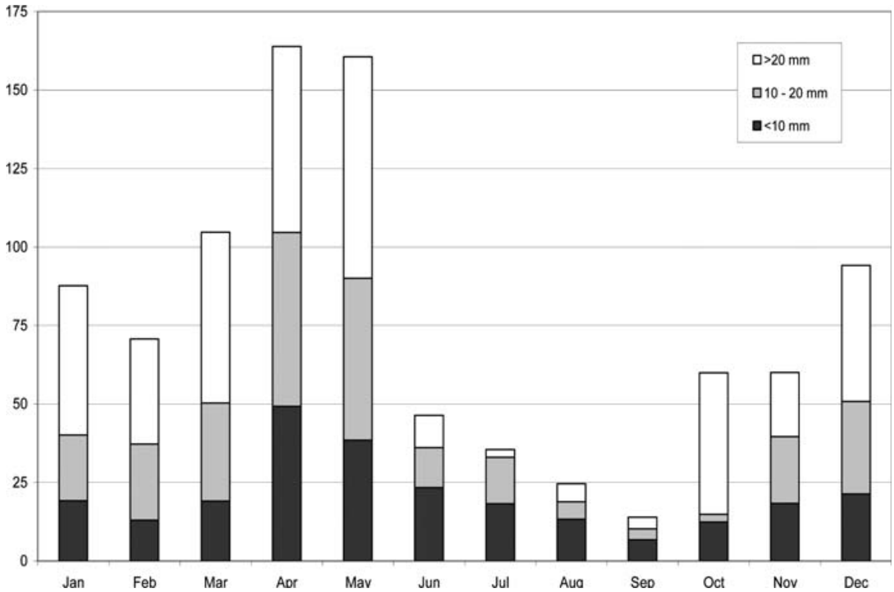


Fig. 9.5. Monthly rainfall of Sakarani Mission (West Usambara Moun-tains, Tanzania) divided over three size classes; < 10 mm, 10–20 mm and > 20 mm

9.3.3
Applications of the diurnal scale: classes of showers (threshold values), return period, dry spell analysis and agronomic and hydrological modelling with time steps of one day

To characterise the rainfall event pattern of Kwalei catchment, the diurnal rainfall totals measured at Sakarani Mission from September 1991 to August 2001 were analysed. Rainfall events were grouped in three classes: rainfall less than 10 mm, between 10 and 20 mm, and more than 20 mm. These classes reflected the probability of overland flow generation, which was considered unlikely for rain events of less than 10 mm in 24h. In the ten years of observation, 66% of events were less than 10 mm, 22% were between 10 and 20 mm and only 12% were above 20 mm. However, in terms of rainfall volume, events of less than 10 mm contributed 27% of the total rainfall, events between 10 and 20 mm contributed 30% and events larger than 20 mm contributed 43% of the total rainfall.

Figure 9.5 shows the composition of rainfall event per month and per rainfall volume per year for Sakarani. Both in terms of number and in terms of rainfall volume, rainfall events larger than 20 mm per 24h were frequent at the beginning of the long rainy season, in March, and during the short rainy season, especially in October, December and January. In these periods of the year, intense rainstorms that may generate overland flow are more likely to occur. During the months of April and May, however, the important contribution of events with less rainfall may affect the soil moisture conditions prior to the rainfall event, therefore increasing the chance of overland flow being generated by both infiltration excess and saturation excess.

In 4 years of observation (1976–1979), Hoogmoed and Stroosnijder (1984) collected similar figures: showers < 10 mm contributed 21 % to the total rainfall, showers 10–20 mm 27 % and the bigger showers > 20 mm contributed the most – 52%!

9.3.3.1
Return period

The maximum 24h events per month of the Kwalei rainfall from September 1991 to August 2001 were analysed with Gumbel's probability distribution, to assess the return period of 24h rainfall. The Gumbel's distribution of the 117 observations resulted in the following equation:

$$Xb = 16.32. (-\ln(-\ln k)) + 15.28 \text{ (with } R^2 = 0.95) \tag{1}$$

Where, Xb indicates the 24h event border and k the probability of non-exceedance.

Using this equation, the 'design' rainfall for a 25- year return period is 67 mm. Notwithstanding the good regression coefficient, the uncertainty increases for high values of rainfall. For example, according to this distribution, the event of 21 October 1997 (120 mm) would occur once every 600 years. From this it is clear that care should be taken when extrapolated return periods.

9.3.3.2
Dry spell analysis

The success or failure of a crop depends more on the distribution of rainfall over the growing season than on the total rainfall in that period (Sivakumar 1991). A method to characterise the 'goodness' of this distribution is an analysis of the probability of dry spells. In meteorological analysis (using Markov chain methods) a dry spell is a period without effective rain. In agricultural terms (using a water balance model) a dry spell is a period with consecutive dry days resulting in a soil water deficit causing crop water stress (Barron 2004). Meteorological analysis either over- or underestimates agricultural dry spell analysis, depending on the soil's waterholding capacity. Barron et al. (2003) consider a dry spell between 5–15 days to be harmful for sub-Saharan Africa. In Kenya and Tanzania, a 10-day dry spell has the potential to damage a maize crop due to water deficit.

9.3.3.3
Agronomic and hydrological modelling with time steps of one day

In agronomic modelling, the growth of a crop is often simulated using daily weather data (Stroosnijder and Kiepe 1998). The soil water, distributed over multiple soil layers is extracted by the plant roots, the driving force being the difference between the water potentials of the soil and the foliage. This allows the effect of land degradation on crop yield to be estimated precisely.

In hydrological modelling one must specify what proportion of the daily rainfall infiltrates into the soil. This depends on the physical conditions at the soil surface (Sheikh et al. 2007). Degraded soils are often topped with a crust that hampers infiltration (Hoogmoed and Stroosnijder 1984). Tilling such soils will break the crust and improve infiltration. No-till, often advocated to combat land degradation, is not a viable option for such soils. Stroosnijder et al. (1994) calculated runoff during 35 growing seasons (1950–1984) for a millet crop in Mali under no-till and conservation tillage (CT, i.e. regular crust-breaking) conditions. Fig. 9.6 shows that for no-till the average runoff was 36.5 % of rainfall (SD = 3.4 %) while CT reduced runoff to 25.6 % (SD = 4.8 %). The difference is equivalent to 37 mm of available water.

9.3.4 Application of the minute scale: rainfall erosivity

With rainfall data at the 'minute' scale one may use the rainfall intensity for a detailed analysis of rainfall as a land degradation factor. The erosive power of rainfall can be expressed as an index. Wischmeier and Smith (1978) found that soil erosion

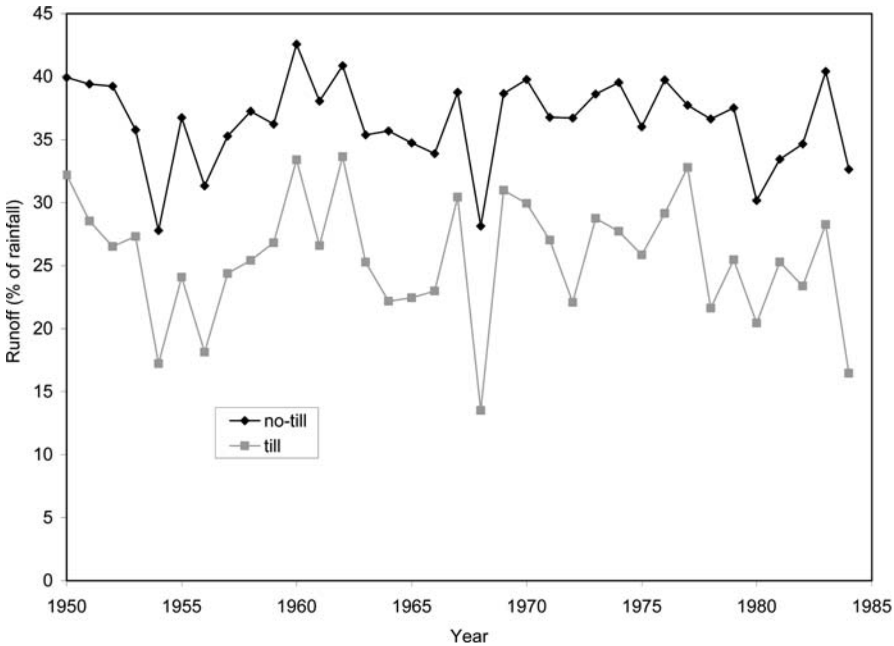


Fig. 9.6. Calculated runoff during 35 growing seasons (1950–1984) for a millet crop in Mali under no-till and conservation tillage (After Stroosnijder et al. 1994)

by water (rill + interrill) correlates best with the kinetic energy of the rain, multiplied by the maximum 30-minute intensity. Various formulas are available for calculating the kinetic energy of rainfall with help of the rainfall intensity. A review is given by VanDijk et al. (2002) who propose using KE = 0.283 (1 – 0.52 * e-0.042 * I) with KE in MJ ha^{-1} mm^{-1} and I in mm h^{-1}. For I > 50 mm h^{-1}, all KE = formulas level off to 0.30 MJ ha^{-1} mm^{-1}. It is commonly accepted that showers with intensity less than 10 mm $h^{-1}$are not erosive.

A study of the spatial and temporal distribution of rainfall characteristics in La Encañada watershed in north Peru from 1995 to 2000 revealed that in the neutral years (9/95–3/96 and 9/96–3/97) mean annual rainfall was < 600 mm (Romero et al. 2006). However, during El Niño (9/97–3/98) and La Niña (9/98–3/99 and 9/99–3/00) years, the annual total increased, the maximum being 1200 mm. In general, rainfall intensities were very low, with 96 % of events < 7.5 mm h^{-1}. But during the El Niño year, the number of high intensity events increased in the lower part of the watershed (18%) where normally only 4 % of events were high intensity. The La Niña year was characterised by a large rainfall total, but lower intensities.

An erosivity analysis showed (Table 9.4) that in the lower part of the watershed, rain events are more erosive, especially during abnormal years such as El Niño. Depending on the year, some spatial variation was observable in the amount of rainfall falling at different altitudes. This variation seems to be related to the topography and to phenomena like El Niño/La Niña that affect wind circulation and the convective movement of air masses. Areas at risk of erosive events can be identified within the watershed, although the response of soils depends not only on rainfall erosivity but on many other factors such as soil type, slope and vegetation.

Table 9.4. Examples of kinetic energy and EI30 indexes for two-hour rainfall events in Peru.

Location Altitude	La Toma 3590 metres a.s.l.		Usnio 3260 metres a.s.l.		Manzanas 3020 metres a.s.l.	
Interval(min)	Intensity (mm h^{-1})	Δ EJ m^{-2}	Intensity (mm h^{-1})	Δ EJ m^{-2}	Intensity (mm h^{-1})	Δ EJ m^{-2}
30	1.2	7.5	2.0	14.5	0.2	0.6
30	0.6	2.9	0.5	2.3	2.8	22.1
30	1.4	9.2	0.3	1.1	1.0	5.9
30	0.2	0.6	0.8	4.4	4.4	38.5
Total E (J m^{-2})	20.3		22.31		67.1	
Max.30-min rainfall	1.4		2.0		4.4	
EI30 (J mm $m^{-2}h^{-1}$)	20.3 x 1.4 = 29.13		22.3 x 2 = 44.6		67.1 x 4.4 = 295.1	

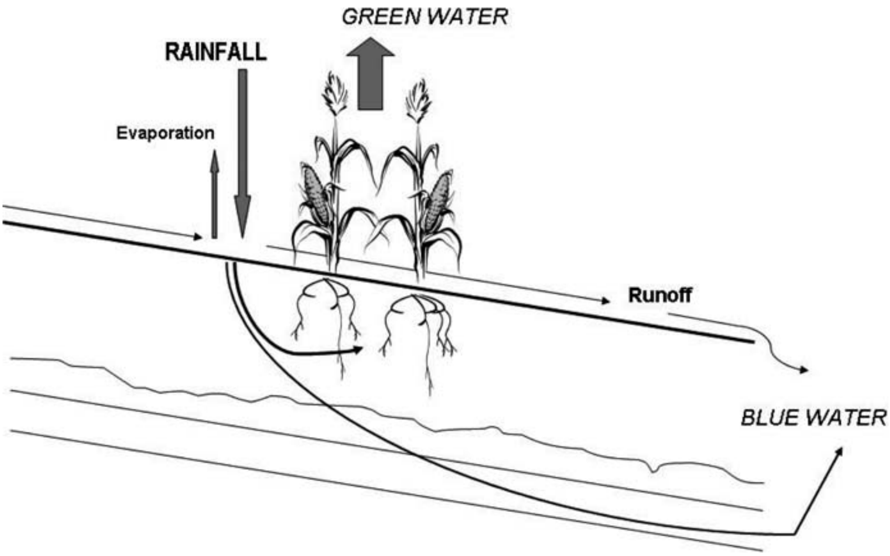


Fig. 9.7. The water stored in the soil and used by plants is green water. Runoff and deep drainage, recharging the groundwater and feeding streams, is blue water. (After Falkenmark and Rockstrom 2004)

9.4 The rain water balance

Rainfall meets the land at the soil surface. The rainfall is divided over several hydrological compartments (Fig. 9.7)

In section 9.1, it was argued that the farmers' perception of drought can be explained as a perception of a lack of available water due to deteriorated soil physical properties like soil depth and waterholding capacity. After testing a number of indices of agricultural drought, Keyantash and Dracup (2002) concluded that the 'computed soil moisture' performed best according to six weighted selection criteria. In this section "computation of soil moisture" will be demonstrated. As land degradation (of which soil erosion is the major cause) decreases infiltration, waterholding capacity and transpiration and enhances runoff and soil evaporation (Stroosnijder 1992), special attention will be given to estimating the effect of land degradation on 'computing soil moisture'.

9.4.1 The field water balance

Rain falling on the land may be intercepted by vegetation, run off the ground surface, or infiltrate into the soil. This is reflected in the field water balance (Stroosnijder and Kone 1982):

$$P = INT + I + R \tag{2}$$

where,
P = rainfall (mm)
INT = interception of rain by vegetation (mm)
I = infiltration (mm) and
R = runoff (mm).

It is generally, assumed that runoff is lost from the field, giving notion to the terms on-site and off-site water. Interception is between 0 and 5 mm. Infiltration depends on the duration of a shower (h) and the soil's infiltration capacity (IR in mm h^{-1}). The latter depends on soil type, soil characteristic, soil surface condition and moisture content. When soils are dry, the IR is high; the IR decreases with time of wetting until it achieves a constant rate, called the terminal rate or final IR. This final-IR value is high (> 50 mm h^{-1}) for sand and low (< 10 mm h^{-1}) for clay (see e.g. Morgan 2005). IR may also be low due to the swelling of clay soils. It will also be reduced if due to land degradation the soils are losing soil organic matter and, as shown by Hoogmoed and Stroosnijder (1984), may be severely reduced if the soil has a crust (due to land degradation). If the surface crust has low infiltrability, the annual runoff on deep coarse soils may even be as much as 13 % (Rockström and Valentin 1997).

9.4.2 The infiltration water balance

Infiltrating water may be stored (S in mm) in the root zone or drain (D in mm) below the root zone to groundwater and stream base flow, contributing to what is nowadays called 'blue water'. These processes are reflected in the infiltration water balance:

$$I = \Delta S + D \tag{3}$$

where, ΔS (positive value) is the change in the amount of water stored in the root zone (mm) and D the drainage below the root zone (mm).

During wetting by rain, the moisture content of root zone may become close to saturation. In the next 24 h, however, the moisture content will fall as the water drains to below the root zone. This process stops when the soil water potential has reached a value that is called (for obvious reasons) the field capacity (FC). The soil water potential is then between -10 kPa (pF 2.0) and -33 kPa (pF 2.5).

9.4.3
The soil water balance

Water stored in the root zone may be lost (negative value of ΔS) as evaporation from the soil surface into the atmosphere (E) or taken up by plants and lost as transpiration (T). This is reflected in the soil water balance:

$$\Delta S = E + T \tag{4}$$

The evaporation rate (mm d^{-1}) depends on the moisture content of the topsoil, the drying power of the atmosphere and to what degree the plants shade the soil. A proxy for the latter is the Leaf Area Index (LAI). Stroosnijder (1987) developed and validated a simple equation for E under semi-arid conditions. As a parametric approximation for crops with an LAI < 1, E can be estimated as 2 mm d^{-1} during the short growing season (of about 100 d) under semi-arid conditions.

Plants in semi-arid regions are often able to produce with little water. An example is millet grown in West Africa. The grain harvest is about 500 kg dry matter (DM) ha^{-1}, straw and roots are each 1000 kg DM ha^{-1}. Hence total dry matter is 2,500 kg DM ha^{-1}. Millet has a C4 photosynthesis mechanism, so uses water rather efficiently. The transpiration coefficient is 200 kg water per kg DM. The total crop then consumes 2500 * 200 = 500 000 kg water ha^{-1}. This is only 50 mm ha^{-1}. It often happens that with a growing season of 100 d, E equals 200 mm and T only 50 mm. This reflects the very inefficient use of precipitation.

9.4.4
Stored and available water

According to Stroosnijder (1982), the maximum amount of water stored in the root zone available for plant growth (i.e. that plant roots can extract from the soil) is a very important soil characteristic because it determines the potential survival of plants under a dry spell (i.e. periods of consecutive days without effective rain). The Total Available Water (TAW) in the rootable part of the soil profile is:

$$TAW = RD * 0.9(FC - WP) \tag{5}$$

where, RD is the rootable depth (mm) WP is the wilting point, i.e. the moisture content if the water potential equals -1.6 MPa (pF 4.2).

Plants in soil at WP will die, hence the safety factor of 0.9. For example, in a non-degraded soil with average physical properties, the root zone soil depth may be 600 mm and (FC-WP) = 0.13. Hence TAW = 70 mm. With an actual evapotranspiration (ET) of 2.5 mm d^{-1} (E = 2 + T = 0.5) this implies that the reserves of water for a crop as described above are sufficient for a dry spell of 28 days or 4 weeks! Of course, this is only the case if the soil moisture content was fully replenished at the start of the dry spell.

In a degraded soil, the root zone soil depth is often reduced because the topsoil has been removed by erosion. Also, the soil texture has become coarser due to selective removal of the finer particles and the structure has degraded due to the decrease of soil organic matter. In the above example this leads to a root zone soil depth of only 400 mm and an FC-WP of only 0.10. This implies that TAW is only 36 mm – sufficient for only 14 days or 2 weeks! This change in the length of the dry spell that plants can overcome is what farmers mean when they speak of a 'drought' problem.

9.4.5 Farmers' perception of drought

During recent research on Soil and Water Conservation (SWC) in the Sahel (Stroosnijder and VanRheenen 2001), Kenya (Biamah 2005), Ethiopia (Tesfaye Beshah 2003) and Tanzania (Hella and Slegers 2006), farmers mentioned drought as one of the main reasons for a decrease in land productivity. Farmers' perception of drought is strongly influenced by and varies according to local environmental conditions and even between individual farmers in the same village, depending on the characteristics of their own fields. This implies that for farmers the concept of drought is contextual (Slegers et al. 2005). Recently it has even been proposed that drought must be considered as a social construction. McMahon and Finlayson (2003), for instance, state that "droughts are not easily defined other than by culturally driven judgements about the extent and nature of impact".

Farmers relate their notion of drought mainly to the occurrence of dry spells. In several recent studies, little evidence has been presented of an increase in the length and/or frequency of dry spells. Using daily rainfall from 11 key stations for 1965–2002, Seleshi and Camberlin (2006), found no trends in the yearly maximum length of Kiremt and Belg dry spells over Ethiopia. Similar conclusions were drawn by Mazzucato and Niemeyer (2002), Conway et al. (2004) and Romero et al. (2007). We must therefore look for another explanation for why farmers perceive dry spells to be more harmful nowadays than previously. I would argue that they perceive a lack of available water due to deteriorated soil physical properties like soil depth and waterholding capacity.

9.4.6 Green water use efficiency (GWUE)

Green water is that part of rainfall that is stored in the soil and available to plants. Infiltrating water may be held in the soil – green water (Ringersma et al. 2003) – or drain to groundwater and stream base flow (Figure 9.7). In transforming a 'natural' landscape into a 'cultural landscape' all physical, chemical and biological soil properties change and affect the field water balance directly and indirectly (Stroosnijder 1996). Food crops, for instance, cover the soil for only part of the year and therefore use less water for transpiration than the 'natural' vegetation that covers the soil permanently. The surplus water either percolates through the soil down to the groundwater (creating higher water tables) or flows over the soil surface as overland flow in sheet flow or in rills, creating new drainage ways (gullies) with inherent erosion.

GWUE not only decreases due to land cover changes but also due to deterioration of physical soil qualities as a result of land degradation (mostly the result of a decrease of soil organic matter). Rain that hits bare soil causes soil aggregates to break up. Due to this surface crusting, only a small proportion of rainwater can infiltrate the soil; most of it runs off over the soil surface and is therefore lost for biomass production. In a complex combination of both direct and indirect soil physical/hydrological processes, the proportion of the rain that is effectively used by vegetation decreases and the proportion that discharges increases. Pimentel (2006) considers the lower water availability due to land degradation and soil erosion to be a major global food and environmental threat.

There are many ways of defining water use efficiency (WUE). Precipitation Use Efficiency (PUE) is defined as the yield divided by the precipitation (possibly corrected for differences in stored water between subsequent years: ΔS). PUE is expressed in kg ha^{-1} mm^{-1} and ranges from 4 (low) to 10 (improved). PUE is particular useful in agricultural systems with a distinctive harvestable yield. However, in more general discussion of 'ecosystems' and in relation to the issue of regreening (and related carbon sequestration in soils), what matters is the total amount of biomass produced (Stroosnijder and Hoogmoed 2004). For given species and location there is a good correlation between the amount of biomass produced and the amount of water transpired. Therefore, in terms of water use efficiency it is of more relevance to use the concept of Green Water Use Efficiency (GWUE), expressed as the fraction Transpiration / Precipitation. In dryland systems in sub-Saharan Africa the GWUE ranges from 5–15 %. In East Africa it may reach 20 %, but in semi-arid but comparable climates in the USA it may exceed 50 %.

9.5 Dry spell mitigation and GWUE improvement

The goal of GWUE improvement is to maximise the productive flow of water as plant transpiration and to minimise the non-productive water flows, including soil evaporation, runoff and percolation beyond the root zone. *In-situ* water conservation and on-farm water harvesting have been advocated and practised (40,000 farm ponds have been created in northern Ethiopia alone in the last 2 years) but what is often missing is sufficient attention to the efficient use of that saved water.

How can the efficiency of rain water use be improved? According to Eq. (2), one should increase I or, to achieve the same effect, reduce R. This is known as in-situ water conservation. If increasing I is not feasible or dangerous (e.g. landslide risk) one must safely dispose of excess water through drainage. Given that our aim is to increase the efficiency of rainwater use, this drainage water should be stored for later use.

According to Eq. (3) one may also increase S (or TAW) and reduce D. According to Eq. (5) this may be achieved by improving FC-WP. Finally, according to Eq. (4)

the last option is to reduce E so that more of ΔS remains available for T. The commonest method is to mulch (Mando and Stroosnijder 1999).

A variety of land management practices contribute to the improvement of GWUE. Examples are given in Table 9.5. Practices can also be classified as area practices where the practice is applied over the entire area of a farmer's field and as line practices where only part of the field (usually along the contours) is treated (Table 9.5). All these practices store and use water on-site, i.e. within the field. Water can also be harvested from fields and stored off-site, i.e. outside the field (Stroosnijder 2007).

9.6 Conclusions and recommendations

9.6.1 Conclusions

The general outcome of this review is that it remains difficult to find proof of widespread land degradation, especially at regional, watershed and farm scale. Vegetation and vegetation cover closely follows rainfall, and African terrestrial ecosystems have proven to be more resilient than was previously thought. At the point scale, however, it seems that physical soil characteristics are deteriorating. This has consequences at the soil surface where rainfall and land meet and the rain is divided over several pedo-hydrological components. The inherent poor quality of most African soils is probably one reason for the current low green water use efficiency, i.e. the low fraction of rainfall used in transpiration leading to biomass production.

Rainfall analysis at multiple scales has also revealed great variability, but not yet a consistent trend in connection with climate change. However, further deterioration of soil characteristics will affect the amount of water that can be stored in the root zone and drawn on to overcome dry spells. Farmers' concerns about drought turn out to be a problem of how to cope with dry spells, as there is little evidence for a significant increase in the length or frequency of such spells. It appears that soils have changed and are less capable of providing crops with water during the dry spells that are so characteristic of African semi-arid areas.

From the above one may derive the following conclusions:

- *Trends in Land Degradation.* We should critically examine the 'hard evidence' from remote sensing, models and measurements, remembering that trends in land degradation are assessed differently in various parts of the world. Classical methods easily lead to doom conclusions but newer methods give a more moderate picture of land degradation.
- *Land Degradation Definition.* There is a need to adjust current definitions of land degradation and desertification in light of new scientific insights like: (1) the concept of ecosystem services, (2) the need to distinguish between land degradation and 'land development' as a consequence of economic development and (3) the contextualisation of land degradation.

Table 9.5. Land management practices and their effect on runoff, TAW and GWUE.

	Reduce Runoff Eq. 1	Improve TAW Eq. 2	Improve GWUE Eq. 4	References
On-site: Area practice				
Mulch	x	x	x	Konig 1992; Mando 1997
Stimulating soil fauna	x		x	Mando 1997; Ouedraogo et al. 2007
Conservation tillage	x	x	x	Hoogmoed 1999; Biamah et al. 2003
Crust breaking	x			Stroosnijder et al. 1994
Organic amendments	x	x		Biamah et al. 2003; Ouedraogo 2004
Water-nutrient synergy			x	Zougmore et al. 2003.
Exclosure	x		x	Descheemaeker et al. 2006
On-site: Line practice				
Hedgerows	x	x	x	Kiepe 1995
Stone rows	x			Azene Bekele Tesemma 1997; Zougmore 2003; Nyssen et al. 2006
Vegetation barriers	x	x	x	Spaan 2003
Trees			x	Azene Bekele Tesemma 1997; Selamyihun Kidanu et al. 2004
Terraces	x			Posthumus and Stroosnijder 2006
Off-site				
Water Harvesting			x	Selamyihun Kidanu 2004: Fleskens et al. 2005; Barron et al. 2007

- *Ecosytem Behaviour.* Vegetation follows rainfall. In sub-Saharan Africa the dynamics of rainfall are related to the combined effect of the North Atlantic Oscillation (NAO) and the El Niño Southern Oscillation (ENSO) (Oba et al. 2001). The authors were able to attribute 75% of inter-annual rainfall variation to that effect. Since NAO and ENSO can now be predicted more accurately, it should be possible to warn farmers to modify their farm management. Natural ecosystems are adapted to the magnitude and frequency of dry periods and these periods are crucial for the long-term functioning of such systems.

- *Green Water Use Efficiency.* Africa's green water use efficiency is very low.
- *Data Availability.* Researchers are finding it increasingly difficult to obtain rainfall data from public organisations without having to pay a (sometimes exorbitant) fee. Some data are available on the Internet, but how reliable are they?
- *Help Farmers.* There is a cornucopia of land management practices and policies that have merits under a certain combination of local circumstances but that fail in other settings. So, the problem is what advice can be given to the already knowledgeable farmers.

9.6.2 Recommendations

The above conclusions lead to the following recommendations:

- *Trends in Land Degradation.* There is a need to agree on a set of 'standard' scales with appropriate proxies for land degradation assessment. The monitoring of land degradation and of weather at these scales must be improved. Model studies should be combined with empirical studies at farm and village level.
- *Land Degradation Definition.* UNCCD, UNEP, GEF and many of the other organisations involved should not hesitate to adjust current definitions of land degradation and desertification. Research and teaching have become too monodisciplinary. Very few professionals have an overview of the complexity of land management. What is needed are interdisciplinary approaches in research and teaching.
- *Ecosytem Behaviour.* There is a need to strengthen the study of thresholds, resilience and dynamic equilibriums of terrestrial ecosystems in order to better understand, predict and value the dangers of land degradation.
- *Green Water Use Efficiency.* Land management practices in Africa should focus on improving the proportion of rainfall that is used in biomass production. Invest in such improvement by introducing a system of conservation credits.
- *Data Availability.* Make the available data more accessible. WMO should continue to strive for free access to meteorological data.
- *Help Farmers.* African farmers have a good record of adapting their land management systems. This should not be ignored and efforts should be made to build on this record. A selection of best management options that would give sufficient benefits with respect to costs should be offered to farmers. There is a need to develop a cost-effective system for communicating early climate warnings to farmers so that they can modify their land management.

References

Aklilu A, Stroosnijder L, DeGraaff J (2006) Long-term dynamics in land resource use and the driving forces in the Beressa watershed, highlands of Ethiopia. J Environ Manage *(in press)*

Ayoub AT (1999) Land degradation, rainfall variability and food production in the Sahelian zone of the Sudan. Land Degrad Dev 10:489-500

Azene Bekele Tesemma (1997) A participatory agroforestry approach for soil and water conservation in Ethiopia. Doctoral thesis Wageningen University, The Netherlands

Barron J (2004) Dry spell mitigation to upgrade semi-arid rainfed agriculture: Water harvesting and soil nutrient management for smallholder maize cultivation in Machakos, Kenya. Doctoral thesis Stockholm University, Sweden

Barron J, Rockstrom J, Gichuki F, Hatibu N (2003) Dry spell analysis and maize yields for two semi-arid locations in east Africa. Agric For Meteorol 117:23-37

Barron J, Rockstrom J, Stroosnijder L (2007) Modelling on-farm water balance effects of water harvesting for Zea Mays in semi-arid Kenya. Agric Water Manage (submitted)

Benjaminsen TA (2001) The population–agriculture–environment nexus in the Malian cotton zone. Global Environ Chang 11:283-295

Biamah EK (2005) Coping with drought: options for soil and water management in semi-arid Kenya. Doctoral thesis Wageningen University, The Netherlands

Biamah EK, Sterk G, Stroosnijder L (2003) Hydrological effects of tillage and farmyard manure on crusting and compacting soils in semi arid Kenya. In: Tullberg J, Hoogmoed WB (Eds.) Soil management for sustainability, Proceedings of 16th International Soil Tillage Research Conference. The University of Queensland, Brisbane, Australia

Biot Y, Blaikie PM, Jackson C, Palmer-Jones R (1995) Rethinking research on land degradation in developing countries. World Bank Discussion Papers No. 289, World Bank,Washington, D.C., USA

Blaikie P, Brookfield H (1987) Land degradation and society. London: Methuen & Co. Ltd

Chang P, Fang Y, Saravanan R, Ji L, Seidel H (2006) The cause of the fragile relationship between the Pacific El Niño and the Atlantic Niño. Nature 443:324-328

Conway D, Mould C, Woldeamlak Bewket (2004) Over one century of rainfall and temperature observations in Addis Ababa, Ethiopia. Int J Climatol 24:77-91

Crosson P (1997) Will erosion threaten agricultural productivity? Environment 39:4-8

DeRidder N, Breman H, VanKeulen H, Stomph TJ (2004) Revisiting a 'cure against land under': soil fertility management and farming systems dynamics in the West African Sahel. Agric Syst 80:109-131

Descheemaeker K, Nyssen J, Rossi J, Poesen J, Mitiku Haile, Moeyersons J, Deckers J (2006) Sediment deposition and pedogenesis in exclosures in the Tigray Highlands, Ethiopia. Geoderma 132:291-314

Fairhead J, Leach M (1996) Misreading the African landscape: Society and ecology in a forest–savanna mosaic. Cambridge University Press, UK

Fairhead J, Leach M (1998) Reframing deforestation: Global analysis and local realities: Studies in West Africa. London: Routledge

FAO (2000) The challenges of sustainable forestry development in Africa: Twenty-first FAO regional conference for Africa, Yaounde, Cameroon. Food and Agriculture Organization, Rome, Italy

Falkenmark M, Rockström J (2004) Balancing water for humans and nature: the new approach in ecohydrology. Earthscan, London

Fleskens L, Stroosnijder L, Ouessar M, DeGraaff J (2005) Evaluation of on-site impact of water harvesting in southern Tunisia. Journal of Arid Environments 62:613-630

Fleskens L, Stroosnijder L (2007) Is soil erosion in olive orchards as bad as often claimed? Geoderma (submitted)

Fresco LO, Kroonenberg SB (1992) Time and spatial scales in ecological sustainability. Land Use Policy 9:155-168

Hein L, DeRidder N (2006) Desertification in the Sahel: a reinterpretation. Global Change Biol 12:751-758

Hella J, Slegers MFW (2006) Exploring drought perceptions: missing links in prioritizing actions for improved productivity in semi-arid Tanzania. Proceedings of a seminar held at Sokoine University of Agriculture, Morogoro, Tanzania

Hoogmoed WB (1999) Tillage for soil and water conservation in the semi-arid tropics. Doctoral thesis Wageningen University, The Netherlands.

Hoogmoed WB, Stroosnijder L (1984) Crust formation on sandy soils in the Sahel; I: Rainfall and infiltration. Soil Till Res 4:5-23

Hoogmoed WB, Stroosnijder L, Posthumus H, Tammes B (2000) Effect of decreasing soil organic matter content and tillage on physical properties of sandy Sahelian soils. In: Laflen, Tian and Huang (eds.). Soil Erosion and Dryland Farming. CRC Press, Boca Raton FL, USA. pp. 191-203

Kakembo V (2001) Trends in vegetation degradation in relation to land tenure, rainfall, and population changes in Peddie district, Eastern Cape, South Africa. Environ Manage 28:39-46

Keyantash J, Dracup JA (2002) The quantification of drought: an evaluation of drought indices. B Am Meteorol Soc 83:1167-1180

Kiepe P (1995) No runoff, no soil loss: soil and water conservation in hedgerow barrier systems. Doctoral thesis Wageningen University, The Netherlands

König D, (1992) The potential of agroforestry methods for erosion control in Rwanda. Soil Technology 5:167-176

Lal R (2001) Soil degradation by erosion. Land Degrad Dev 12:519-539

Lambin EF, Turner BL, Geist HJ, Agbola SB, Angelsen A, Bruce JW, Coomes OT, Dirzo R, Fischer G, Folke C, George PS, Homewood K, Imbernon J, Leemans R, Li X, Moran EF, Mortimore M, Ramakrishnan PS, Richards JF, Skånes H, Steffen W, Stone GD, Svedin U, Veldkamp TA, Vogel C, Xu J (2001) The causes of land-use and land cover change: moving beyond the myths. Global Environ Chang 11:261-269

Leach M, Mearns R (eds) (1996) The lie of the land: Challenging received wisdom in African environmental change. James Currey/International African Institute, London

Lomborg B (2001) The skeptical environmentalist: measuring the real state of the world. Cambridge University Press

Mando A (997) The role of termites and mulch in the rehabilitation of crusted Sahelian soils. Doctoral thesis Wageningen University, The Netherlands

Mando A, Stroosnijder L (1999) The biological and physical role of mulch in the rehabilitation of crusted soil in the Sahel. Soil Use Manage 15:123-130

Mando A, Stroosnijder L, Brussaard L (1996) Effects of termites on infiltration in crusted soil. Geoderma 74:107-113

Mazzucato V, Niemeijer D (2000a) The cultural economy of soil and water conservation: Market principles and social networks in eastern Burkina Faso. Dev Change 31: 831-855

Mazzucato V, Niemeijer D (2000b) Rethinking Soil and Water Conservation in a Changing Society: a case study in Eastern Burkina Faso. Doctoral thesis Wageningen University, The Netherlands

Mazzucato V, Niemeijer D (2001) Overestimating land degradation, underestimating farmers in the Sahel. IIED, London, UK

McMahon TA, Finlayson BL (2003) Droughts and anti-droughts: the low flow hydrology of Australian rivers. Freshwater Biology 48:1147-1160.

MEA (Millennium Ecosystem Assessment) (2005) Ecosystems and Human Well-being: Desertification Synthesis. World Resources Institute, Washington, DC, USA

Morgan RPC (2005) Soil erosion and conservation (Third edition). National Soil Resources Institute. Cranfield University. Blackwell Publishing, UK

Mortimore MJ, Adams WM (1999) Working the Sahel: Environment and Society in Northern Nigeria. Routledge, London.
Nicholson S (2000) Land surface processes and Sahel climate. Rev Geophys 38:117-139
Niemeijer D, Mazzucato V (2002) Soil degradation in the West African Sahel. How serious is it? Environment 44:20-31
Nyssen J, Poesen J, Desta Gebremichael, Vancampenhout K, D'aes M, Gebremedhin Yihdego, Govers G, Leirs H, Moeyersons J, Naudts J, Nigussie Haregeweyn, Mitiku Haile, Deckers J (2006) Stone bunds for soil conservation in the northern Ethiopian highlands: Impacts on soil fertility and crop yield. Soil Tillage Res. (in press)
Oba G, Post E, Stenseth NC (2001) Sub-saharan desertification and productivity are linked to hemispheric climate variability. Global Chang Biol 7:241-246
Okoba BO (2005) Quantification of soil erosion and sedimentation using farmers' knowledge and field measurements in the highlands of East Africa. Doctoral thesis Wageningen University, The Netherlands
Oldeman LR, Hakkeling RTA, Sombroek WG (1991) World map of the status of human-induced soil degradation: An explanatory note. Second edition, International Soil Reference and Information Centre/United Nations Environment Programme, Wageningen/Nairobi
Ouédraogo E (2004) Soil quality improvement for crop production in semi-arid West Africa. Doctoral thesis Wageningen University, The Netherlands
Ouédraogo E, Stroosnijder L, Mando A, Brussaard L, Zougmore R (2007) Agroecological analysis and economic benefit of organic resources and fertiliser in till and no-till sorghum production in semi-arid West Africa. Nutr Cycl Agroecosys 77:245–256
Pieri C (1989) Fertilité des terres de savanes: Bilan de trente ans de recherche et de développement agricoles au sud du Sahara. Paris: Ministère de la Coopération et du Développement & Centre de Coopération internationale en Recherche Agronomique pour le Développement.
Pimentel D, Harvey C, Resosudarmo P, Sinclair K, Kurz D, McNair M, Crist S, Shpritz L, Fitton L, Saffouri R, Blair R (1995) Environmental and economic costs of soil erosion and conservation benefits. Science 267:1117-1123
Pimentel D (2006) Soil Erosion: a food and environmental threat. Environ Dev Sustain 8:119-137
Posthumus H (2005) Adoption of terraces in the Peruvian Andes. Doctoral thesis Wageningen University, The Netherlands
Prince SD, Brown De Colstoun E, Kravitz LL (1998) Evidence from rain-use efficiencies does not indicate extensive Sahelian desertification. Global Change Biol 4:359-374
Rasmussen D, Fog B, Madson JE (2001) Desertification in reverse? Observations from northern Burkina Faso. Global Environ Chang 11:271-282
Ringersma J, Batjes NH, Dent DL (2003) Green Water: definitions and data for assessment. Report 2003/02, ISRIC – World Soil Information, Wageningen, The Netherlands
Rockström J, Valentin C (1997) Hillslope dynamics of on-farm generation of surface water flows: The case of rain-fed cultivation of pearl millet on sandy soils in the Sahel. Agr Water Manage 33:183-210
Romero CC, Baigorria GA, Stroosnijder L (2006) Changes of erosive rainfall for El Nino and La Nina years in the northern Andean highlands. Clim Chang (in press)
Scherr SJ (1999) Soil degradation: A threat to developing-country food security by 2020? Paper No. 27, International Food Policy Research Institute, Washington, D.C., USA
Scoones I, Toulmin C (1998) Soil nutrient budgets and balances: What use for policy? Agric Ecosyst Environ 71:255-267
Scoones I, Toulmin C (1999) Policies for soil fertility in Africa. A Report prepared for the Department of International Development, by Institute of Development Studies and International Institute for Environment and Development, DFID, Brighton/London, UK.
Sheikh V, Visser S, Stroosnijder L (2007) A simple model to predict soil moisture: Bridging event and continuous hydrological modelling (BEACH). Hydrological Processes (submitted)

Smaling EMA, Nandwa SM, Janssen BH (1997) Soil fertility in Africa is at stake. In: Buresh RJ, Sanchez PA, Calhoun F (eds). Replenishing soil fertility in Africa, Soil Science Society of America, Madison, USA, pp. 47-62

Selamyihun Kidanu (2004) Soil and water conservation with Eucalyptus on the highland Vertisols of Ethiopia. Doctoral thesis Wageningen University, The Netherlands.

Selamyihun Kidanu, Mamo T (2005) Land use changes and erosion on highland Vertisols of Ethiopia. Ethiopian Journal of Natural Resources.

Selamyihun Kidanu, Mamo T, Stroosnijder L (2004) Eucalyptus–wheat interaction on Ethiopian Nitosols. Agric Syst 80:151-170

Seleshi Y, Camberlin P (2006) Recent changes in dry spell and extreme rainfall events in Ethiopia. Theor Appl Climatol 83:181-191

Sivakumar MVK (1991) Drought spells and drought frequencies in West Africa. Research Bulletin No. 13, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, India.

Slegers MR, Zougmore R, Stroosnijder L (2005) Closing the gap between priority problems for natural resource management in Burkina Faso: Exploring drought perceptions of farmers and natural resource management institutions. ICRISAT, Niger.

Some L, Taounda JB, Guillobez S (1992) Le milieu physique du Burkina Faso et ses contraintes. INERA, Ouagadougou.

Spaan WP (2003) Consuming the savings: Water conservation in a vegetation barrier system at the Central Plateau in Burkina Faso, Doctoral thesis Wageningen University, The Netherlands.

Stocking MA, Murnaghan N (2001) Field assessment of land degradation. EARTHSCAN.

Stoorvogel JJ, Smaling EMA (1990) Assessment of soil nutrient depletion in Sub-Saharan Africa 1983-2000. Report No. 28, The Winand Staring Centre for Integrated Land, Soil and Water Research (SC-DLO), Wageningen, The Netherlands.

Stroosnijder L (1982) Simulation of the soil water balance. In: Penning de Vries FWT et al. (Eds), Simulation of plant growth and crop production. Simulation Monograph, PUDOC, Wageningen, pp.175-193

Stroosnijder L (1987) Soil evaporation: test of a practical approach under semi-arid conditions. Neth J Agr Sci 35:417-426

Stroosnijder L (1992). La désertification en Afrique Sahélienne. Le Courrier 133:36-39

Stroosnijder L (1996) Modeling the effect of grazing on infiltration, runoff and primary production in the Sahel. Ecol Model 92:79-88

Stroosnijder L (2003) Technologies for improving green water use efficiency in semi-arid Africa. In: Beukes B, DeVilleirs M, Mkhize S, Sally H, VanRensburg L (eds.). Proceedings Water Conservation Technologies for Sustainable Dryland Agriculture in Sub-Saharan Africa. Symposium and Workshop, Bloemfontein, South Africa, pp. 92-102

Stroosnijder L (2005) Measurement of erosion: is it possible? Catena 64: 162-173

Stroosnijder L (2007) Combating drought and water scarcity in African Highlands by modifying land management in order to improve efficiency of rainwater use. Soil Tillage Res (*submitted*).

Stroosnijder L, Kiepe P (1998) Simulation of Maize growth under conservation farming in tropical environments. Tropical Resource Management Papers no. 19, Wageningen University, ISBN 90 6754 550 3.

Stroosnijder L, Koné D (1982) Le bilan d'eau du sol. Dans: F.W.T. Penning de Vries FWT, Djitèye MA (Editors), La productivité des pâturages Sahéliens. Agric. Res. Rep. 918, p.133-165. PUDOC, Wageningen.

Stroosnijder L, Hoogmoed WB (1984) Crust formation on sandy soils in the Sahel; II: Tillage and its effects on the water balance. Soil Till Res 4:321-337

Stroosnijder L, Hoogmoed WB (2004) Contribution of soil and water conservation to carbon sequestration in semi-arid Africa. Bulletin du Réseau Erosion 23: 528-539

Stroosnijder L, VanRheenen T (eds.) (2001) Agro-silvo-pastoral land use in Sahelian villages. Adv GeoEcol 33. CATENA VERLAG GMBH.

Stroosnijder L, Hoogmoed WB, Berkhout JAA (1994) Modelling effects of water conservation tillage in the semi-arid tropics. In: Bilan hydrique agricole et sécheresse en Afrique tropical. John Libbey, Paris. pp. 235-251

Tenge AJM (2005) Participatory appraisal for farm level soil and water conservation planning in Usambara highlands in Tanzania. Doctoral thesis Wageningen University, The Netherlands.

Tesfaye Beshah (2003) Understanding farmers: Explaining soil and water conservation in Konso, Wolaita and Wello, Ethiopia. Doctoral thesis Wageningen University, The Netherlands.

Tiffen M, Mortimore M, Gichuki F (1994) More people, less erosion: Environmental recovery in Kenya. John Wiley & Sons, Chichester, UK.

UNCCD (1997) United Nations Convention to Combat Desertification in those countries experiencing serious drought and/or desertification, particularly in Africa. Geneva, Switzerland.

UNEP (1997) World atlas of desertification (second edition). Arnold, London.

VanderPol F (1992) Soil mining: An unseen contributor to farm income in southern Mali. Amsterdam: Royal Tropical Institute.

VanDijk AIJM, Bruijnzeel LA, Rosewell CJ (2002) Rainfall intensity–kinetic energy relationships: a critical literature appraisal. J Hydrol 261:1-23

Warren A (2002) Land degradation is contextual. Land Degrad Dev 13:449-459

Warren A, Batterbury S, Osbarh H (2001) Soil erosion in the West African Sahel: a review and an application of a 'local political ecology' approach in South West Niger. Global Environ Chang 11:79-95

Wischmeier WH, Smith DD (1978) Predicting Rainfall–Erosion Losses: A Guide to Conservation Planning. USDA Agriculture Handbook 537. U.S. Government Printing Office, Washington, D.C.

Woldeamlak Bewket (2003) Towards integrated watershed management in highland Ethiopia: the Chemoga watershed case study. Doctoral thesis Wageningen University, The Netherlands.

Woldeamlak Bewket, Stroosnijder L (2003) Effects of agroecological land use succession on soil properties in Chemoga watershed, Blue Nile basin, Ethiopia. Geoderma 111:85-98.

Zougmoré R, Mando A, Ringersma J, Stroosnijder L (2003) Effect of combined water and nutrient management on runoff and sorghum yield in semi-arid Burkina Faso. Soil Use Manage 19:257-264

Frequency of Wet and Dry Spells in Tanzania

Faustine F. Tilya and Mohamed S. Mhita

Abstract. Forty one years of daily data (1960-2000) have been used to investigate the spatial and temporal distribution of wet and dry spells during the rainfall seasons of Tanzania. The frequency characteristics of wet and dry spells were based on the threshold of 1.0 mm of daily rainfall events. The observed frequency of wet and dry spells during the rainfall seasons over the period of study showed that at both bimodal and unimodal locations the frequency of occurrence of one-day wet and dry spell was highest at all locations then reduced smoothly as the length of the season progress. The analysis gave an indication that the longest run of wet spell of 25-days occurred during March – May rainfall season at Lushoto over the north eastern highlands on the bimodal regime. Similarly, longest run of wet spells of 28 days was also observed at Mbeya and Mahenge over the southwestern highlands on the unimodal regime. Longest dry spells run were noted over the semi arid parts of Tanzania including Dodoma, which registered the longest run of 249 days that occurred in 1999 and coincided to a cold El Niño–Southern Oscillation (ENSO) event.

10.1 Introduction

Land degradation is threatening the livelihood of many communities in Tanzanian today. The degradation may be looked upon as a process or combination of processes arising from human activities and habitation patterns which include soil erosion caused by wind and or water, deterioration of the physical, chemical and biological properties of soils and long term loss of natural vegetation. Land degradation processes escalated by climate variability, climate change, droughts, flash floods, dust storms, famine, migratory movements and forest fires are leading to high socio economic costs including food insecurity. Climatic variations are recognized as one of the major factors contributing to land degradation and it is thus important that greater importance be paid to understand the role of different climatic factors in land degradation. Accessibility of sustainable land management practices becomes realistic when climate resources (historical data and research findings) are used together with management development practices for development of appropriate mitigation technologies.

The objective of this work was to enhance the basic understanding of the spatial and temporal characteristics of wet and dry spells in order to provide improved climate information tools that can be used to reduce the vulnerability of the climate sensitive socio-economic activities to extreme weather/climate events in Tanzania. The work specifically investigated the frequency pattern of distribution of wet and dry spells and their respective run during the wet seasons. Similar studies were previously made during the rainy months in East Africa by Alusa and Gwage (1978), Ogallo and Chillambo (1984) and Mhita (1984).

10.2
Data

The data used in this study consisted of daily rainfall records obtained from Tanzania Meteorological Agency for the period 1960 to 2000 (Fig. 10.1). Mass curve analysis was adopted in this study to ensure consistency of the rainfall records. The analysis involved plotting cumulative annual rainfall amounts for a given station against duration of the series. Single/multiple lines fitted to the plot of the cumulative values indicated homogeneity/heterogeneity of data respectively as used by

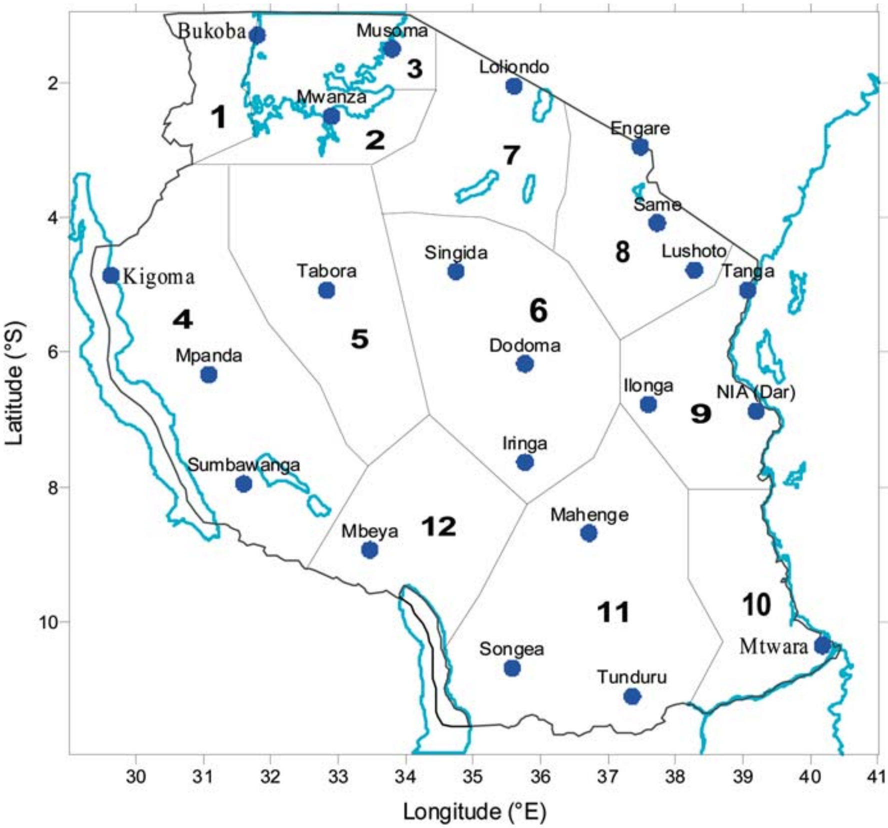


Fig. 10.1. Homogeneous climatic zones of Tanzania

Owiti (2005). Double mass curve approach was used to adjust the heterogeneous records as shown by Wilks (1995).

10.3 Methodology

The basic method employed on the daily rainfall data included derivation of wet and dry spells using various threshold values and then investigating the frequency of occurrences of the wet/dry spells during the wet seasons for some selected stations representative of the homogeneous climatic zones of Tanzania (ICPAC 2003). Wet day in the study was defined as any day recording at least one mm of rainfall. Similarly, a dry day is one in which less than one mm of rainfall is recorded. Furthermore a wet (dry) spell occurs when sequence of wet (dry) days are preceded and followed by dry (wet) days. These are normally the adopted thresholds of both wet and dry days by the Meteorological Service in Tanzania and other countries of East Africa. Other thresholds that have been used in some studies include those by Barrow (2004) and Gitau (2005). Frequencies of wet spells of some given runs of

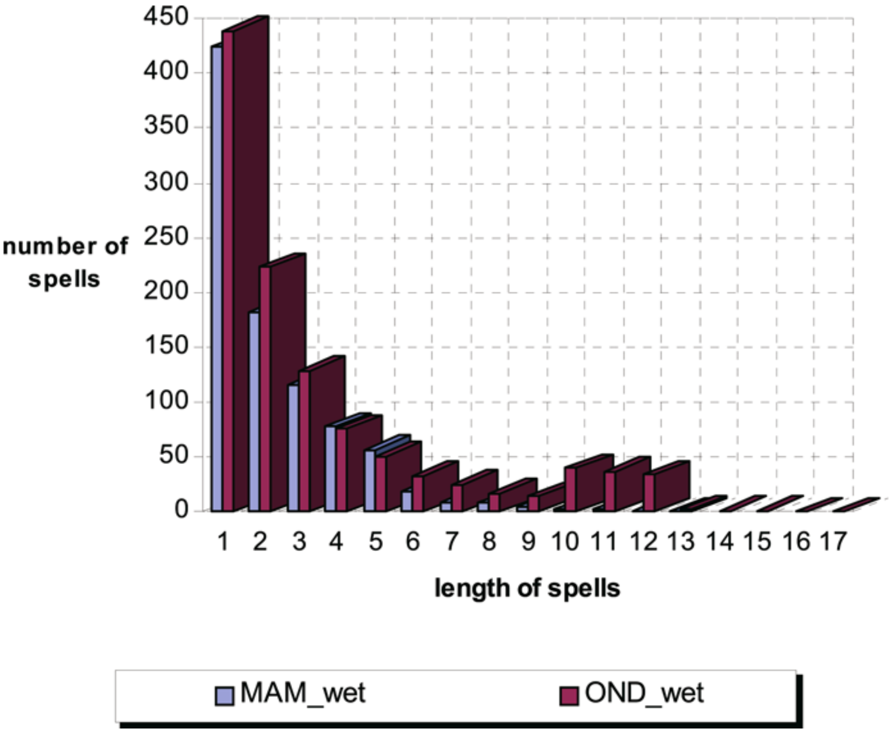


Fig. 10.2. The observed frequency of wet spell runs during the March-May (MAM_wet) and October-December (OND_wet) seasons at Engare Naibor

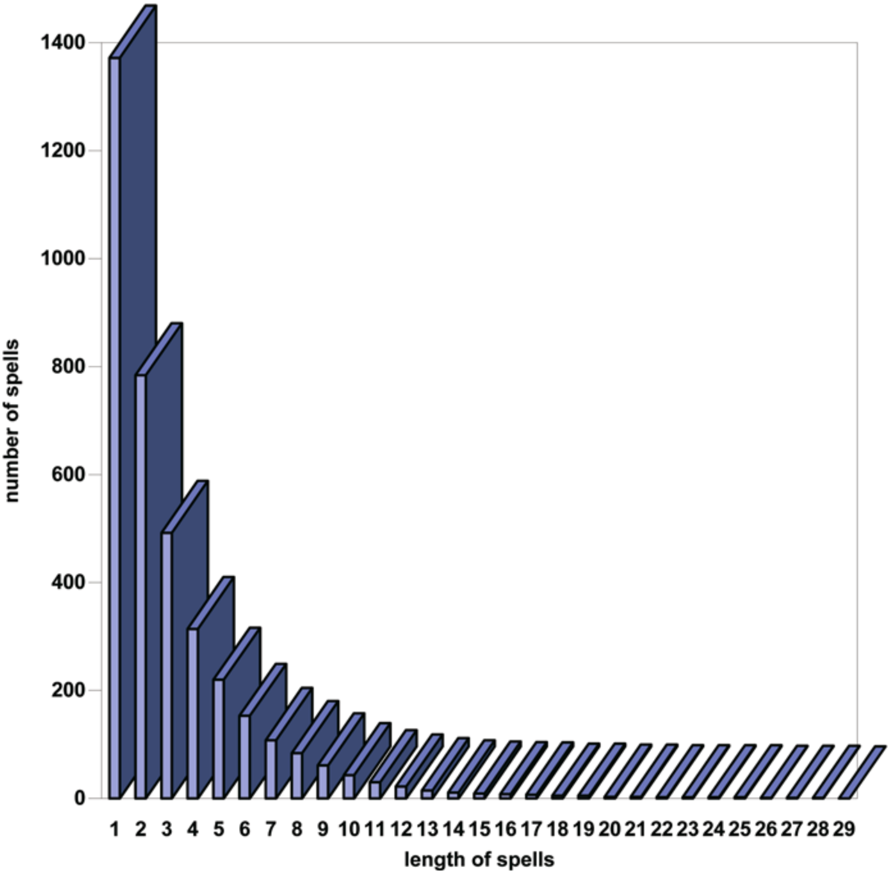


Fig. 10.3. The observed frequency of dry spell runs during the October – May period at Mahenge

days were derived from the daily data from a location during the period of study. If a spell of i wet days occurs in a month j and year k, then the number of occurrences of the spell during a month and year for a station was expressed mathematically as

$$F_{ijk} = \sum_{i=1}^{m} F_{ijk} \tag{1}$$

where, m is the total number of years (41).

The frequency of such spells in any month Fj or any season Fs can be evaluated as

$$\mathrm{Fj} = \sum_{i=1}^{n} \sum_{k=1}^{m} \mathrm{Fijk} \tag{2}$$

Table 10.1. Observed distribution of maximum runs of wet spells

	Station	Oct	Nov	Dec	Jan	Feb	Mar	April	May
Bimodal	Bukoba	10	13	14			11	23	16
Stations	Mwanza	9	14	10			9	11	8
	Musoma	10	12	13			10	11	12
	Same	6	10	9			9	10	11
	Lushoto	8	11	8			10	25	18
	Tanga	9	13	7			6	11	15
	DIA**	6	11	9			11	17	14
Unimodal	Kigoma	9	9	12	5	7	6	16	12
Stations	Mpanda	9	17	10	11	12	10	9	4
	Tabora	5	17	18	10	8	11	10	6
	Sumba*	4	10	14	12	11	11	12	6
	Mbeya	5	8	20	28	13	11	15	7
	Iringa	2	6	12	12	11	13	11	6
	Songea	2	12	14	15	11	14	13	13
	Mahenge	5	9	19	16	14	17	28	10
	Tunduru	2	7	10	11	9	10	6	4
	Mtwara	3	6	10	11	10	11	17	10
	Loliondo	6	7	17	12	7	8	12	9
	Ilonga	9	14	8	8	8	8	12	11
	Singida	3	4	12	9	12	12	9	3
	Dodoma	2	7	10	9	8	7	8	4

or

$$Fs = \sum_{j=1}^{3} \sum_{i=1}^{n} \sum_{k=1}^{m} Fijk = \sum_{j=1}^{3} Fj \tag{3}$$

for bimodal locations and

$$Fs = \sum_{j=1}^{8} \sum_{i=1}^{n} \sum_{k=1}^{m} Fijk = \sum_{j=1}^{8} Fj \tag{4}$$

Table 10.2. Observed distribution of maximum runs of dry spells

	Station	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
	Bukoba	18	13	13			12	9	19
	Mwanza	136(1986)	20	22			20	19	31
Bimodal	Musoma	61(1963)	24	29			27	16	18
Stations	Engare	209(2000)	210(2000)	20			55(2000)	46	77
	Same	143(1992)	82(1973)	45			65(2000)	23	27
	Lushoto	99(1996)	109(1996)	25			26	19	17
	Tanga	20	23	45			74(1984)	14	17
	DIA**	45	39	47			59(1997)	16	26
	Kigoma	153(1979)	20	11	14	19	15	14	41
	Mpanda	189(1963)	178(1993)	16	13	12	17	14	36
	Tabora	179(2000)	174(1964)	33	22	15	20	26	39
Unimo-dal	Sumba*	176(1973)	181(1998)	47	12	18	15	21	49
Stations	Mbeya	188(1964)	193(1964)	20	21	10	13	22	53(1977)
	Iringa	198(1999)	228(1999)	240(1999)	23	17	23	23	50(1995)
	Songea	192(1963)	201(1963)	49	20	24	12	15	43
	Mahenge	139(1989)	80(1978)	53(1963)	23	32	12	12	36
	Tunduru	205(1987)	229(1970)	233(1968)	40	25	17	30	52(1986)
	Mtwara	117(1984)	120(1984)	51(1960)	35	20	18	19	35
	Lo-liondo	157(1976)	177(1976)	51(1980)	82(1980)	111(1982)	38	37	42
	Ilonga	85(1978)	90(1978)	71(1998)	38	23	24	12	30
	Singida	216(1993)	240(1993)	238(1991)	24	23	29	44	75(1972)

for unimodal locations, where n is the longest possible dry or wet spell. Bimodal locations experience rainfall between October and December (vuli) and between March and May (masika) while unimodal stations ob-serve seasonal rains between October and May in the subsequent year. So from (3), j =1 on the first day of October (March) for vuli (masika) and j = 92 at end of December and May respectively. Similarly, from (4), j = 1 on first of October and j = 243 or 244 at end of May. Climatologically, the wet seasons lasts for 3 (8) months on bimodal (unimodal) locations as also presented by Alusa and Gwage (1978) and Ogallo and Chillambo (1984).

10.4 Results on the Frequency of wet/dry spells

The observed frequency of wet and dry spells during the rainfall seasons over the period of study showed that at both bimodal and unimodal locations the frequency of occurrence of one-day wet/dry spell was highest at all locations then decreased gradually as the length of the season progress as shown in figures 10.2 and 10.3. Ogallo and Chillambo (1984) also observed similar frequency run patterns in Tanzania.

The spatial observed distribution of maximum runs of wet spells is presented in Table 10.1. Wet spells of longer durations of over 10-days were dominant over high lands and close to large water bodies including Lakes Victoria and Tanganyika and along the coast. The longest run of wet spell of 25-days was observed during March–May (masika) rainfall season at Lushoto over the north eastern highlands on the bimodal regime. Similarly, longest run of wet spells of 28 days was also observed at Mbeya and Mahenge over the southwestern highlands on the unimodal regime. Ogallo and Chillambo (1984), also using daily rainfall data for the period 1950 to 1980, observed longest wet spells of 47 days at Mbeya over the south western highlands of Tanzania.

Similarly, the spatial distribution of observed maximum runs of dry spells is given in Table 10.2. They were found to be prevalent over the semi arid areas of Tanzania. The longest frequency run was observed at Dodoma, which registered 249 days that occurred in 1999. Alusa and Gwage (1978) and Ogallo and Chillambo (1984) observed longest dry spell run of 61 days over central Tanzania. However, this study indicates that several stations exceeded this limit. The years with longest dry spells occurred in 1998/1999/2000 period when the region observed persistent drought associated with cold El Niño–Southern Oscillation (ENSO) events also called La Niña events as indicated by Redmond and Koch (1991) in the classification of El Niño and La Niña Winters. The return period of the ENSO events varies from 2 to 7 years, their intensity and duration vary and are hard to predict. ENSO events are noted to last from 14 to 22 months and said to be much longer or shorter (Glantz et al. 1991).

10.5 Conclusions

The results of this study show the spatial statistical distribution of the dry and wet spells that can be expected in any season during the 41-year period. The observed frequency distribution of wet/dry spells showed that the frequency of occurrence of one-day wet/dry spell was highest at all locations and decreases gradually as the length of the spells progresses over time. Wet spells of longer durations of over 10-days were dominant over high lands and close to large water bodies of Lakes Victoria and Tanganyika and along the coast. This study indicates that several stations are recording fewer wet spells. Conversely, the number of dry spell run was noted to escalate in the semi-arid regions of Tanzania exemplified by Dodoma.

Enhanced dry spells and reduced wet spells in a location always has an effect on the available green water use efficiency as reflected by water balance in the soils expressed in terms of transpiration and rainfall availability for meaningful agriculture. Combating land degradation processes may therefore be successful if appropriate measures including approaches to mitigate wet/dry spells are adhered to. These results may therefore constitute some useful information to monitor and assess land degradation and hence strategies to restore degraded land in Tanzania. Further strategies may include continued research on land degradation and rainfall monitoring, combining model findings with empirical studies at farm and village levels and timely transfer of rainfall information to end users.

It is expected that the Government will continue in future to adequately assist Tanzania Meteorological Agency and other research institutions in the country to enhance their contribution in accelerating the pace of economic growth and attain the United Nations Millennium Development Goals by 2015.

References

Alusa AL, Gwage PM (1978) The occurrence of Dry Spells during the East African Long rains. Research report No. 2/78.

Barrow J (2004) Dry spell mitigation to upgrade semi-arid agriculture: Water harvesting and soil nutrient management for smallholder maize cultivation in Machakos, Kenya. Doctoral thesis in Natural Resources management, Department of Systems Ecology, Stockholm University, Sweden

ICPAC (2003) Homogeneous zones of East Africa. IGAD Climate Predic-tion and Applications Centre, Nairobi, Kenya.

Gitau W (2005) Characteristics of the wet and dry spells during the wet seasons over Kenya. M,Sc. thesis, Department of Meteorology, Univer-sity of Nairobi.

Glantz M, Katz R, Nicholls N (eds.) (1991) Teleconnections Linking Worldwide Climate Anomalies. Cambridge University Press, Cam-bridge.

Mhita MS (1984) The use of water balance models in the optimization of cereal yields in seasonally-arid tropical regions. PhD thesis, Depart-ment of Meteorology, University of Reading.

Ogallo LJ, Chillambo WA (1984) The characteristics of wet spells in Tan-zania. E Afr Agr For J 47:87-95.

Owiti ZO (2005) Use of the Indian Ocean Dipole indices as a predictor of East African rainfall anomalies. Msc Thesis, Department of Meteorol-ogy, University of Nairobi.

Redmond KT, Koch RW (1991) Surface climate and streamflow variabil-ity in the western United States and their relationship to large-scale cir-culation indices. Water Resour Res 27:2381-2399.

Wilks DS (1995) Statistical Methods in the Atmospheric Sciences: an In-troduction. International Geophysics Series, Vol. 59, Academic Press, 464 pp.

CHAPTER 11

Climate Variability, Climate Change and Land Degradation

Beverley Henry, Greg McKeon, Jozef Syktus, John Carter, Ken Day, and David Rayner

Abstract. Effective response by government and individuals to the risk of land degradation requires an understanding of regional climate variations and the impacts of climate and management on condition and productivity of land and vegetation resources. Analysis of past land degradation and climate variability provides some understanding of vulnerability to current and future climate changes and the information needs for more sustainable management. We describe experience in providing climate risk assessment information for managing for the risk of land degradation in north-eastern Australian arid and semi-arid regions used for extensive grazing. However, we note that information based on historical climate variability, which has been relied on in the past, will now also have to factor in the influence of human-induced climate change. Examples illustrate trends in climate for Australia over the past decade and the impacts on indicators of resource condition. The analysis highlights the benefits of insights into past trends and variability in rainfall and other climate variables based on extended historic databases. This understanding in turn supports more reliable regional climate projections and decision support information for governments and land managers to better manage the risk of land degradation now and in the future.

11.1 Introduction

The interaction between climate, human activities and land condition is complex. The extent to which land management practices affect the condition of the land is influenced by climatic factors, and conversely, the climate restricts the range of land management practices that can be sustainably employed. These interactions, and their consequences, can lead to a deterioration of land condition which in turn has been shown to have impacts on the atmosphere and future climate. Hence, when discussing climate variations and land degradation, it is critical to be aware of the complex processes and feedbacks that occur on a range of temporal and spatial scales. Many of these processes and feedbacks are only partially understood, and so sustainable practices will inevitably be planned against a background of limited scientific understanding and uncertainties surrounding future climate changes.

Nevertheless, there are good reasons to act. It is widely accepted that land use practices must minimise land degradation in order to be sustainable in the long-term. It is also widely accepted that climate variations are an important contributor to the degradation of productive and natural lands. Many of the countries most severely affected by land degradation are already economically disadvantaged and their scope to withstand any downturn in productivity is limited. However, land degradation is a global issue affecting both developed and developing nations. Global efforts to understand how climate variability has contributed to resource damage and how current and future climate change may further exacerbate the damage is critical for economic and environmental sustainability. There is a clear need for continued research into global and regional climate systems, seasonal climate forecasting, climate trends, risk assessments and communication of those risks to land managers. Decision support tools and policy development based on sound science are prerequisites for the sustainable and productive use of lands.

A number of definitions of land degradation and desertification have been proposed, and the choice of definition will impact to some extent on the interpretation of the role of climate. However, the definitional question will not be addressed in this paper. We will use, as the basis for analysis, the definition of the United Nations Convention to Combat Desertification (UNCCD), i.e. land *degradation* is a "reduction or loss, in arid, semi-arid, and dry subhumid areas, of the biological or economic productivity and complexity of rain-fed cropland, irrigated cropland, or range, pasture, forest, and woodlands resulting from land uses or from a process or combination of processes, including processes arising from human activities and habitation patterns, such as: (i) soil erosion caused by wind and/or water; (ii) deterioration of the physical, chemical, and biological or economic properties of soil; and (iii) long-term loss of natural vegetation". The UNCCD further describes *desertification* as "land degradation in the arid, semi-arid and dry subhumid areas resulting from various factors, including climatic variations and human activities". It is the role of climatic variations that provides the focus of this paper.

The socio-economic aspects of land management in dryland regions, where profitability and long-term productivity is often marginal, compound the scientific complexity of this issue. It is impossible to cover all aspects of this problem in a single paper and we do not attempt to do so. Rather, we describe one approach to analysing and addressing the relationship between climate and land degradation, derived from our experience in Australia. The United Nations Development Programme (UNDP) estimated that there are 54 million km^2 of drylands globally, representing approximately 40% of land area. About 15% of this total is in Australia, with the majority in Asia (34.4%), Africa (24.1%) and the Americas (24%). While all drylands can be considered to be at risk of degradation, the extent of degradation at any point in time is difficult to assess, again raising definitional questions (Prince 2002; Walker et al. 2002). Perhaps the scale of the problem can best be summarised in the assessment of the UNCCD that over 250 million people are directly affected by land degradation, and that one billion people, many already suffering severe poverty, in over 100 countries are at risk

In the discussion that follows, we focus on the arid and semi-arid rangelands that are used for grazing domestic livestock in Australia – about 406 million ha across the continent. European settlement in Australia, beginning a little over 200 years ago, had a major impact on the landscape,. However, reliable records are available for only a shorter period (i.e. a little over 100 years). The processes of land degradation occur on a range of time scales and can be attributed to both natural factors and human activities. Determining the causes of changes in land condition is not straightforward because natural climate variations and other, often related, natural factors such as wildfires interact with human-caused factors such as overgrazing, the introduction of animal and plant pests and inappropriate use of burning. A major study of eight well-documented episodes of degradation in Australia's rangelands provides an understanding of the natural and human factors that contributed to those regional episodes (McKeon *et al.* 2004). Following a discussion of what we have learnt from analysing those historical events, we provide a description of preliminary research on how land use, land use change and climate change may exacerbate the risk of land degradation in the future. To illustrate this aspect, we present the example of a dynamical climate modelling experiment in which feedbacks cause regional land degradation to exacerbate drought conditions in central Australia. Further research aimed at a better understanding of how land degradation and climate feedbacks operate through the carbon, energy and water balances will enable dynamical climate modelling to provide more accurate climate projections in the future and so support sustainable resource management.

11.2
The risk of land degradation in Australia

Agriculture remains the major land use in Australia, occupying 61.5% of the land area (7.6 million ha) with 56% used for the grazing of natural vegetation and a further 2.5% used for dryland grazing on improved pastures (SOE 2006). Australia's rangelands are environmentally diverse landscapes and are susceptible to the impacts of rainfall variability. Rainfall is not only very low in Australia, with over 50% of the land area receiving less than 300 mm median annual rainfall, but also highly variable on timescales from intra-seasonal to multi-decadal and longer. A major driver of variations in rainfall on inter-annual timescales is the El Niño – Southern Oscillation or ENSO (e.g. Nicholls 1988), particularly in the north-east of the continent.

In Australia, the combination of agricultural land use and high natural climate variability – particularly the occurrence of severe and protracted drought periods – presents a challenge for sustainable land management. This challenge has resulted in a national and regional focus on policies and research into natural resource management and climate science that provides a valuable foundation for responding to climate change. Examples include:

- Australia has implemented a National Drought Policy that encourages rural land managers to manage for climate variations, but which also provides financial assistance to farmers in "Exceptional Circumstances", i.e. in rare and severe drought events. The current definition of an exceptional circumstance is one that is rare and severe, assumed to occur on average once in 20 to 25 years, and that causes a severe downturn in farm income over a prolonged period (Botterill 2003; Day et al. 2003).
- The Australian Bureau of Meteorology provides climate data and seasonal outlooks that enable farmers and graziers to proactively minimise the risk of environmental and economic damage to their properties during unfavourable

seasons. The Bureau's information is complemented by application-driven information provided by private companies and by State governments, e.g. the Queensland Government Long Paddock website (www.Longpaddock.qld.gov.au) which provides rainfall outlooks and probabilities for pasture growth for the season ahead.
- The National Agricultural Monitoring System (NAMS), coordinated by the Commonwealth government, brings together a large amount of information from national and State organisations for land managers. The NAMS information supports the adoption of risk management strategies as well as the development of submissions for Drought Exceptional Circumstances financial assistance.

Responsibility for land management in Australia lies with State governments. This paper focuses on Queensland (northeast Australia) in which over 85% of the 173 M ha land area is managed for grazing domestic animals. Most of this area is semi-arid to arid grasslands and woodlands. These rangelands are sensitive to the highly variable rainfall regime, with the risk of long-term degradation also linked to total grazing pressure from the combination of domestic livestock, native herbivores (particularly macropods), and feral animals including rabbits, goats and camels. Management of fire frequency, woody vegetation proliferation, weeds, and vegetation removal are additional factors in the land degradation equation.

In this chapter, an integrated approach to providing climate science information to support better management of the risk of land degradation (Fig. 11.1) is described. The approach is based on: (i) maintaining a comprehensive program of land and vegetation condition monitoring using both remote sensing and field assessment; (ii) modelling rangeland systems to understand biophysical processes in historical, present and future contexts; (iii) modelling regional climate systems and providing climate projections on seasonal and longer timescales (e.g. 3 months to 50 years into the future); and (iv) engaging with government and the community to provide information on current resource condition and risks of degradation.

This approach illustrates the critical aspects of managing the risk of land degradation in a variable and changing climate:
- Objective assessment of land condition, and analysis of how the current conditions compare with historical conditions;
- Understanding the climatic and socio-economic factors that contribute to productivity loss, degradation and recovery of land and vegetation resources;
- Climate risk assessments based on seasonal and longer-term outlooks, and an understanding of the reliability of these climate projections; and
- Information and education on the risk of land degradation and desertification, e.g. 'safe' livestock carrying capacities both now and under future climate change.

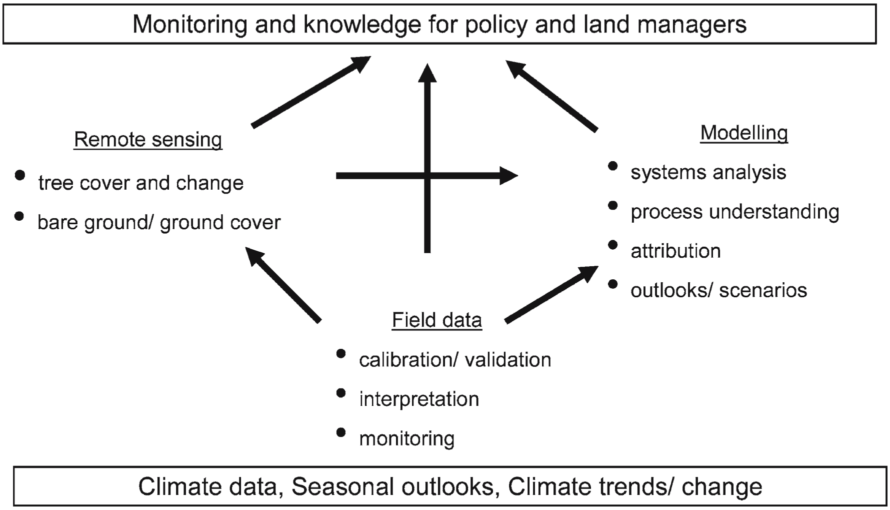


Fig. 11.1. Illustration of the multi-faceted approach used in Queensland for monitoring the risk of land degradation in extensive semi-arid and arid grazing lands and providing advice for managing the risk of land degrada-tion in a variable and changing climate

11.3 Monitoring land condition and degradation risk

The objective assessment of land condition over the extensive and diverse landscapes that characterise Australia's extensive grazing lands requires innovative monitoring techniques. In Queensland an extensive remote sensing program (Statewide Landcover and Trees Study, SLATS) uses moderate resolution (25m x 25m) Landsat imagery to detect and map woody vegetation change (clearing or regrowth) (www.nrw.qld.gov.au/SLATS). The Landsat analyses are used in combination with other products such as MODIS imagery to monitor resources on other spatial and temporal scales. Foliage projective cover and extent of bare ground are analysed to indicate rangeland condition.

Bare ground (or its converse, ground cover) is sometimes used as a surrogate for land condition but time series of remotely sensed data may be difficult to interpret, even where trends in an index are detected accurately. For example, an increase in cover on grazing lands may be interpreted as improving land condition when in fact it is due to weed infestation rather than an increase in cover of edible perennial grasses. Field verification is critical to confirm the interpretation of remotely-sensed imagery. Land managers need to feel confident that the remote sensing can successfully monitor the risk of land degradation, and field verification is essential in establishing acceptance of the technique. Further, experience in Queensland has shown that maintaining ongoing field data collection programmes to support the objective monitoring of land condition is essential. Transect and point measurements are used to calibrate the remote sensing programs and process models (e.g.

www.nrw.qld.gov.au/slats; Carter et al. 2000). In addition, a program of Rapid Mobile Data Collection covering the extensive area of rangelands (Hassett et al. 2006) provides a large database of quantitative, calibrated pasture attribute records as well as qualitative expert observations. Over the past 14 years, approximately half a million km were travelled as part of this program, and close to a million observations have been taken, with, on average, three attributes recorded per observation. These data provide a valuable record of field conditions and are supported by extensive photographic records.

Complementary field and remote sensing programs deliver objective and reliable monitoring of the impacts of climate and management practices on the arid and semi-arid lands used for broadscale grazing. However, understanding the changes in the condition of these lands requires an understanding of biophysical processes that affect landscape conditions. In arid and semi-arid systems, available water often determines plant growth, which influences the availability of feed for domestic livestock and other herbivores, and, through ground cover, susceptibility to soil loss. A process model that reflects plant function and soil water balance is required to provide a basis for analysing how the landscape functions.

Australian Grassland and Rangeland Assessment by Spatial Simulation (AussieGRASS) is a simulation model developed to monitor grass production and land cover, and to analyse the impact of climate variability on grazing lands. In the operational system, AussieGRASS runs a calibrated and validated water balance and pasture growth model on a 5 km grid across the continent, although in extensive broadscale grazing enterprises data-availability often significantly limits the accuracy of simulated values (Carter et al. 2000). AussieGRASS is based on the deterministic, point-based, daily time-step model GRASP (Figure 11.2), which simulates soil-water, pasture growth and cattle or sheep production (McKeon et al. 2000). Simulations of other indicators, including carbon stocks and grass cover, make the framework a valuable environmental calculator for rangelands.

Total precipitation provides only a partial indication of drought impacts, whereas pasture response, measured as growth, biomass and cover, provides a better assessment of the impact of drought on rangelands, and a more realistic ranking of the current conditions in a historical context. Pasture growth integrates additional climatic factors such as temperature, humidity, solar radiation and the pattern of rainfall, as well as the initial condition of the ecosystem (particularly grass basal cover and soil moisture).

AussieGRASS generates pasture simulations in near-real time, and the model is also linked to a seasonal climate forecast system (currently the SOI-Phase system, Stone et al. 1996) to provide outlooks for three months ahead. By taking into account livestock numbers, AussieGRASS can also assess grazing pressure, and therefore be used to indicate degradation risk and identify opportunities for improved management. Climate risk assessments provide land managers with information to support proactive decision-making and during drought the information is also used to advise the government about the risk of land degradation. Hence spatial modelling and climate risk assessment in arid and semi-arid rangelands can produce benefits at the enterprise and regional scale, as well as providing an equitable and objective assessment of pasture status in different Australian regions.

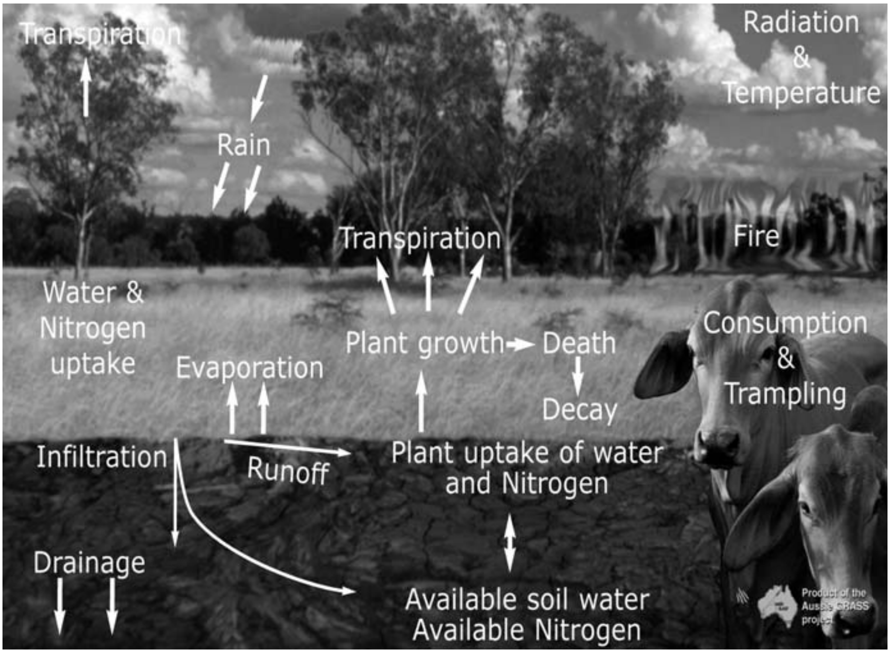


Fig. 11.2. Components of the rangelands systems, applicable to the grasslands and woodlands that characterise the extensive grazing lands of northern Australia, as simulated using the GRASP pasture growth and water balance model in the AussieGRASS spatial simulation framework

AussieGRASS is used to generate information products tailored for land managers, and for assessing the impacts of droughts. These products are made available in near-real time, and for the season ahead. However, the process-based modelling framework also makes AussieGRASS a useful generic environmental calculator. Thus AussieGRASS is used to analyse current and emerging issues of critical importance to natural resource management in Queensland such as landscape water balance, climate change impacts, carbon stocks in vegetation and soils, and impact of grazing on groundcover and sediment loss. Research is continuing to improve the accuracy of simulations and create new applications to support priority policy issues for government.

11.4 Climate information

High quality climate data, as both historical information and future projections, are a critical requirement for analysing the processes of resource condition. The Australian Bureau of Meteorology (BoM) provides daily national meteorological data. The Silo project, a collaboration between the Queensland Government and

BoM, provides unbroken time-series of daily interpolated climate data from 1889 to the present. Silo was initiated in 1997 in response to the need for long time-series of daily climate data for use in biophysical modelling applications, particularly for agricultural, water and rangeland management. Silo allows spatial models such as AussieGRASS to provide analyses of not only actual land condition, but also land condition ranked relative to conditions over more than a hundred years. Expressing current land condition in relation to history is critical to support drought policy where financial assistance is based on 'rare and extreme' conditions. The approach is also useful for showing trends and changes over time.

Time-series of historical data are also required for seasonal forecasting or climate risk assessments that are based on analogue years, such as the SOI phase system (Stone et al. 1996). Statistical modeling is used operationally to provide climate risk assessments using the AussieGRASS framework, but there is also a capability to link dynamical systems to the five km gridded surface, as described later in this chapter. Future developments in climate science will improve the accuracy of high-resolution climate change scenarios, and it is may be possible to use these scenarios within AussieGRASS to simulate the impact of climate change on the risk of land degradation and on productivity (Hall et al. 1998).

11.5 Understanding past land degradation in Australia's rangelands

An analysis of eight well-documented episodes of degradation in Australia's rangelands has provided insights into the factors that contribute to land and vegetation degradation (McKeon et al. 2004). Rainfall variability is a major driver, but land degradation is more than low moisture availability during droughts. Similarly, recovery will not occur with one good season, and managing the breaking of a drought may be as important in avoiding long-term damage to grazed landscapes as managing the onset of dry conditions. A first step in understanding the sequence of conditions that precede the damage is, therefore, to understand the pattern of climate fluctuations, as discussed in the previous section, and the pressures on the land imposed by natural and human activities.

11.5.1 Climate regime

Australia's climate reflects its location in the tropics/sub-tropics (approximately 11°S to 39°S) and relatively small land mass in relation to surrounding oceans. Table 11.1 summarises timescales of climate variations relevant to providing climate risk information for land management in north-eastern Australia. Climatic variations, particularly in rainfall, are the result of both the inherently chaotic nature of the climate system and also the effects of variations in sea surface temperatures and atmospheric circulation patterns (Fig. 11.3). The latter are to some degree predictable. Probabilistic seasonal climate outlooks in this region are based largely on

Table 11.1. Major components of climate variation relevant to land management in Australian rangelands.

Climate system variation Component	Time Period	Literature Cited
Weather	Daily/Weekly	
Madden-Jullian Oscillation (MJO)	Intra-seasonal (30-60 days)	Donald et al.(2006)
Seasons	Seasonal	
Quasi-biennial	2.5 years	White et al. (2003)
El Niño – Southern Oscillation (ENSO	Inter-annual (2-7 years)	Pittock (1975); Allan (1985); Nicholls(1988); Nicholls (1991)
Quasi-decadal	9-13 years	Noble & Vines (1993); White et al. (2003); Meinke et al. (2005)
Pacific Decadal Oscillation (PDO) or Inter-decadal Pacific Oscillation (IPO)	Inter-decadal	Power et al. (1999); White et al. (2003)
Multi-decadal	30-100 years	Hendy et al. (2003)
Climate Change components		
Global Warming and Greenhouse	Since late-1800s	Cai et al. (2005); Nicholls(2006)
Stratospheric Ozone Depletion	Since 1970s	Syktus (2005) ; Cai et al. (2006)
Asian Aerosols	Since 1980s	Rotstayn et al. (2006)
Land Cover Change	Since mid-1800s	Lawrence et al. (sumitted)
Milankovitch cycles or Ice Ages	Thousands of years	De Decker et al. (1988); Barrows et al. (2000)

an understanding of the development of the ENSO phenomenon and its impact on rainfall. The strength of the relationship between ENSO and rainfall, and consequently the reliability of ENSO-based forecasts, varies regionally and throughout the year.

Farmers and graziers managing broadscale production against a background of highly variable rainfall would benefit from more reliable rainfall outlooks or climate risk assessments. However, even when the strength of signal is low, an understanding of regional climatology and the variability characteristic of the location is beneficial because it is recognised that a series of favourable years can lead to over-

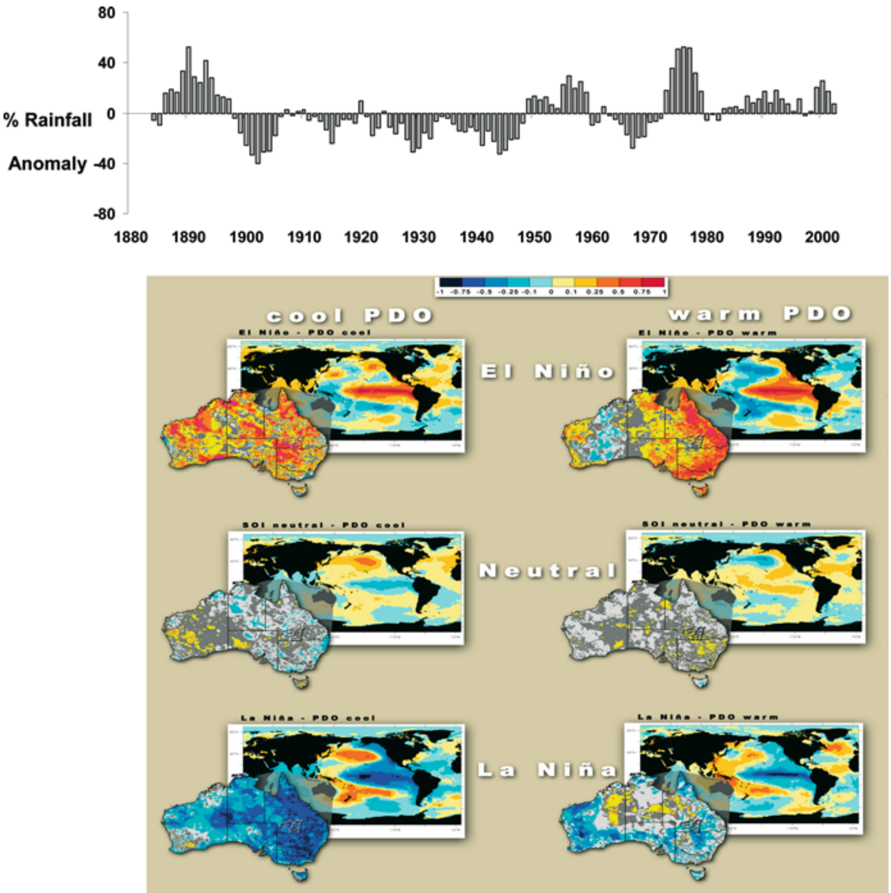


Fig. 11.3. Graphic illustration of the high variability in annual rainfall in Australia's rangelands taking the example of average values for the 12 months from April to March averaged across the western New South Wales grazing lands and expressed as a percent anomaly of the long-term mean. The patterns of inter-annual and inter-decadal variability can be related to state of ENSO and the Pacific Decadal Oscillation

expectations of livestock carrying capacity, and that contributed to past episodes of land degradation (Fig. 11.4; McKeon et al. 2004).

A dominant influence on sustainable management of Australia's rangelands is extended periods (more than three years) of above or below median rainfall (Fig. 11.3). In these sequences of above-average years, stock and other herbivore numbers have built up, e.g. in the 1880s/90s, 1920s, 1950s, 1970s, 1998-2001. If commodity prices declined rapidly, graziers tended to retain stock in the hope of an upturn in market conditions. Examples of such a decline in prices in Australia were seen in the1890s due to global depression, 1925 when wool price collapsed, 1929 due to a severe global depression, 1960s when wool and cattle price again de-

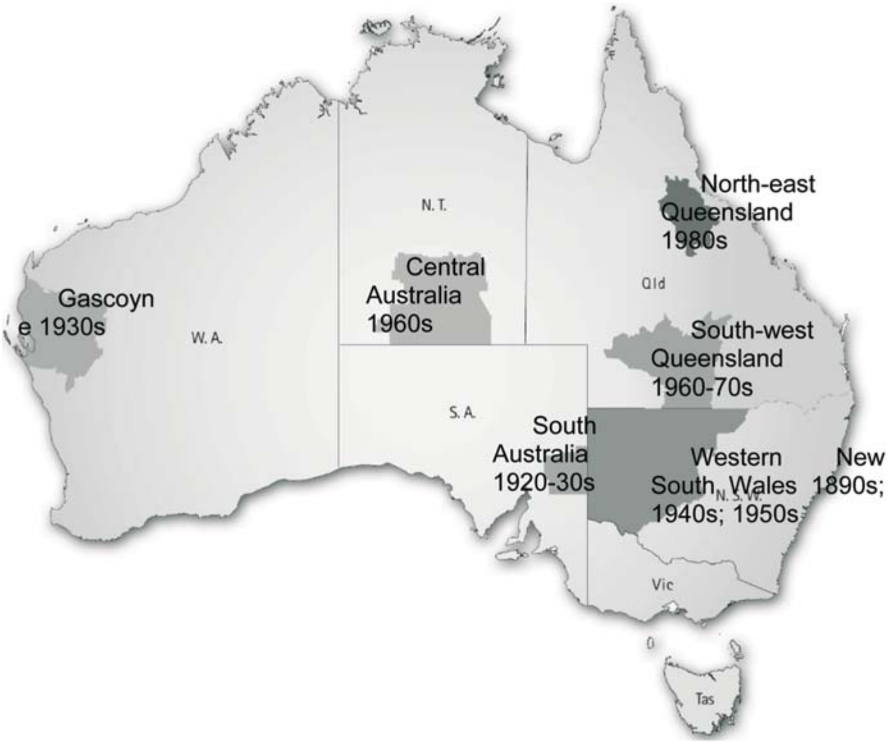


Fig. 11.4. Degradation episodes recorded in regions of Australia's range-lands as described by McKeon *et al.* 2004

clined, and 1974 with a beef price collapse. High stocking rates and poor markets provided conditions more likely to result in degradation of arid or semi-arid rangelands if drought sets in. A severe drought in combination with high stock numbers can then result in loss of ground cover and resource damage. Recovery can occur relatively rapidly with a sequence of above-average rainfall years, but if there has been a loss of topsoil, depletion of seed stores, and related long-term degradation. In some cases, recovery could require decades or the resource may not return to its previous state.

These analyses highlight the value of an integrated approach to assessing the risk of land degradation. Reducing stock numbers early when going into a dry period will conserve ground cover and reduce degradation. Information on current condition and seasonal outlooks provides support for more sustainable management decisions especially on suitable stocking rates. Ground cover and pasture biomass monitored using satellite imagery and field data, combined with seasonal climate forecasting systems and pasture growth modelling, provide the basis for a seasonal conditions report, climate risk assessment and drought alert. Integrating such assessment with information on stock numbers and total grazing pressure enables the degradation risk to be estimated and provide an alert system for severe conditions. Delivery to graziers by email or website provides timely support for responsive management.

11.5.2
Climate change and land degradation

Key requirements for climate risk assessment are understanding of: (1) the interaction of climate and management practices on land condition; and (2) the reliability of climate outlooks. Seasonal forecasts have been developed using statistical systems but climate change means that the past climate may not provide a reliable guide for future conditions. The threat to land and vegetation in arid and semi-arid regions, in particular, may be greater than previously experienced (IPCC 2007).

Australia experienced protracted dry conditions with a strong El Niño in 2002/03 and this resulted in severe drought in much of the east and south-west of the continent (Fig. 11.5). In some of these areas, there had not been a return to average rainfall at the time of writing (February 2007). Although graziers have reduced stock numbers, the extended dry conditions have resulted in groundcover loss, tree death, and dust storms and other evidence of soil loss and land degradation (R. Hassett, Queensland Department of Natural Resources and Water, Pers. Comm.).

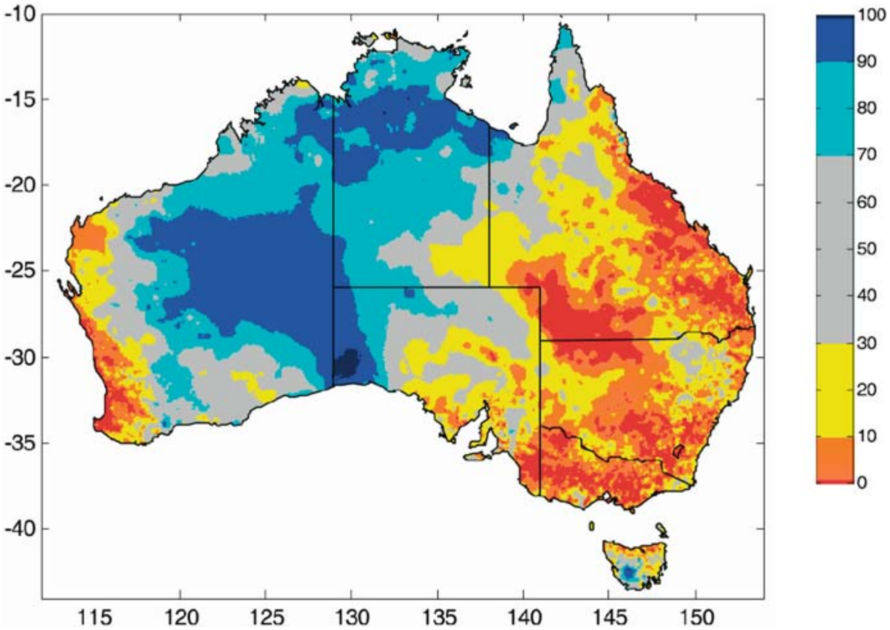


Fig. 11.5. Rainfall for the period April 2001 to January 2007 ranked relative to historical values since 1890 shows that large areas of Australia's rangelands have experienced extremely dry conditions with many in the lowest percent of records

The extensive dry conditions since 2002 are only partly due to the state of the ENSO. Factors that have contributed to the decline in rainfall include very warm conditions in the central equatorial Pacific Ocean, large-scale changes in the hemispheric circulation related to stratospheric ocean depletion, and changes in land cover (Watkins 2005).

11.5.3 Future climate variations and land degradation

Climate change is expected to increase vulnerability of arid and semi-arid regions to degradation. There is growing evidence that the frequency and extent of droughts has increased as a result of global warming. The fraction of land surface area experiencing drought conditions has risen from 10-15% in the early 1970s to more than 30% by early 2000 (Dai et al. 2004). There has been a general tendency towards increased precipitation in the high latitudes, particularly in the Northern Hemisphere, and decreased precipitation in semi-arid regions. A global analysis showed that abrupt changes in rainfall are more likely to occur in arid and semi-arid regions, and that this susceptibility is possibly linked to strong positive feedbacks between vegetation and climate interactions (Narisma et al. 2007). It has not been possible to determine the cause of rainfall decline in eastern Australia (Nicholls 2006), but the observed trends are consistent with broader changes observed in the global sub-tropics (Dai et al. 2004; Vecchi et al. 2005).

Analysis of the observed Australian climate record since 1950 shows that mean surface temperatures have increased by approximately 1°C on average, that there has been an increase in the frequency of heatwaves and a decrease in the occurrence of frosts, and that rainfall has decreased across eastern Australia and increased in the north-west (Manins et al. 2001; Smith 2004; Nicholls 2006).

During the past decade there has been a strong and persistent rainfall deficit in eastern Australia and similarly the reduced rainfall conditions in the south-west corner of Australia have continued. Reductions of up to 20% in annually averaged totals are common across large regions of the continent (Fig. 11.6a). At the same time large parts of north-western Australia have experienced a significant rainfall increase of greater than 30%. The persistent changes in the pattern of rainfall over the continent have placed significant stress on ecosystems and landscapes. The decline in rainfall over this period has resulted in an even greater reduction in soil moisture and a significant reduction in environmental river flows. The reduction in available soil moisture combined with increasing surface temperatures (Fig. 11.6b) contributes to lower plant growth, loss of ground cover, thus increasing the risk of erosion. The potential flow to stream simulated by the AussieGRASS model using daily observed climate parameters shows a reduction of 40 to 60% over the continent (Fig. 11.6d).

Climate risk assessment and climate forecasting skill have been shown to be important in improving decision making in the rangelands of Australia. However climate risk information for Australia has been based largely on the behaviour of ENSO. A challenge for assessing the risk of land degradation in the future is to develop a climate forecasting capability that can account for both human-induced

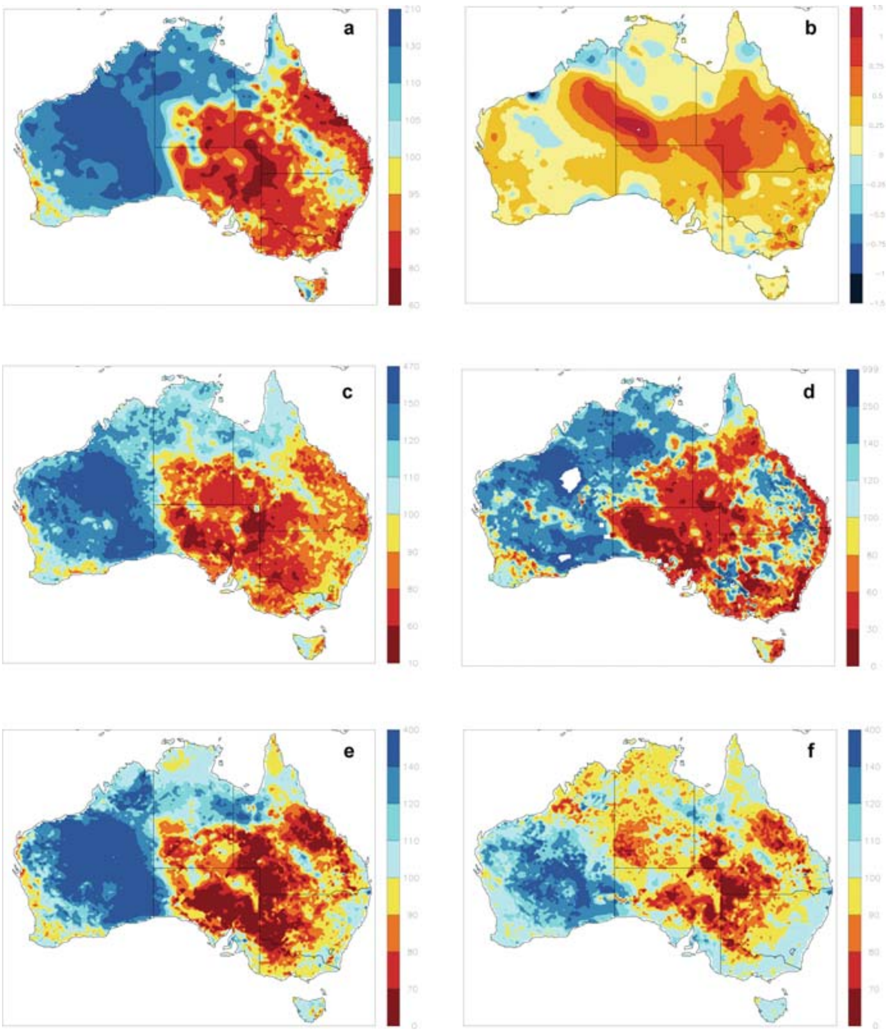


Fig. 11.6. Observed and simulated anomalies in annual (**a**) rainfall, (**b**) mean surface temperature, (**c**) soil moisture in upper 1metre of the soil profile, (**d**) potential flow to stream, (**e**) pasture growth and (**f**) pasture cover, for the period 1993-2006 expressed as a percent of averages for 1970-1992. 1970-1992 is assumed to represent the long-term 'normal' conditions

and natural climate variations, especially on quasi-decadal to longer time-scales. It is no longer possible to assume that the next 30 years will be some random sample of historical climate variations and existing statistical systems will need to be monitored for assessing whether they retain the skill in assessing the probabilities of ENSO development and associated seasonal rainfall. New approaches are therefore needed to more accurately estimate seasonal climate risk and provide projections.

Global Climate Models (GCMs) are increasingly being used to interpret historical climate variability and to provide seasonal climate forecasts based on current sea-surface temperatures, i.e. conditions that include global warming. Interpretation of natural climate variations will benefit from improved historical datasets such as those being developed by the Atmospheric Circulation Reconstructions over the Earth (ACRE) initiative. The ACRE project involved recovery of historical instrumental surface data and using this to improve and extend the time series of digitised records. These data will then support surface observations-based reanalysis with sufficient data coverage to be valid globally to the mid-19th century (Dr Rob Allan, Hadley Centre for Climate Change, Met Office, UK, Pers. Comm., Compo et al. 2006). The reanalysis products are expected to also provide an observational basis for assessing ocean-atmosphere model integrations simulating anthropogenic effects on recent climate and allow current and future climate change impacts to be assessed against a reliable background. However, a major challenge remaining for climate scientists is to link low resolution (e.g. 2^o) climate models with historical climate data to create high resolution, e.g. (0.05^o) spatial biophysical models (e.g. Syktus et al. 2003). With such models, the impacts of a range of climate change scenarios can be tested to support the adoption of appropriate adaptation strategies for future conditions.

In summary, the risk of land degradation will be better managed with (1) an understanding of past trends and variability in rainfall and other climate variables; (2) plausible regional climate change projections; and (3) a basis for resource managers and government policy to more confidently change decisions in response to a likely changing climate.

Acknowledgements

The contribution of many climate and rangeland scientists is gratefully acknowledged. Particular thanks go to Robert Hassett for expert advice on land condition and degradation risk across Queensland over more than a decade and Alan Peacock for preparing many of the figures. The financial support of the World Meteorological Organization (WMO), Department of Natural Resources and Water and Meat and Livestock Australia to attend the International Workshop on Climate and Land Degradation is gratefully acknowledged.

References

Allan RJ (1985). The Australasian Summer Monsoon, Teleconnections, and Flooding in the Lake Eyre Basin. Royal Geographical Society of Australasia.

Barrows TT, Juggins S, De Deckker P, Thiede J, Martinez JI (2000). Sea-surface temperatures of the southwest Pacific Ocean during the Last Glacial Maximum. Paleoceanography, 15:95-109.

Botterill LC (2003). Beyond Drought in Australia: The Way Forward. In: (Botterill LC, Fisher M eds.) Beyond Drought: People, Policy and Perspectives. CSIRO Publishing, Collingwood, Victoria, pp. 197-207.

Cai W (2006). Antarctic ozone depletion causes an intensification of the Southern Ocean super-gyre circulation. Geophys Res Lett 33, L03712, doi:10.1029/2005GLO24911.

Cai W, Shi G, Cowan T, Bi D, Ribbe J (2005). The response of the Southern Annular Mode, the East Australian Current and the southern mid-latitude ocean circulation to global warming. Geophys Res Lett 32, L23706, doi:10.1029/2005GL024701.

Carter JO, Bruget D, Hassett R, Henry B, Ahrens D, Brook K, Day K, Flood N, Hall W, McKeon G, Paull C (2003). Australian Grassland and Rangeland Assessment by Spatial Simulation (AussieGRASS). In: (Stone R, Partridge I ed.) Science for Drought, Proceedings of the National Drought Forum, Brisbane, April 2003. Queensland Department of Primary Industries, pp. 152-159.

Compo GP, Whitaker JS, Sardeshmukh PD (2006) Feasibility of a 100-year reanalysis using only surface pressure data. B Am Meteorol Soc 87:175-190.

Dai A, Trenberth KE, Qian T (2004) A global data set of Palmer Drought Severity Index for 1870-2002: Relationship with soil moisture and effects of surface warming. J Hydrometeorol 5:1117-1130.

Day K, Ahrens D, McKeon G (2003) Simulating historical droughts: some lessons for drought policy. In: Proceedings of the National Drought Forum: Science for Drought. 15-16 April 2003. Brisbane, Queensland, pp. 141-151.

De Deckker P, Kershaw AP, Williams MAJ (1988) Past environmental analogues. In: (Pearman GI ed.)Greenhouse, Planning for Climate Change. CSIRO Australia, East Melbourne, Vic. pp. 488.

Donald A, Meinke H, Power B, Maia A de HN, Wheeler MC, White N, Stone RC, Ribbe J (2006). Near-global impact of the Madden-Julian Oscillation on rainfall. Geophys Res Lett 33: L09704, doi:10.1029./2005GL025155.

Hall WB, McKeon GM, Carter JO, Day KA, Howden SM, Scanlan JC, Johnston PW, Burrows WH (1998) Climate change and Queensland's grazing lands: II. An assessment of the impact on animal production from native pastures. Rangeland J 20: 177-205.

Hassett R, Carter J, Henry B (2006) Rapid Mobile Data Collection – A Technichue to monitor rangeland condition and provide quantitative and interpretive information for a range of applications. In: (Erkelenz P ed.) The Cutting Edge: Proceedings of the 14th Biennial Conference of The Australian Rangeland Society, Renmark, South Australia 3rd-7th September 2006, pp.202-205.

Hendy EJ, Gagan MK, Lough JM (2003) Chronological control of coral records using luminescent lines and evidence for non-stationary ENSO teleconnections in northeast Australia. The Holocene 13:187-199.

IPCC (Intergovernmental Panel on Climate Change) (2007). Climate Change 2007 Working Group I: The Physical Basis of Climate Change. Cambridge University Press.

Lawrence PJ, McAlpine CA, Skytus J, McGowan H, Phinn SP, Crimp S (2007). Modelling the impact of historical Australian land cover change on Australian regional and continental climate. Global Plane Change *(In review)*

Manins P, Allan R, Beer T, Fraser P, Holper P, Suppiah R, Walsh K. (2001). Atmosphere, Australia State of the Environment Report (Theme Report). Department of Environment and Heritage: Canberra.

McBride JL, Nicholls N (1983) Seasonal relationships between Australian rainfall and the Southern Oscillation. Mon Weather Rev 111:1998-2004.

McKeon GM, Ash AJ, Hall WB, Stafford Smith M (2000) Simulation of grazing strategies for beef production in north-east Queensland. In: (Hammer G, Nicholls N, Mitchell C eds.) Applications of seasonal climate forecasting in agricultural and natural ecosystems – the Australian experience. Kluwer Academic Press, Netherlands, pp.227-52.

McKeon GM, Hall WB, Henry BK, Stone GS, Watson IW (2004) Pasture Degradation and Recovery in Australia's Rangelands: Learning from History. Queensland Department of Natural Resources, Mines and Energy. pp. 256

Meinke H, Stone RC (2005) Seasonal and inter-annual climate forecasting: The new tool for increasing preparedness to climate variability and change in agricultural planning and operations, Clim Chang 70:221-253.
Narisma GT, Foley JA, Licker R, Ramankutty N (2007) Abrupt changes in rainfall during the twentieth century. Geophys Res Lett 34, L06710, doi:10.1029/2006GL028628.
Nicholls N (1988) El Niño Southern Oscillation and Rainfall Variability. *J. Climate* 1: 418–421.
Nicholls N (1991) The El Nino/Southern Oscillation and Australian Vegetation. Vegetatio 91:23-36.
Nicholls N (2006) Detecting and attributing Australian climate change: a review. Aust Meteorol Mag 55:199-211.
Noble JC, Vines RG (1993) Fire studies in mallee (Eucalyptus spp.) communities of western New South Wales; grass fuel dynamics and associated weather patterns. Rangeland J 15: 270-97.
Pittock AB (1975) Climatic change and the patterns of variation in Australia rainfall. Search 6:498-504.
Power S, Casey T, Folland C, Colman A, Mehta V (1999). Inter-decadal modulation of the impact of ENSO on Australia. Clim Dynam 15:319-24.
Prince SD (2002) Spatial and Temporal Scales for Detection of Desertification. In: (Reynolds JF, Stafford Smith DM, eds.) Global Desertification: Do Humans Cause Deserts?. Report of the 88th Dahlem Workshop, Dahlem University Press, Berlin, pp. 23-40.
Rotstayn LD, Cai W, Dix MR, Farquhar GD, Feng Y, Ginoux P, Herzog M, Ito A, Penner JE, Roderick ML, Wang M (2006) Have Australian Rainfall and Cloudiness increased due to the Remote Effects of Asian Anthropogenic Aerosols? J Geophys Res 83p. DOI:10.1029.
Smith I (2004) An assessment of recent trends in Australian rainfall, Aust Meteorol Mag *53*:163-173.
Stone RC, Hammer GL, Marcussen T (1996) Prediction of global rainfall probabilities using phases of the Southern Oscillation Index. Nature 384: 252-255.
Syktus J (2005) Reasons for decline in eastern Australia's rainfall. B Am Meteorol Soc 86:624.
Syktus J, McKeon G, Flood N, Smith I, Goddard L (2003) Evaluation of a dynamical seasonal climate forecast system for Queensland. In: (Stone R, Partridge I eds.) Science for Drought, Proceedings of the National Drought Forum, Brisbane, April 2003. Queensland Department of Primary Industries, pp. 160-173.
Vecchi GA, Soden BJ, Wittenberg AT, Held IM, Leetmaa A, Harrison MJ (2005) Weakening of tropical Pacific atmospheric circulation due to anthropogenic forcing. Nature: 441:73–76.
Walker BH, Abel N, Stafford Smith DM, Langridge J (2002) A framework for the determinants of degradation in arid ecosystems. In: (Reynolds JF, Stafford Smith DM eds.) Global Desertification: Do Humans Cause Deserts? Report of the 88th Dahlem Workshop, Dahlem University Press, Berlin, pp. 75-94.
Watkins AB (2005) The Australian Drought of 2005. WMO Bull 54:156-162.
White WB, McKeon GM, Syktus JI (2003) Australian Drought: The Interference of Multi-spectral Global Standing Modes and Travelling Waves. Int J Climatol 23: 631-662.

CHAPTER 12

Fire Weather and Land Degradation

Opha Pauline Dube

Abstract. Recent years have witnessed a global increase in more intense, widespread and frequent fires that threaten human security and ecosystems and contribute to green house gas emissions which result in climate change with feed-backs on both fire patterns and land degradation. The interplay between fire weather-risk and land degradation is complex and involves several non linear inter-actions that influence trends in both fire patterns and land degradation processes. Majority of fires are lit by humans but the influence of humans on fire patterns is closely related to fire weather. Weather conditions are the main factors of fire readiness in a given fire prone area. Frequent and more intense fires reduce bio-mass supported in an area, affecting the productive soil layer which leads to soil erosion, change in species composition and a general decline in biodiversity and hence land degradation. In this regard fire is an agent of land degradation which is defined here as a persistent reduction in the capacity of ecosystems to supply services. In arid to semi-arid and dry sub-humid areas, extensive burning may be followed by low rainfall periods thus exposing soil to erosion agents such as heat, and wind and subsequent encroachment of the area by fast growing weeds when normal rainfall return which increases fire risk in that area than before.

Of major concern is how climate change will influence the interaction between fire weather and land degradation. Observations in different regions already link more intense fires witnessed in the past decade to climate change generated hotter and drier summer weather, in addition to fire suppression practices. Prolonged drought under climate change is likely to intensify land degradation due to land use pressure setting conditions for the spread of more fast growing highly flammable weeds during the onset of rainfall. Current evidence suggests that in arid to semi-arid lands, invasive highly flammable herbaceous species associated with degraded lands may out-compete native vegetation during abnormally wet periods under climate change. And with increased fire weather-risk, these areas will undergo increased hot fires facilitated by accumulated dry highly flammable biomass of these invasive species and hence putting the landscape under a perpetual cycle of increased susceptibility to land degradation and fire. Future land degradation studies need to put greater emphasis on the role of fire weather for a better assessment of burning conditions and interaction with land degradation processes.

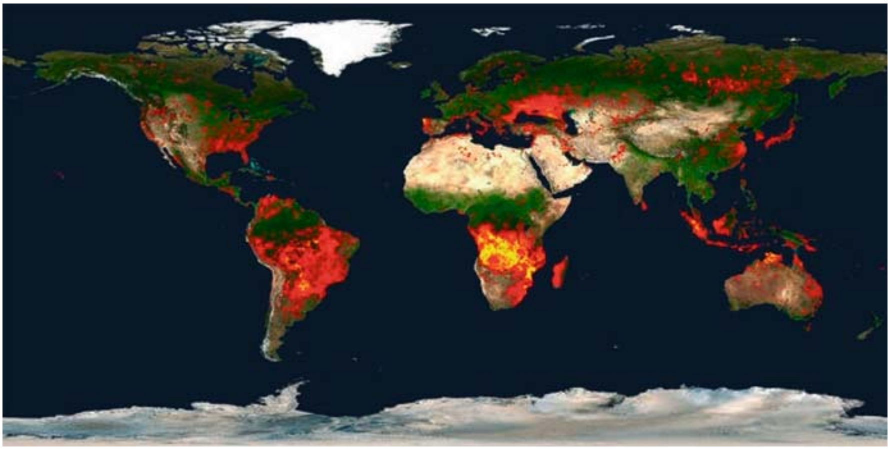


Fig. 12.1. MODIS Global fire map for period: 07/30/06–08/08/06 (2006211-2006220). An accumulation of active fires over a 10-day period detected by MODIS on board the Terra and Aqua satellites. Each colored on the map dot indicates a location where MODIS detected at least one fire during the compositing period. Color ranges from red where the fire count is low to yellow where number of fires is large. (Credits: Fire maps by Jacques Descloitres, MODIS Rapid Response System at NASA/GSFC; Fire detection algorithm by Louis Giglio; Fire locations produced by the MODIS Rapid Response System since mid-2001 and Background image created by Reto Stokli) (http://rapidfire.sci.gsfc.nasa.gov/firemaps/)

12.1 Introduction

Fires burn large areas annually in all continents, affecting boreal and temperate forests, tropical forests, tropical and subtropical savannas, wood-lands and open forests (Bond et al. 2005; Carmona-Moreno 2005) (Figure 12.1). About 168 million ha burn annually south of the equator in Africa; in the US the ten-year average of area burnt (1990-1999) was 1.5 million ha; and in Europe the annual burnt area reached 740,379 ha during the 2003 drought (Goldammer and de Ronde 2004; Amatullia et al. 2007). Recent decades have experienced incidents of frequent, more intense and widespread fires that threaten human security, ecosystems and contribute large green house gases into the atmosphere and ultimately influence climate processes (Goldammer 1998; Soja et al. 2007). These fires have been linked to hotter and drier weather due to climate change in addition to land management (Stocks et al. 1998; Bond et al. 2003). There is a need for increasing our understanding of the effects of fire on the productivity of ecosystems, in particular, its interaction with land degradation and resulting feedbacks (Bond et al. 2005; Soja et al. 2007).

Fire is a process of combustion which requires fuel (in this case vegetation), heat (by human or natural processes) sufficient to ignite available fuels and oxygen to feed the chemical reaction (oxidation) that occurs during the process of burning (Stocks et al. 1997; Trollope et al. 2004). The process of combustion and spread of burning is closely linked to climatic factors such as precipitation, temperature and wind and these define the fire weather. Fire weather influences:

- Pre-fire conditions that determine if a fire will occur at all
- The process of burning which relates to the spread and intensity of the fire and
- The post-fire period that is, the short and long term consequences of fire (Pyne et al. 1996).

A combination of these meteorological parameters and other factors such as soil fertility, topography, herbivore and land management in general can increase or decrease fire-weather risk and influence the effect of fire on the landscape (Van Wilgen and Scholes 1997; Goldammer and de Ronde 2004).

The importance of fire in shaping ecological processes has long been recognized (Frost and Robertson 1987; Pyne 1995; Pyne et al. 1996; Goldammer and de Ronde 2004). For example, rainfall and landscape factors may define the distribution of forests but the actual location of forests is influenced by fire patterns (Geldenhuys, 1994; Bond et al. 2004). Under natural conditions fire is considered to be one of the most important rejuvenating factors in nearly all forest ecosystems (Hagner 1999; Keeley and Rundel 2005; Savadogo et al. 2007). It is known to stimulate seed germi-nation in different *Acacia* species in semi-arid lands and there are indications that smoke treatments from fires can be of use in the propagation of economically important wild plants (Kulkarni et al. 2007). In the boreal region wildfire ignited by lightning clears old and dead trees thus opening space for new seedlings and increasing availability of nutrients and in the process maintaining age structure, species composition, and the floristic diversity of these forests (Pyne et al. 1996; GEO 3 2002; Beverly and Martell 2005; Soja et al. 2007).

While the ecological role of fire is well documented, its broader role in environmental processes and resulting feedback on climate and ultimately livelihood systems has until recently received limited attention (Pyne et al. 1996; Van Wilgen et al. 1997; Goldammer 1998; Gonzalez-Perez et al. 2004). Recent work has shown that in addition to its known ecological dimensions, fire is also an important land use tool, a growing global hazard and a factor in climate processes with feed backs on land degradation (IPCC 2001a; Dube 2005; Goldammer and de Ronde, 2004).

Land degradation, which occurs in all continents that have dryland areas (Asia, Africa, Australia, America and to a lesser extent Europe) has received wide international recognition since the 1970s following the devastating drought in the Sahel region and the subsequent establishment of the UN Convention on Combating Desertification (UNCCD) in 1994 (MA 2005b; WMO 2005). The UNCCD defined desertification as "land degradation in arid, semi-arid and dry sub-humid lands resulting from various factors including climatic variation and human activities". Land degradation is defined as the reduction or loss of the biological or economic pro-ductivity of dry lands (MA 2005b). Changes in fire regimes due to climate change are likely to extend susceptibility to land degradation to, for instance, humid-temperate and boreal zones, regions which are not normally considered to be the most vulnerable to this phenomenon (Hagner 1999; Soja et al. 2007; Groisman et al. 2006).

Drylands are marked by seasonal moisture patterns, a factor which also makes them fire prone areas (Feddema and Freire 2001; Goldammer and de Ronde 2004; Soja et al. 2007; MA 2005b). Water scarcity limits plant production and other ecosystem provisioning services in these regions (Nicholson 2002; Leemans and Kleidon 2002). Drylands are home to a third of the global population, majority of which are greatly depended on ecosystem services than in any other region (MA 2005b; Nicholson 2002). But about 20% of these regions are already degraded and scenarios of future development point to intensification of land degradation if interventions are not made (Feddema and Freire 2001). Sub-Saharan and Central Asia are the most vulnerable (MA 2005b). Land degradation affects 46% of the surface area of Africa and most of those residing in these areas live in poverty (WMO 2006; AEO 2002; AEO II 2006).

Although fire occurs over a short time and has visible immediate impacts in contrast to the slow and somewhat imperceptible processes of land degradation, both processes are strongly driven by climate and also result in feedbacks on climate processes (Gitay et al. 2002; Foley et al. 2003). In addition to climate, topography and land use management are also influential (Dukes and Mooney 1999). The interplay between fire, land degradation and links to climate carries multiple dimensions and will become more complicated under climate change. Depending on climate, topography and other factors, fire can lead to land degradation (MA 2005a and b). But under certain conditions, land degradation too can create conducive conditions for fire to thrive (Lovich and Bainbridge 1996).

This chapter aims to highlight the link between fire-weather risk and land degradation and potential feed backs. The focus of the chapter is on the role of fire weather on pre and post-fire effects on the landscape. Understanding the interactions between fire- weather risk and land degradation and feed backs under the current climate will, hopefully help to model future trends and determine appropriate mitigation and adaptation measures required. The first section of the chapter provides background on the land degradation phenomena, fire and fire weather. This is followed by a section on the role of fire in land degradation, the interface between fire and land degradation and implications of climate change. The final section covers the need for international collaborations to mitigate the negative effects of fire on the landscape.

12.2
The land degradation Problem

Land degradation processes result from reduction of vegetation cover through for example; frequent burning and subsequent exposure of soil to agents of soil erosion such as heat, wind and water (Shakesby et al. 2007). Ultimately this leads among others to fragmentation of the landscape; loss of soil fertility; change in vegetation species composition and loss of bio-diversity; salinisation in some regions; and siltation which reduces the capacity of reservoirs, increases susceptibility to flooding and has negative effects on fresh water fish production (Lorup et al. 1998; Dube and Kwerepe 2000; Dube and Pickup 2001) (Figure 12.2). Depending on the landscape and other factors, degraded areas are quickly colonized by annual grasses and or woody weeds (bush encroachment) (Gitay et al. 2002; Leemans and Kleidon 2002).

Climatic factors such as large inter-annual variability in precipitation and extreme temperatures contribute to increased vulnerability of dry lands to land deg-

Fig. 12.2. Sheet and gully erosion along drainage lines over areas with depleted vegetation due to overgrazing and other wood harvesting activities in the vicinity of a village in the North east District, Botswana. (Courtesy of M.B.M. Sekhwela)

radation (Feddema and Freire 2001; Leemans and Kleidon 2002). In some parts of the Kalahari in Southern Africa annual precipitation during dry years deviates from the long-term average by as much as 80% (Geist and Lambin 2004). Dry land areas have poorly formed soils with low organic matter which make them highly susceptible to erosion processes once exposed (WMO 2006). The role of socio-economic factors in addition to climate in land degradation processes have been noted in various studies (Dube and Pickup 2001; IPCC 2001a; Vogel and Smith 2002; MA 2005b; Geist and Lambin 2004). Land use impacts that threaten ecosystem resilience in dry lands usually intensify over drought periods when demand for ecosystems services far exceeds supply (Dube and Pickup 2001; AEO 2002; Gitay et al. 2002; Geist and Lambin 2004; MA 2005b; AEO II 2006). Land degradation is an interactive process involving multiple factors among which climate variability and land use play a significant role (Reynolds and Stafford Smith 2002; Geist and Lambin 2004; Lioubimtseva and Adams 2004).

12.3 Influential characteristics of fire in land degradation

In general about 90% of bush fires globally are lit by humans (Main and Haines 1974; Frost and Robertson 1987; Pyne et al. 1996; Van Wilgen and Scholes 1997; Goncalves et al. 2006); some through arson, carelessness, prescribed burns, but majority of ignition sources are linked to population increase, livelihood systems practiced and the breakdown of traditional land management systems (Frost 1994; Goldammer and de Ronde 2004; Sheuyange et al. 2005). The number of fires lit does not always relate to area burnt for instance, in Alaska human ignitions account for about 85% of the fires but only 10% of the area while the rest is due to lightning (Soja et al. 2007).

Most fire prone areas have a distinct wet period which allow fuel to accumulate and a dry period providing conditions for fire to easily ignite and spread quickly, hence the susceptibility of dry lands to fire (Beverly and Martell 2005; Keeley and Rundel 2005; Shakesby et al. 2007). These areas also tend to experience cycles of drought and exceptionally wet years; examples include Sub-Sahara Africa (Goldammer and de Ronde 2004) and areas under the Mediterranean climate (the Mediterranean region, the coasts of California and Chile and the east coast of Australia) (Pyne et al. 1996; Gimeno-García et al. 2007; Goncalves et al. 2006).

12.4 Fire Weather

The effect of fire on land degradation depends on fire behavior which is mostly influenced by weather but also by topography and human activities. Land management and herbivores can reduce fuel load or change the vegetation structure for instance from grasslands to woody layers with limited herbaceous cover and hence lower the fire-weather risk environment (Van Wilgen and Scholes 1997; Dube and Pickup 2001; Moleele et al. 2002) (Table 12.1). Other land uses such as timber harvesting help open forests and increase susceptibility to fire as was the case for the 1983 Indonesia fires (Pyne et al. 1996). The role of humans in fire patterns occur under a conducive fire environment (Pyne et al. 1996; Van Wilgen et al. 2004). Large fierce fires of 2000 in the United States of America were due to human interventions including timber harvesting and years of fire suppression which led to expansion of fire sensitive species such as *Calocedrus decurrens* (Torrey) and *Florin* (incense-cedar) but also the severe drought experienced during that year (Franklin 2006).

Fire weather defines the environment that is conducive for fire to occur. The basic elements in fire weather are meteorological factors: air temperature, precipitation, relative humidity, wind speed (Table 12.2. and Fig. 12.3) (Van Wilgen and Scholes 1997). The effect of these variables on fire spread rates is the same in different regions for example, the savannas with fire fuel consumption of 500 g m^{-2} in arid zones to 1500g m^{-2} in sub-humid experience similar effects as humid boreal and temperate ecosystems where forest fuel can be as high as 4000-5000g m^{-2} (Stocks et al. 1997).

Topography can influence fire weather in various ways. Depending on steepness, slope influences wind speed and direction and also through soil moisture it influences fuels load (Geldenhuys 1994). Rough terrain may change direction and variability of wind speed affecting fire spread and ability for fire to be suppressed (Geldenhuys et al. 2004). Soil fertility combined with rainfall influences fuel type and density. Aspect influences amount of rainfall and exposure to the sun. Fuels that are located on slopes facing the sun are likely to loose moisture rapidly and therefore have a higher fire-weather risk.

Table 12.1. Fire scars relative to distance from water source on historical Air Photographs in Ranch 19 in the Hainaveld, Ngamilad District, Botswana. The scars were visually identified using tone, texture and shape and assessment of their spatial dimension was also estimated visually.

Year	Zones*	Fire scar	Average of 5year Rainfall compared to long term annual mean of the area**
1957	1	Limited area burned	> Mean
	2	Moderate to extensive burn	
1973	2	Moderate to extensive burn	> Mean
	3	Moderate to extensive burn	
1983	–	None at all distances	< Mean
1991	2	Limited area burned	< Mean
1996	2	Limited area burned	< Mean
	3	Moderate to extensive burn	

* Zones mark distance from the water source such that Zone 1 = 0-1.5 km: Zone 2 = 1.5-3 km: and Zone 3 = 3-5km.
**Long term mean annual rainfall is 450mm

12.4.1 Fire season

Meteorological factors are instrumental in determining the fire season i.e. the period over the year when the fire-weather risk is at its highest and fires are most likely to occur (Fig. 12.3). In Botswana, south of the equator, the fire season begins around August and reaches its peak in September after which it declines. Temperatures are high over November to March in Botswana but few fire incidents occur at this time due to high relative humidity (RH) and moisture in the fuel since this is the wet season (Figure 12.3). For the African savannas north of the equator, the peak fire season is in January when rainfall reaches the lowest levels, less than 25 mm (de Ronde et al. 2004).

Lighting fires are more likely between October and January in Southern Africa at the beginning of the wet season, when thunderstorms are active. In contrast majority of human induced fires occur within May to September (de Ronde et al. 2004) extending from winter to the dry season. In general early dry season fires i.e. at the onset of the dry season, when the vegetation is still moist, are less harmful than middle to late dry season fires, when vegetation has lost most of the moisture, air temperature is high and relative humidity RH is low (August to October for much of Southern Africa) (Figure 12.3). Frequent middle to late season fires are the most destructive because in addition to reduction of vegetation cover they may kill the seed bank and emerging plants and destroy soil properties as noted below.

Table 12.2. Elements of fire weather and their relation to fire (Sources: Frost and Robertson 1987; Pyne et al. 1996; Van Wilgen and Scholes 1997; Goldermmar and de Ronde 2004)

Elements of Fire weather	Interaction with fire
Wind	Affects the rate of fire spread i.e. it provides oxygen for fire to burn and helps to dry fuel ahead of the fire which further facilitates burning. This positive relationship with fire occurs for head fires in particular and up to a certain wind speed after which for the case of grasses for instance, the rate of fire spread may be decreased (Trollope et al. 2004)
Air temperature	Reduces fuel moisture hence fire is likely to be more in-tense at mid-day or during hot weather conditions when maximum temperatures occur. The positive relation with fire is maintained depending on other factors, such as precipitation.
Precipitation (rainfall heavy fog, dew, snow)	Determines quantity, type and condition of fuel which influences type and intensity of fire. For instance, there is a positive relationship between fire and rainfall. But precipitation also increases fuel moisture and hence reduces ability for fire to occur and as a result it also has a negative effect during certain periods.
Relative hu-midity (RH)	Because the amount of moisture in the air affects fuel moisture content there is a negative relationship between RH and fire. RH is lowest in the afternoon and this increases the potential for fire to occur. Fire tends to occur during months of low RH depending on general plant moisture and other weather parameters such as wind (Figure 12.3).

In addition to the fire season there is also a difference in fires in terms of timing within a day. Night or morning fires are likely to be cooler and of lower intensity and hence less destructive than day time fires when temperatures are higher.

12.4.2
Types of fire

There are different types of fires and these have different impacts on the landscape. Using fuel types, especially vertical projection, which are defined by climatic factors, fire has been categorized into different classes: ground fires that burn organic matter underground; surface fires that burn litter, grasses and shrubs (Figure 12.4); and crown fires that cover the crown layer fuels (Trollope et al. 2004; Govender et al. 2006). Other classifications of fire are based on spread in relation to wind and position of fire in relation to fire perimeter: a head fire is a surface fire driven by wind hence it burns in the direction of the wind; a back fire is a fire that burns against the wind and or down slope; flank fire is intermediate to the other two; and spot fires are caused by burning embers carried a distance from the head

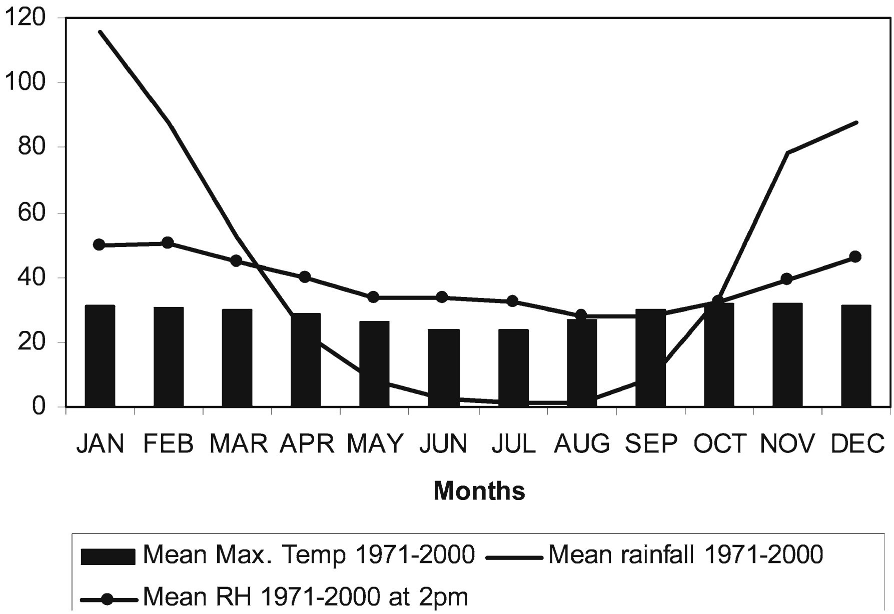


Fig. 12.3. Monthly mean rainfall, temperature and relative humidity (RH) related to fire distribution at Francistown, Botswana. The fire season begins roughly in August over the dry season, when vegetation has had nearly 3 months of no rainfall and by then temperatures begin to rise while RH declines. The peak of the fire-weather risk is in September when RH is below 30%. The fire season declines by end of October when rainfall peaks and RH increases. (Data was provided by the Department of Meteorological Services – Botswana)

fire. In general slope has a positive effect on head fires and a negative impact on back fires.

Fire types relate to heat energy produced and maintained during burning and as a result they have different effects on vegetation and soil. Surface fires burning as back fires in the grassland and savannas tend to maintain high temperatures for a slightly longer period than surface head fires and as a result they can depress the re-growth of grass more than head fires (de Ronde et al. 2004). Both head and back fires cause great damage on lower height shrubs. But when the shrub heights increases head fires have more effect due to the fact that they tend to have greater flame height than back fires (Pyne et al. 1996).

12.4.3 Fire intensity

Fire intensity is the key factor determining the impact of fire on ecosystems and the probability for fire to give rise to land degradation. Meteorological factors together with fuel available to burn, affect the heat produced during burning, the amount of

Fig. 12.4. A controlled surface fire at the Kruger National Park, July 2003. The fire burned the herbaceous layer and shrubs of about 2m in height. (Courtesy of Diane Davies and Chris Justice)

fuel burnt and the spread of a fire, all of which influence fire intensity. Fire intensity is given as follows (Trollope et al. 2004):

$$I = H \times w \times r$$

where, I = fire intensity (kJ s^{-1} m^{-1})
H = heat yield (kJ kg^{-1})
W = mass of available fuel (kg m^{-2})
r = rate of spread of the fire front (m s^{-1})

On average intense fires spread at rates of 30-60 m min^{-1} but exceptionally high speed fires of about 100 m min^{-1} have been registered (Stocks et al. 1997). For areas of lower fuel loads such as the savanna intensity levels rarely exceed 20 000 kW/m^{-1} in contrast to boreal fires with levels between 50 000 and 100 000kW/m^{-1} occur (Stocks et al., 1997). In the Kruger National Park in South Africa it has been noted that for large fires to occur there is need for fuel in excess of 3500 kg ha^{-1} in addition to the dry hot weather (Van Wilgen et al. 2000).

Because arid to semi-arid and dry sub humid areas experience a highly variable climate, the fire-weather risk is also variable and this influence fire intensity and plant response to fire (Govender et al. 2006). High fire intensity is experienced when prolonged hot and dry conditions follow periods of high fuel production i.e. average to exceptionally wet years. Fire timing influences fire intensity and hence the level of damage on vegetation and soil (Hiers et al. 2000). In general high frequency of fire-weather risk that results in high intensity fires is the most detrimental on ecosystems. Post-burn conditions such as level of land use pressure and rainfall experienced on burnt sites also determine the short and long-term effects of fire on the landscape (Pyne et al. 1996; Frost and Robertson 1987).

Understanding fire weather, fire season, fire type and intensity forms the basis for developing a fire danger index. Fire danger rating is a key factor in fire early warning systems providing information on the degree of fire-weather risk (Pyne et al. 1996; Pearce et al. 2005; Goncalves 2006).

12.5 Fire weather and land degradation

The need to use fire in land use management in developing countries contribute to frequent fire outbreaks while in developed countries past fire protection programmes and increased public access to forests are some of the factors that contribute to outbreaks of large scale burning under high fire-weather risk (Frost 1994; Goldammer and de Ronde 2004 and GEO 3 2002). This section looks at how the different characteristics of fire behavior noted above interactively affect ecosystem productivity and contribute to land degradation.

12.5.1 Effect of Fire on vegetation

The effects of fire on vegetation depend on a variety of factors among which is fire intensity, frequency, type and timing and vegetation type and post burn conditions (Hall 1994; Hiers et al. 2000). In the short term fire reduces vegetation cover while long term effects may include change in vegetation structure and species composition with implications on biodiversity and general productivity of the landscape (Shakesby et al. 2007).

12.5.2 Fire and vegetation structure

The effect of fire on vegetation structure depends on tree species, height and diameter in addition to fire type, timing and frequency. In general woody plants become more resistant to fire as their height increase (Tews et al. 2006). In grass fires for instance, in the savannas, high intensity and repeated burning kill young woody plants (less than 0.5 m to 2 m height) and seeds (Frost and Robertson 1987; Tews et al. 2006) (Figure 12.4). Ground fires damage shallow rooted tree species through injury to the roots (de Ronde et al. 2004).

High intensity crown fires occurring during the late dry season can be very destructive on woody vegetation because they result in complete combustion of leaves, killing the aerial portions of trees and shrubs such that they can only resprout from the bottom (Figure 12.5). From experiments in Eastern Cape in South Africa crown and surface head fires were found to cause greater damage on shrubs; 75% reduction in phytomass as opposed to crown and surface back fires with 42% reduction (de Ronde et al. 2004).

Late dry season fires in southern Africa reduce the regeneration of Miombo species such as *Baikiaea plurijuga* and *Guibourtia coleosperma* (Geldenhuys et al. 2004). About 44% of the of the total population of *P. angolensis* Miombo woodland species in Nagmiland in Botswana were found dead after the 1998 dry season fires (Ministry of Agriculture 1999). Frequent and intense day time prescribed burning in the Kruger National Park over the 1957-1991 period contributed to the decline in big trees (Van Wilgen 2004).

The decline of large tress in particular, may also be due to herbivory in addition to fire. Elephants (*Loxodonta Africana*) for example, destroy large trees and accumulate dead plant material on the ground which is easy to ignite. By so doing they change forest into open woodlands which are sus-ceptible to fires (Yeaton 1988; Geldenhuys et al. 2004). Others have also noted that in some cases the impacts of fire on woody vegetation might be event driven i.e. occurrence of a certain type of fire at certain threshold intensity may cause major damage in contrast to annual fires that are below threshold (de Ronde et al. 2004).

Nevertheless, repeated burning progressively changes the vegetation structure to open shrub-woodland vegetation type which is a more fire prone system because of high grass biomass production (Bond et al. 2003 and 2004; Geldenhuys et

Fig. 12.5. A fire scar with burnt shrubs resprouting from the base on the sandy soils Etsha – Gumare area, western Okavango Delta in Ngamiland District in Botswana, 2003 (Courtesy of Balakidzi Nduna)

al. 2004; Van Wilgen et al. 2004; Keeley and Rundel 2005; Sheuyange et al. 2005; Franklin et al. 2006; Styger et al. 2007). Fire is noted to have had a role of stabilizing open vegetation formations by impeding establishment of forest species in the subtropical South America zones now covered by grassland vegetation, despite the humid climatic conditions that allow for forest development (Bond et al. 2005; Overbeck and Pfadenhauer 2005). Similar conclusions have been made for the grasslands of Ethiopia using Carbon isotope pattern in the soil profiles indicating that current vegetation patterns in fire prone areas reflect effects of past fire regimes (Michelsen et al. 2004).

Areas of frequent burning result in reduced biodiversity and a landscape that supports fast growing flammable invader species which are known to colonize disturbed areas (Bond et al. 2005; Sheuyange et al. 2005; Overbeck and Pfadenhauer 2005; Franklin et al. 2006; Savadogo et al. 2007). Repeated fires may breed a fire loop i.e. the more the fires the more open the vegetation resulting in higher fire proneness which increases the fire return period (Frost and Robertson 1987; Keeley and Rundel 2005; Styger et al. 2007). Indications are that withdrawal of fire under favorable conditions i.e. with sufficient rainfall, invariably leads to the development of a dense closed canopy which eventually develops into a forest with more diverse species composition (Frost and Robertson 1987; Bond et al. 2005; Sheuyange et al. 2005; Franklin et al. 2006).

12.5.3 Fire and Biodiversity

One indicator of land degradation is loss of biodiversity and this can be enhanced by fire. The role of fire in biodiversity is however, complex and is also influenced by factors other than fire regime (defined in terms of fire frequency, season, severity and area burnt and the vegetation type) and post-fire conditions (Gill 1994; Hiers et al. 2000; Castellano and Ansley 2007). For example, *Themeda triandra* in East Africa increases under frequent burning and decreases if fire is excluded. But because this species is susceptible to drought in a semi-arid environment, less burning or total protection will be most favorable (Frost and Robertson 1987).

Frequent fire affects species richness because species have different fire tolerance levels. Fire tolerance include among others: developing insulating tissues in the young stages such as a thick, corky bark and high wood moisture and or a developed underground swollen root systems which grow coppice shoots after fire (Van Wilgen and Scholes 1997; Geldenhuys et al. 2004). Fire may favor certain species and reduce or eliminate others under different conditions (Van Wilgen et al. 2004; Savadogo et al. 2007). For the Fynbos ecosystem in South Africa, biodiversity is maintained through periodic burning. But this depends on the fire regime such that where the fire return interval is short then species such as *serotinous proteas* which mature after 3-10 years may not get adequate time to accumulate seedbank for species continuity. On the same token if the fire interval is longer the *serotinous proteas* may get extinct because very few seeds produce seedlings without post-burn conditions (Geldenhuys et al. 2004).

Fire season has differential effects on the reproductive phenology and total flower production in different species. Lightning-season fires have been found to cause more synchronized and delayed flowering within and among species in longleaf pine savannas in northern Florida (Hiers et al. 2000). Most plants burned prior to mid-April produced flowers before May while those burned in the late spring and summer did not produce flowers until July or August in longleaf pine savannas.

Plant regeneration is also affected by fire season as noted for woody plants above. Several understorey species within the Fynbos regenerate best when exposed to autumn fires (March-April) than winter fires (June, July and August). Frequent winter fires may promote some species of *Asteraceae* which are known to suppress other species and create a fire hazard environment if allowed to occur at high density (Geldenhuys et al. 2004). But autumn burn only can result in high density of *proteas* hence the need for a mix of summer and autumn burns and limited winter fires to maintain biodiversity. While in the southern Great Plains in the USA, high intensity summer fires favored C4 over C3 grasses and this is thought to be due to differences in post-fire soil conditions such as increased temperature, reduced moisture and reduced mineralizable nitrogen while C3 grasses were negatively affected by fire regardless of the season (Castellano and Ansley 2007). In general C4 grasses are favoured by warm, dry conditions, have greater nitrogen use efficiency (NUE) and store a larger proportion of their total N in belowground structures than C3 grasses (Dukes and Mooney 2001).

A combination of fire and other disturbances on the landscape result in greater loss of biodiversity and the development of land degradation. In eastern Madagascar the slash and burn agricultural practice has led to the loss of native species to exotic invader shrubs and herbaceous species (Styger et al. 2007). Low intensity early dry season burning can be detrimental if followed by heavy grazing of the emerging highly nutritious forage in post-burn areas because of loss of soil water required to sustain vegetation over the dry season. The same may apply to areas of severe burn if followed by intense post-burn herbivory activity or low rainfall resulting in recruitment failure (van de Vijver 1999; Geldenhuys et al. 2004; Van Wilgen et al. 2004).

For the herbaceous layer the effect of fire on species composition is characterized by reduction in perennials species (Savadogo et al. 2007). In the Kruger National Park in South Africa low diversity of grass species was linked to frequent and intense day time prescribed burning during the 1957-1991 period (Van Wilgen et al. 2004). Frequently burnt areas are eventually dominated by fire resistance species i.e. that have the capacity of regrowth after fire and the capacity for seeds to germinate after thermal exposure. These are usually annual and pioneer species which quickly establish themselves on post-burnt areas (Brooks and Pyke 2001).

In an endeavor to reduce negative impacts of fire in the Kruger National Park, a range of thresholds relating to fire patterns which if exceeded signal that burning will progressively lead to loss of biodiversity were developed. These thresholds were based on fire-return interval, seasonal distribution of fires, and ranges of fire intensities and area burnt (Van Wilgen et al. 2004). However, it has been noted for the fire-dependent longleaf pine savannas known for their highest levels of endemism in North America, that a variable fire regime (i.e. variation in fire seasons) might be a better approach to conserving biodiversity than relying on a particular fire regime (Hiers et al. 2000). Similar conclusions have been made regarding fire severity (defined by biomass consumed) for the Fynbos (Geldenhuys et al. 2004; Van Wilgen et al. 2004).

12.5.4
Impacts of fire on soil

As with biodiversity the impacts of fire on soils are very complex and vary with soil properties, soil moisture, slope, fire regime and fuel load and post-burn conditions (Geldenhuys, et al. 2004; Gonzalez-Perez et al. 2004). Fire affects both physical and chemical properties of soils particularly the productive soil layer. Changes in the soil physical properties leads to loss of the productive soil, increased runoff during wet periods, lower underground water recharge which increases water deficit over dry periods and thus increasing the intensity of drought over dry periods (Feddema and Freire 2001). These changes eventually contribute to the noted change in vegetation structure, species composition and general decline in biodiversity, all of which are features of land degradation (Gimeno-García et al. 2006; Shakesby et al. 2007).

12.5.4.1
Degradation of physical properties of soil

The effect of fire on physical properties of soil result from indirect effects related to loss of above ground biomass leaving the soil exposed to agents of soil erosion: sunlight, wind and rainfall/water which leads to soil degradation (Hall 1994; Geldenhuys et al. 2004; Gonzalez-Perez et al. 2004; Gimeno-García et al. 2006). Fires in African savannas can consume about 70-90% of the herbaceous standing crop and grass litter leaving much of the soil exposed (Frost and Robertson 1987). On sites burnt annually for many years, infiltration rates have been found to be much lower than on adjacent unburnt sites, largely as a result of changes in soil surface structure (Frost and Robertson 1987; Savadogo et al. 2007).

The effects of frequent intensive fire depend on soil type. In fine textured soils, aggregate stability is reduced and soil compaction may occur which gives rise to decrease in infiltration capacity and aeration and increased runoff (Frost and Robertson 1987; Gonzalez-Perez et al. 2004; Savadogo et al. 2007; Shakesby et al. 2007). In coarse textured soils, there may be a development of a water repellent layer in the soil profile resulting in reduction of runoff. Water repellency is due to organic matter transformed into vapour phase during burning and later condensed and chemically bonded to soil particles (Geldenhuys et al. 2004; Gonzalez-Perez et al. 2004; Shakesby et al. 2007).

In areas of steep slope, leaching occurs along with loss of fine particles down slope. In such cases, heavy runoff due to reduced infiltration capacity can be experienced even from mild rain showers. Frequent high intensity fires should be avoided on steep slopes. Reduction of infiltration leads to low water table, low soil moisture and increased siltation down slope which increases susceptibility to flooding (Shakesby et al. 2007).

One of the immediate effects of fires on soil depending on heat produced during burning is loss of soil moisture especially within the top soil layer and this has negative implications in vegetation productivity (Castellano and Ansley 2007). Soil has a low thermal conductivity and as a result it has been noted that temperatures recorded at 2 cm below the surface seldom exceed 35°C and below this depth there is almost no rise in temperature particularly for savanna fires which are generally of relatively lower temperatures (Frost and Robertson 1987). But in post-burn soil temperatures can be significantly higher than in areas not affected by fire, differences of 80°C compared to 23°C respectively have been noted (Frost and Robertson 1987; Geldenhuys et al. 2004; Gonzalez-Perez et al. 2004; Savadogo et al. 2007). These high temperatures combined with increased wind speed on bare post burn areas result in rapid loss of soil moisture in the top soil layer which usually is the most important in vegetation production. The effect of fire on soil moisture is likely to be greatly felt in arid and semiarid areas where water is already a major limiting factor in vegetation growth (van de Vijver 1999).

12.5.4.2
Soil chemical properties

Chemical effects of fire are also very complex. Intense repeated burning has negative effect on soil chemical properties, first through loss of soil organic matter leading to loss of mineral nutrients through leaching although this varies depending on type of fire, soil and vegetation (Hall 1994; Michelsen et al. 2004). In Ethiopia decreasing carbon concentration downwards the soil profile and relatively high soil respiration were found in infrequently burnt forest and woodland in contrast to fire prone grassland systems suggesting loss of carbon during dry season fires which has implications on nutrient cycling (Michelsen et al. 2004). But in some cases there may be an increase in organic matter due to deposition of dry leaves and charred plant materials in fires that partially affect the tree canopy (Gonzalez-Perez et al. 2004).

In the savannas where soil nutrients are concentrated in the surface soil, fire induced erosion gives rise to depletion of the nutrient status of the soil, in addition to reduction in soil depth and water holding capacity. The soil top layer is the most affected because it is the most exposed to thermal effects of fire. However, others have also noted in the case of the savannas, where grass cover dominates, that the effect of few dry season fires on soil nutrients can be limited because by then the growth of most grasses is retarded and nutrients are relocated to underground storage organs (van de Vijver 1999; Castellano and Ansley 2007).

The effect of fire on chemical properties of soil can be divided into two categories i) rapid mineralization of organic matter into ash, and ii) change in microclimate which affects rates of decomposition and mineralization (Frost and Robertson 1987; Pyne et al. 1996; Johansen 2001). In the short term, fire causes a drastic reduction in soil microbial biomass. Burning has been observed to favour bacteria over fungi which is less fire tolerant (Gonzalez-Perez et al. 2004).

Initially fire releases mineral nutrients in the form of ash into the top soil layer hence making it readily available for plant use. The fertilization effect of fire which is partly a result of increased presence of N-fixing bacteria after wildfires and an increase in soil pH linked to increase in exchangeable cations in soil, explain the reasons behind the slash and burn practice and fast regrowth in post-burn areas (Gonzalez-Perez et al. 2004). Annual plants respond more rapidly to this increased level of nutrients after fire than native plants perennial plants (Asher et al. 2001; Brooks and Pyke 2002).

The effect of mineralization on production is mostly transitory in most cases lasting for the early part of the growing season (Frost and Robertson 1987; Hall 1994; Michelsen et al. 2004; Styger et al. 2007). It depends among other factors on soil properties, the amount of vegetation converted to ash, the weather, fire frequency and intensity. Ash disposal lasts for roughly 2-3 weeks after fire and therefore is not a long term source for nutrients. If moisture levels are very low, this temporary fertilization may not be used but it might be lost to the wind. In sandy soils there might be rapid leaching of nutrients and as a result, nutrient pools may decrease after fire. Hall (1994) found that nearly 100 times more calcium and magnesium, 30 times more phosphorus and 20 times more potassium were lost in runoff from burnt plots in a forest area in Australia indicating that significant nutrient movement can occur due to burning leading to loss of soil productivity.

Nitrogen loss can reach 96% of the total available from the top soil especially where fire temperatures are above 400°C (Frost and Robertson 1987; Geldenhuys et al. 2004; Castellano and Ansley 2007). Loss of nitrogen through volatilization and through leaching becomes a strong limiting factor for plant growth and cannot be compensated by mineral disposal (Hall 1994). Legumes (plant fixing nitrogen) can balance this nitrogen loss to some extent subject to availability of suitable conditions. In contrast, phosphorus which has been found to have a role in stimulating tree growth after fire, has a higher temperature volatilization, up to 500°C and is less susceptible to leaching (Frost and Robertson 1987). In arid to semi-arid lands, nitrogen and phosphorous are in general, the most important nutrients limiting the productivity of plant communities, second only to water (Billing et al. 2003).

12.6 Interface between fire weather and land degradation

Increased land use pressure during drought depletes vegetation cover and exposes the landscape to agents of soil erosion (Holmgren and Scheffer 2001). When rainfall returns and depending on severity of the problem and other factors such as soil type, these areas are invaded by fast growing more flammable annual and pioneer species as is the case for areas of repeated burning (Brooks and Pyke 2002; Sheuyange et al. 2005). Hence while fire can be an agent of land degradation, land degradation too may provide conditions that shorten fire intervals setting the area into a land degradation-fire cycle. With persistent drought, the land degradation-fire cycle might be broken due to declining fuel loads but it may return with the onset of rain as invaders will be quick to recruit before native species get established.

Land degradation is exacerbated where the effect of fire is combined with other land use pressures (Dukes and Mooney 1999). Investigations in semi-arid parts of Argentina found that soil carbon in burnt non-grazed areas increased by 16% as opposed to burned and overgrazed sites where loses of 38% were registered (Abrila et al. 2005). Reduction in fallow period under the slash and burn practice in Madagascar, from 8-15 years to 3-5 years within a period of 30 years, led to loss of the rainforest vegetation and eroded soils that are invaded by *Aristida* and *Hyperrhenia* grass species. The use of annual burning to manage pasture for cattle grazing in these areas further perpetuates a fireland degraded environment (Styger et al. 2007). While in the Mediterranean basin of southern Europe, a combination of overgrazing and fire on mountain ranges puts the area at great risk of severe land degradation (Kosmas et al. 2000; Geist and Lambin 2004).

Depending on various factors including soil type and rainfall, depletion of indigenous vegetation either through fire or other land use pressures in drylands has in some areas provided favorable conditions for woody plants to out compete grasses leading to the spread of woody weeds (or bush encroachment) (Tews and Jeltsch 2004; Sheuyange et al. 2005). Bush encroachment is another indicator of land degradation. A long history of grazing in the Mediterranean basin of southern Europe led to loss of indigenous forests and the colonization of the area by highly resilient shrub, phrygana vegetation reflecting various stages of soil degradation (Geist and Lambin 2004). In Botswana species such as *Dichrostachys cenario, Acacia tortilis* and *Melefera* dominate overgrazed areas although this depends on soil type (Dube and Pickup 2001; Moleele et al. 2002). Areas dominated by shrubs suffer greater soil loss and higher evaporation because of lack of a total surface cover that is provided where there is a herbaceous layer.

12.7 Fire weather, Climate change, and Land degradation

The effect of climate change on fire and land degradation and the resulting interaction and potential feedbacks on the climate process in the long run are of great concern (Lioubimtseva and Adams 2004; Abrila et al. 2005; Soja et al. 2007). The inter-relationship between land degradation and climate change are still not clear and others argue that the contribution of dry land degradation to global warming is unlikely to be more than a few percent of the total greenhouse forcing (Feddema and Freire 2001; Hulme and Kelly 1993). While Geist and Lambin (2004) have noted in their analysis that fire is reported as a cause of desertification only one-third as often as prolonged drought periods. Further work is required in the light of future climate change induced fire regimes and the effect of this on fireland degradation interactions and feedbacks.

Intensive fire and land degradation can have a significant effect on climate because of the influence on amount of carbon stored and released into the atmosphere (Michelsen et al. 2004). Lal et al. (1999) estimate an average reduction in the soil organic carbon pool by 8–12 tons of carbon ha^{-1} in the arid regions due to land degradation. Large scale destruction of soil has major implication on global carbon budget given that the total carbon content in the soil over the whole planet is three times larger than total carbon stored in terrestrial vegetation (Houghton 1995). Because fire and widespread land degradation either individually or acting together alter sources and sinks of greenhouse gases and influence the hydrological cycle they can significantly influence global warming (Abrila et al. 2005).

Heat from burning fires results in high surface temperature which induces aridity because of rapid loss of moisture from the top soil layer and from vegetation as it burns. The loss of vegetation over extensive areas whether through fire or other land use induced land degradation reduces evapotranspiration resulting in low latent heat flux which influence meteorological processes (Nicholson 2002; Geist and Lambin 2004; Herrmann and Hutchinson 2005). Desertification induced mineral dust in the atmosphere has also been shown to have a potential to modify both the incoming shortwave solar radiation and outgoing longwave radiation resulting in either a cooling or heating effect depending on cloud cover or the albedo of the underlying surface (Nicholson 2001). The potential role of large scale land cover change in perpetuating the severe 30 years drought of the Sahel has been noted in various studies (Otterman 1974; Charney et al. 1975; Foley et al. 2003; Geist and Lambin 2004). Similar observations are being made regarding possible effects of large scale changes in the boreal forest region due to climate change induced disturbances such as fires (Soja et al. 2007).

Fire releases large quantities of carbon stored in soils and vegetation into the atmosphere within a short time (Michelsen et al. 2004). The 1997-1998 peat and forest fires in Indonesia are estimated to have released up to 2.57 Pg (10^{15} g) of carbon, equivalent to 40% of the annual global carbon emissions from fossil fuel burning (Page et al. 2002). In Siberia, an average of 203 Tg C was released from forest fires in the years from 1998 to 2002 (Soja et al. 2004). While much of the CO_2 released is recaptured on decadal timescales through vegetation regrowth, this depends on availability of favourable plant growth conditions. In addition to carbon, fires emit various trace gases such as carbon monoxide, methane, nitrogen compounds, and other trace pollutants which are important in atmospheric chemistry (Van Wilgen et al. 1997; Choi et al. 2006).

Current evidence suggests that anthropogenic emissions are already changing the climate (IPCC 2001b). The world is 0.6° C warmer than about 150 years ago and observations show that this trend is continuing, for example 1998 was the hottest year on record. The increase in global mean temperatures has been shown to account for the increase in climate extremes globally since mid 1970s (Groisman et al. 2007). In particular there has been an increase in the areas under drought affecting for instance the Sahel, eastern Asia and southern Africa and cases of both the drought and wet periods in for example, the U.S. and Europe. This has been linked to the observed shift in ENSO activity towards more warm phases after about 1970s compared to the period since 1900 coinciding with high global mean temperatures (Dai et al. 1998; Holmgren and Scheffer 2001; IPCC 2001b; Dayton-Johnson 2004). The increasing climate variability generates high fire-weather risk conditions and also susceptibility to land degradation (Geist and Lambin 2004; Beverly and Martell 2005).

Increased fire activity in the recent decades has been linked to an increasing fire-weather risk due to drought resulting from the El Niño- Southern Oscillation phenomenon. For example, the 1983 destructive "Ash Wednesday" fires in Australia which left large areas covered in smoke for weeks (Pyne et al. 1996; Goldammer 1998); and the 1982-1983 and 1997-1998 peat and forest fires in Indonesian and Malaysian provinces estimated to have caused damages to livelihoods systems of the amount exceeding $14 billion (Goldammer 1998). In the high and mid-latitudes, the warming trend has been linked to the increase in summer drought and elevated evapotranspiration which is associated with increasing frequency of extreme fire years across the circumboreal region (North America and Russia) (Groisman et al. 2006; Soja et al. 2007) (Figure 12.1). Soja et al. (2007) notes that in Siberia, 7 of the last 9 years have resulted in extreme fire seasons, and that more frequent extreme fire incidents have been experienced in Alaska and Canada.

In the boreal forest, potential fire weather under a CO_2 doubling scenario shows an increased fire season length by 30 days across Canada (Soja et al. 2007). The increased fire-weather risk results from high surface temperatures which give rise to more thunderstorms, increasing ignitions from lightning, for instance by 20 to 40% between 50 and 60° N latitude (Groisman et al. 2006; Soja et al. 2007). Because of increased fire weather severity, ignition by humans is also expected to increase, 18 and 50% for 2050 and 2100, respectively, for Ontario (Soja et al. 2007). In Australia it has been shown that the frequency of days with very high and extreme Forest Fire Danger Index ratings is likely to increase in south-east Australia by 4–25% by 2020 and 15–70% by 2050 (Hennessy et al. 2006). Similar conclusions have been made for New Zealand (Pearce et al. 2005). Forest fires will result in important feedback mechanism affecting climate processes in future and trends in land degradation. However, there are limited studies on future trends in fire patterns over most of the developing world particularly the fire prone systems such as Sub-Saharan Africa which are characterized by highly vulnerable economies.

Climate extremes experienced in the form of exceptionally wet conditions under elevated CO_2 are likely to facilitate greater potential for invasive species to spread by outcompeting indigenous ones (Dukes and Mooney 1999; Brooks et al. 2004). Observations show that a number of invasive species respond favorably to increasing levels of CO_2 concentration in the atmosphere under wet conditions although this requires further work (Bassiri et al. 1998; Smith et al. 2000; Lioubimtseva and Adams 2004). Results of experiments in the US showed that a non-native invasive grass *Bromus* (cheatgrass) known to increase the frequency of intense fires from a 75–100-year cycle to a 4–7-year cycle was far more productive than native plants during wet years under high CO_2 (Smith et al. 2000; Lioubimtseva and Adams, 2004). Elevation of CO_2 under climate change is also likely to increase shrub cover (Dukes and Mooney 1999; Lioubimtseva and Adams 2004). Bond et al (2003) has linked the spread of shrubs in Southern Africa to increase in CO_2 over the last century. Indications are that there might be an increased likelihood of accumulation of large highly flammable biomass in areas that normally support lower fuel load resulting in high fire–weather risk which will have an impact on wild-life and soil (Brooks et al. 2004; Liebhold et al. 1995).

Recent studies suggest that by 2090s the land area in drought at a global scale will increase from 1% in the present day to 30 %, 40 % and 50 % for extreme, severe and moderate drought respectively (Burke et al. 2006). A decrease in rainfall by as much as 1.5% annually over the last quarter of the 20th century has been observed over southern Africa, accounting for the frequent droughts and subsequent land degradation experienced in the past decades (Geist and Lambin 2004). As noted earlier, drought and wetting cycles increase fire-weather risk. Increased fire activity under climate change will markedly reduce plant biomass and also given that there is likely to be an increase in climate variability, these conditions will greatly increase susceptibility to land degradation. This will have long term consequences on the productivity of soil particularly in dry lands where soils take a longer time to develop for example up to 5,000–10,000 years in arid southern Utah (Johansen 2001; Billings et al. 2003; Lioubimtseva and Adams 2004).

12.8
Fire forecasting for mitigation of land degradation

Future land degradation programs should incorporate monitoring of fire patterns at all levels to establish changes in fire type, behaviour and regimes in response to changes in influential climatic parameters due to global warming. Large parts of the developing world are already vulnerable to fire for several reasons including widespread poverty which necessitate use of fire as a land use tool and inadequate resources deployed to monitor and control destructive fires. In contrast in the developed world billions of dollars are spent annually to mitigate bush fires eg., $1.6 billion was used in 2000 fires only in the USA (Williams 2001). Recent large scale hot fires driven by global warming and indications from model work that severe fire weather events will increase in future, point to the potential for fire to pose a problem of magnitude beyond the capacity of a single nation to handle regardless of its economic position. Feedbacks of these fires extend beyond the areas burnt and are still not well understood (Bond et al. 2003 and 2004; Soja et al. 2007). There is also limited effort particularly in developing world to establish the area burned annually and identify areas that are under threat of too-frequent burning (Roy et al. 2005). However various satellite products that can be used to map burnt areas have become more readily available (Figure 12.6a).

International fire frameworks need to be in place to monitor fire weather in different regions and provide timely information on the dimension of the problem, its link with development of land degradation, feed-backs on global warming and implications on livelihoods. Initiatives to develop international cooperation on Wildland Fire Management were made at the 3rd International Wildland Fire Conference and Fire Summit held in Sydney in 2003. These and other similar initiatives need to be moved to an implementation stage.

International fire monitoring should be established as part of fire early warning systems and should be linked to land degradation studies. This can be built upon the fire danger rating systems which is quickly developing to incorporate satellite based information (Goncalves et al. 2006). Satellites provide timely, repetitive and global coverage of various parameters required to study fires and land degradation (Figure 12.6b). Examples of available pool of satellite fire products include the normalized difference vegetation Index (NDVI) for fuel load assessment and the MODIS Fire Rapid Response Data System providing timely information on active fires globally (http://rapidfire.sci.gsfc.nasa.gov) (Figure 12.6b). Most of these data is underutilized particularly in Africa (Dube 2005).

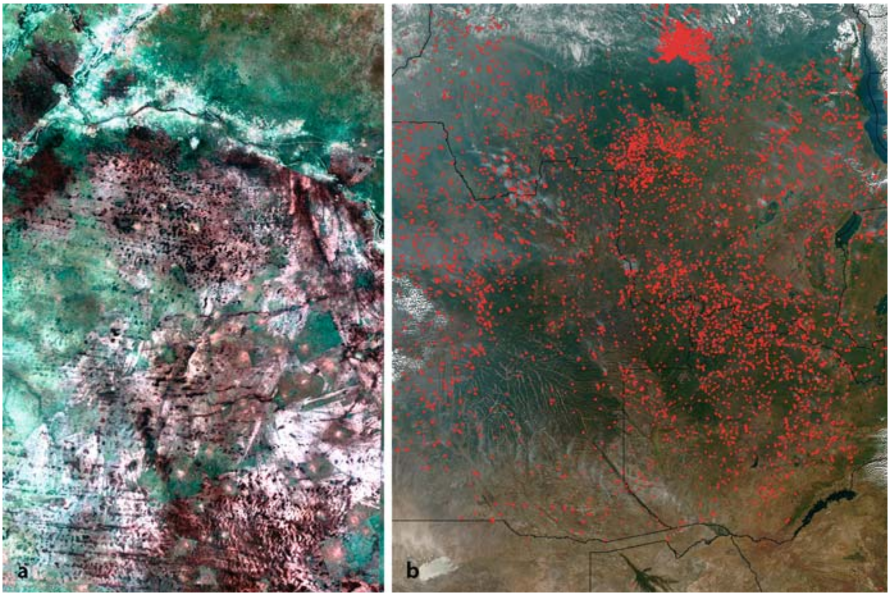


Fig. 12.6 a, b. **a** A false colour Landsat Thematic Mapper September 1996 (dry season) image of part of Hainaveld Ranches in Ngamiland, Botswana showing burnt scars in shades on white through brown to dark brown depending on the condition of post-burn areas. The False colour image is based on the Green (band 2 represented by blue), Red (band 3 represented by green) and Middle infrared (band 5 represented by a red colour) radiation bands. **b** Active fires over Angola, Democratic republic of Congo, Zambia and neighboring countries captured on MODIS Aqua satellite overpass on 11 July 2003. The image is shown at the resolution of 2 km pixel size. The red dots represent fires that were burning when the satellite passed over the area. However, this product needs to be validated in the field. (http://rapidfire.sci.gsfc.nasa.gov/firemaps/)

Also less used in developing countries, is the fire danger rating system which requires engagement of Meteorological Services in provision of fire weather information. Regional and international initiatives are ongoing to address these deficiencies. The Global Fire Monitoring Center (GFMC) provides global information on fire. The Global Observation of Forest Cover and Global Observation of Land Cover Dynamics (GOFC-GOLD) is an international initiative which among others has set up a series of regional networks in Southern and Central Africa, Northern Eurasia, Latin America, South East Asia and Australia to address global land cover and fire dynamics (Brady et al. 2006). For example, the GOFC-GOLD regional network in Southern Africa, the Southern Africa Fire Network (SAFNet), has functioned since 2000 focusing on use of satellite data in fire management and monitoring (Dube 2005; Roy et al. 2006). These structures form rudimental frameworks upon which a global fire early warning system can be built.

GOFC-GOLD and other international organizations working on fire have developed a collaborative proposal for a global early warning system for wildland fire (Brady et al. 2006). This proposal was put in place following recommendations of the UN World Conference on Disaster Reduction (WCDR) in Kobe, Japan, January 2005, and the proposal of the UN Secretary General to develop a Global Multi-Hazard Early Warning System (GEWS). The goal of the proposed global early warning system for wildland fire (EWS-Fire) is to provide a scientifically supported, systematic procedure for predicting and assessing international fire danger that can be applied from local to global scale (Brady et al. 2006). In this case the GOFC-GOLD networks will form important channels for dissemination of information on mechanisms of fire early warning as well as early warning for frequently burnt areas that have increased susceptibility to land degradation.

12.9 Conclusions

Not all fires cause land degradation and the effect of fire varies over time depending on vegetation type. In fire-dependent vegetation communities fire plays an integral role in determining community structure and nutrient cycling such that fire suppression threatens biodiversity in those cases (Hiers et al. 2000). Controlled fires are used in different parts of the world to reduce the potential for fires to cause long term negative effects on the landscape and property and to stimulate increased productivity. In southern United States of America, fire is used to treat 2–3 million ha of forest and agricultural lands each year (Wade et al. 2000).

Climatic factors are key drivers of fire and land degradation despite the influence of human activity. Climate has been found to account for 86% of driving factors of desertification in Southern Africa (Geist and Lambin 2004). But the link between fire and land degradation is complex and variable. While under certain climatic conditions and over a certain time span fire can play a positive role on the ecosystem, this can change mostly due to change in fire weather driven by climatic factors (Lambin and Geist 2006). Meteorological factors increase the possibility for human lit fires to occur hence reducing fire intervals and or increasing fire intensity by influencing fuel load.

Frequent hot fires can create a fire loop through loss of native vegetation to flammable fast growing species hence maintaining a landscape marked by low biodiversity and that is highly susceptible to land degradation. Climate may also create a fire prone environment through land use induced land degradation aggravated by prolonged drought. The inter-relationship between climate, fire and land degradation and the cumulative effect of burning at the local level are currently not receiving appropriate attention. This is a concern given their direct link to landscape productivity and livelihoods particularly for dry land areas where a large section of the population is directly depended on immediate environmental resources.

Climate change makes the link between climate and fire and implications on land degradation an important area to consider in future resource utilization plans and general ecosystem wellbeing. Fire due to lighting has been known to be an important natural factor in ecosystem maintenance. But climate change induced lightning fires are changing this positive role of lightening in fire on ecological processes by changing the fire-weather risk. Global warming has been linked to recently experienced fire regimes which have a greater potential to increase soil and nutrient losses and a great impact on nutrient pathways. These fires rapidly alter sources and sinks of greenhouse gases and influence the hydrological cycle and as a result have feedbacks on climate change processes. It is not clear how climate change will influence the role of fire on land degradation in different parts of the world and the implication on livelihood systems. It is therefore important to establish fire monitoring structures, provide information on fire intensity and area burnt and monitor post burn areas. A global fire early warning system is required given the potential for climate change to increase the fire-weather risk which will increase fire hazards and result in feedbacks on the climate.

Acknowledgement

I am very grateful of the assistance provided by Cheikh Mbow from the Université Cheikh Anta Diop de Dakar-Sénégal at the initial stages of this chapter.

References

Abrila A, Barttfelda P, Bucherb EH (2005) The effect of fire and overgrazing disturbes on soil carbon balance in the Dry Chaco forest. Forest Ecol Manag 206:399–405

AEO (2002) Africa Environmental Outlook. Past Preset and future perspectives. United Nations Environmental Programme (UNEP), Nairobi and Earthprint limited Hertfordshire. 422 pp.

AEO II (2006) Africa Environmental Outlook 2. Division of Early Warning and Assessment, United Nations Environmental Programme (UNEP), Nairobi. 541 pp.

Amatullia G, Perez-Cabelloa F, de la Rivaa J (2007) Mapping lightning/human-caused wildfires occurrence under ignition point location uncertainty. Ecol Model 2: 321–333

Asher J, Dewey S, Johnson C, Olivarez J (2001) Reducing the spread of invasive exotic plants following fire in western forests, deserts, and grasslands. In: Galley KEM, Wilson TP (eds.). Proceedings of the Invasive Species Workshop: the Role of Fire in the Control and Spread of Invasive Species. Fire Conference 2000: the First National Congress on Fire Ecology, Prevention, and Management. Miscellaneous Publication No. 11, Tall Timbers Research Station, Tallahassee, FL. pp 102–103

Bassiri R, Reynolds HJF, Virginia RA, Brunelle MH (1998) Growth and root NO_3- and PO43- uptake capacity of three desert species in response to atmospheric CO_2 enrichment. Aust J Plant Physiol 24:353–358

Beverly JL, Martell DL (2005) Characterizing extreme fire and weather events in the Boreal Shield ecozone of Ontario. Agric For Meteorol 133:5–16.

Billings SA, Schaeffer SM, Evans RD (2003) Nitrogen fixation by biological soil crusts and heterotrophic bacteria in an intact Mojave Desert ecosystem with elevated CO_2 and added soil carbon. Soil Biol Biochem 35:643-649.

Bond WJ, Midgley GF, Woodward FI (2003) What controls South African vegetation-climate or fire? S Afr J Botany 69:1–13

Bond WJ, Woodward FI, Midgley GF (2005) The global distribution of ecosystems in a world without fire. New Phytol 165:525-538

Brady MA, Goldammer JG, Keenan T, Lynham TJ, Justice CO, Csiszar IA, O'Loughlin K (2006) Developing a global early warning system for wildland fire. In: Sivakumar MVK, Motha RP (eds) Managing Weather and Climate Risks in Agriculture, Springer.

Brooks ML, D‘Antonio CM, Richardson DM, Grace JB, Keeley JE, Ditomaso JM, Hobbs RJ, Pellant M, Pyke D (2004) Effects of invasive alien plants on fire regimes. Bioscience 54:677-688

Brooks ML, Pyke DA (2001) Invasive plants and fire in the deserts of North America. In: Galley KEM, Wilson TP (eds.). Proceedings of the Invasive Species Workshop: the Role of Fire in the Control and Spread of Invasive Species. Fire Conference 2000: the First National Congress on Fire Ecology, Prevention, and Management. Miscellaneous Publication No. 11, Tall Timbers Research Station, Tallahassee, FL, pp 1–14

Burke EL, Brown SJ, Christidis N (2006) Modelling the recent evolution of global drought and projections for the 21st century with the Hadley Centre climate model. J Hydrometeorol 7:1113-1125.

Carmona-Moreno M, Belward A, Caperan P, Malingreau J-P, Hartley A, Garcia-Alegre M, Antonovskiy M, Buchshtaber V, Pivovarov V (2005) Spatiotemporal Correlation Analyses of Global Burned Surface Time Series from Remote Sensing data (1982-1999): Inter-annual Variability of Global fire calendar. 31st ISRSE Conference on Global Monitoring for Sustainability and Security, 20-24 June 2005, Saint Petersburg, Russia

Castellano MJ, Ansley RJ (2007) Fire season and simulated grazing dif-ferentially affect the stability and drought resilience of a C4 bunch-grass, C3 bunchgrass and C4 lawngrass. J Arid Environ 69:375-384

Charney JG (1975). Dynamics of deserts and drought in the Sahel. Qtly J Roy Meteor Soc 101:193–202

Charney J, Stone PH, Quirk WJ (1975) Drought in the Sahara: a biophysical feedback mechanism. Science 187: 434–435

Choi S, Chang Y, Park B (2006) Increase in carbon emissions from forest fires after intensive reforestation and forest management programs. Science Total Environ 372: 225–235.

Dai A, Trenberth KE, Karl TR (1998) Global Variations in Droughts and Wet Spells: 1900-1995. Geophys Res Lett 25:3367-3370

Dayton-Johnson J (2004) Natural Disasters And Adaptive Capacity. OECD Development Centre. Working Paper No. 237. Paris.

de Ronde C, Trollope WSW, Parr CL, Brockett B, Geldenhuys CJ (2004) Fire effects on flora and fauna. In: Goldammer JG, de Ronde C (eds). Wildland fire management handbook for Sub-Sahara Africa. Global Fire Monitoring Centre (GFMC). pp. 60-87

Dube OP (2005) A Collaborative Effort Towards Developing Capacity for Operational Fire Monitoring and Management Systems in Southern Africa. AIACC Working Paper No.11. www.aiaccproject.org. 16 pp.

Dube OP, Pickup G (2001). Effects of rainfall variability and communal and semi-commercial grazing on land cover in Southern Africa rangelands. Clim Res 17:195-208

Dube OP, Kwerepe RM (2000). Human induced change in the Kgalagadi sands: Beyond the year 2000. In: Ringrose S, Chanda R (eds) Towards sustainable management in the Kalahari region – Some essential background and critical issues. Proceedings of the Botswana Global Change Committee-START Kalahari Transect Meeting held in Gaborone, 1998. Directorate of Research and Development, University of Botswana, Gaborone. pp 244-258.

Dukes JS, Mooney HA (2001) Does global change increase the success of biological invaders? Tree 14:135-139

Feddema JJ, Freire S (2001) Soil degradation, global warming and climate impacts. Clim Res 17: 209–216.

Franklin J, Spears-Lebrun LA, Deutschman DH, Marsden K (2006) Impact of a high-intensity fire on mixed evergreen and mixed conifer forests in the Peninsular Ranges of southern California, USA. Forest Ecol Manag 235:18–29

Foley JA, Coe MT, Scheffer M, Wang G (2003) Regime Shifts in the Sahara and Sahel: Interactions between Ecological and Climatic Systems in Northern Africa. Ecosyst 6:524–539

Frost PGH, Robertson F (1987) The Ecological Effects Of Fire. In: Savannas. In: Brian H. Walker (ed). Determinants Of Tropical Savannas. The International Union of Biological Sciences, IUBS Monograph Series, No. 3. IRL Press, Oxford. pp 93-140

Frost PGH (1994) Suggestions for the further development of a fire management programme in the rangelands of the western province, Zambia. Department Of Veterinary And Tsetse Control Services Department Of Agriculture – Animal Husbandry Section .Western Province. Livestock Development Project Phase II. 20 pp

Geist HJ, Lambin EF (2004) Dynamic Causal Patterns of Desertification. Bioscience 54:817-829

Geldenhuys CJ (1994) Bergwind fires and location patterns of forest patches in southern Cape landscape. S Afr J Biogeogr 21:49-62

Geldenhuys CJ, Van Wilgen BW, Bond WJ, van de Vijver CADM, de Ronde C (2004) Fire effects on the maintenance of biodiversity, soil and nutrients. In: Goldammer JG, de Ronde C (eds) Wildland fire management handbook for Sub-Sahara Africa. Global Fire Monitoring Centre (GFMC). pp. 88-113

GEO 3 (2002) Global Environmental Outlook 3. Past Present and Future Perspectives. UNEP. Earthscan, London. 446 pp.

Gill AM (1994) How Fires Affect Biodiversity. Fire and Biodiversity: The Effects and Effectiveness of Fire Management. Proceedings of the Conference held 8 – 9 October 1994, Footscray, Melbourne Biodiversity Series, Paper No. 8. Biodiversity Unit.

Gimeno-García E, Andreu V, Rubio JL (2007) Influence of vegetation recovery on water erosion at short and medium-term after experimental fires in a Mediterranean shrubland. Catena 69:150–160.

Gitay H, Suarez V, Watson RT, Dokken DJ (2002) Climate Change and biodiversity. IPCC Technical Paper V. IPCC WGII TSU. WMO, UNEP. 45 pp.

Goldammer JG (1998) Fire watch. OUR PLANET 9.6 – Climate and Action. A UNEP's magazine for environmentally sustainable development. November 1998. http://www.ourplanet.com/txtversn/96/contents.html.

Goldammer JG, de Ronde C (eds) (2004) Wildland fire management handbook for Sub-Sahara Africa. Global Fire Monitoring Centre (GFMC). pp 432.

Gonzalez-Perez JA, Gonzalez-Vila FJ, Almendros G, Knicker H (2004) The effect of fire on soil organic matter—a review. Environ Int 30: 855– 870

Goncalves AM, Silva JG, Gomes PMV (2006) Meteorological support to forest fire prevention. Forest Ecol Manag 234S:S41. DOI: 10.1016/j.foreco.2006.08.062.

Govender N, Trollope WSW, Van Wilgen BW (2006) The effect of fire season, fire frequency, rainfall and management on fire intensity in savanna vegetation in South Africa. J Appl Ecol 43:748–758.

Groisman PY, Sherstyukov BG, Razuvaev VN, Knight RW, Enloe JG, Stroumentova NS, Whitfield PH, Førland E, Hannsen-Bauer I, Tuomenvirta H, Aleksandersson H, Mescherskaya AV, Karl TR (2007) Potential forest fire danger over Northern Eurasia: Changes during the 20th century. Global Planet Change doi:10.1016 /j.gloplacha.2006.07.029

Hagner S (1999) Forest Management in Temperate and Boreal Forests: Current Practices and the Scope for Implementing Sustainable Forest Management. FAO Consultant Report. A Paper for the World Bank Forest Policy Implementation Review and Strategy. Forestry Policy and Planning Division, Rome. 47 pp.

Hall RG (1994) The Effects Of Fuel Reduction Burning On Forest Soils. In: Fire and Biodiversity: The Effects and Effectiveness of Fire Management. Biodiversity Series, Paper No. 8. Proceedings of the Conference held 8–9 October 1994, Footscray, Melbourne, Australia.

Hennessy K, Lucas C, Nicholls N, Bathols J, Suppiah R, Ricketts J (2006) Climate change impacts on fire-weather in south-east Australia. CSIRO and the Bureau of Meteorology, Canberra, Australia. 91 pp.

Hiers JK, Wyatt R, Mitchell RJ (2000) The effects of fire regime on legume reproduction in longleaf pine savannas: is a season selective? Oecologia 125:521–530

Holmgren M, Scheffer M (2001) El Niño as a window of opportunity for the restoration of degraded arid ecosystems. Ecosyst 4:151-159

Houghton RA (1995) Changes in the storage of terrestrial carbon since 1850. In: Lal R, Kimble JM, Levine E, Stewart VA (eds), Soil and Global Change. Lewis Publisher CRC, Boca Raton, pp. 45–65

Hulme, M., Kelly, M., 1993. Exploring the links between desertification and climate change. Environment 5, 4–11 and 39–45.

IPCC (2001a). Impacts, adaptation, and vulnerability. Cambridge University Press, Cambridge, 1031 pp.

IPCC (2001b) Climate change 2001. Synthesis Report. Contribution of working Groups I, II and II to the Third Assessment Report of the Inter-Governmental Panel of Climate Change. Cambridge University Press. 397 pp.

Johansen RJ (2001) Impacts of fire on biological soil crusts. In: Belnap J, Lange OL (eds) Biological soil crusts: Structure, Funtion, and Management, Springer, New York, pp. 386-397.

Keeley JE, Rundel PW (2005) Fire and the Miocene expansion of C4 grasslands. Ecol Lett 8:683–690

Kosmas C, Gerontidis S, Marathianou M (2000) The effect of land use change on soils and vegetation cover over various lithological formations on Lesvos (Greece). Catena 40:51–68

Kulkarni MG, Sparg SG, Van Staden J (2007) Germination and post-germination response of Acacia seeds to smoke-water and butenolide, a smoke-derived compound. J Arid Environ 69:177–187

Lal, R., Hassan, H. M. and Dumanski, J.. 1999. Desertification control to sequester carbon and mitigate the greenhouse effect. In: Rosenberg N, Izaurralde RC (eds) Carbon sequestration in soils: Science, monitoring and beyond. Malone Battelle Press, Columbus, Ohio.

Lambin, E.F. and Geist, H.J., 2006. Land-use and land-cover change. Local processes and global impacts. Springer-Verlag, Berlin. pp.222

Leemans R, Kleidon A (2002) Regional and global assessment of the dimensions of desertification. In: Reynolds JF, Stafford-Smith DM (eds). Global desertification. Do human cause deserts? Dahlem University Press, Berlin. pp. 215-231.

Liebhold AM, Macdonald WL, Bergdahl D, Mastro VC (1995) Invasion by Exotic Forest Pests: A Threat to Forest Ecosystems. Forest Sci Mono 30, 49 pp.

Lioubimtseva E, Adams JM (2004) Possible implications of increased carbon dioxide levels and climate change for desert ecosystems. Environ Manage 33:388-404

Lorup JK, Refsgaard CJ, Mazvimavi D (1998) Assessing the effect of land use change on the catchment runoff by combined use of statistical tests and hydrological modeling: Case studies from Zimbabwe. J Hydrol 205:147-163

Lovich JE, Bainbridge D (1996) Anthropogenic degradation of the southern California desert ecosystem and prospects for natural recovery and restoration. Environ Manage 24:309–326

MA (Millennium Ecosystem Assessment) (2005a) Ecosystems and Human Well-being: Synthesis. World Resources Institute. Island Press, Wash-ington, DC.

MA (Millennium Ecosystem Assessment) (2005b) Ecosystems and Human Well-being: Desertification Synthesis. World Resources Institute, Washington. 26 pp

Main WA, Haines DA (1974) The causes of fires on North Eastern National Forest. North Central Forest Experiment Station Forest Service. Department of Agriculture. USDA Forest services Research Paper NC-109. U.S. Government Printing Office. pp 762-485

Michelsen A, Andersson M, Jensen M, Kjøller A, Gashew M (2004) Carbon stocks, soil respiration and microbial biomass in fire-prone tropical grassland, woodland and forest ecosystems. Soil Biol Biochem 36:1707–1717.

Ministry of Agriculture (1999). Thamacha Forestry Resource Pilot Inventory Project Department of Crop Production and Forestry, Botswana. Maun. 26 pp.

Moleele NM, Ringrose S, Matheson W, Vanderpost C (2002) More woody plants? The status of bush encroachment in Botswana's grazing areas. J Environ Manage 64:3-11
Nicholson SE (2001) Climatic and environmental change in Africa during the last two centuries. Clim Res 17:123–144
Nicholson SE (2002) What are key components of climate as a driver of desertification? In: Reynolds J.F. and Stafford-Smith, D.M. (eds). Global desertification. Do human cause deserts? Dahlem University Press, Berlin. pp 41-57
Otterman J (1974) Baring high-albedo soils by overgrazing: a hypothesized desertification mechanism. Science 186:531–533
Overbeck GE, Pfadenhauer J (2002) Adaptive strategies in burned sub-tropical grassland in southern Brazil. Flora 202:27–49.
Page SE, Siegert F, Rieley JO, Boehm H-DV, Jaya A, Limin S (2002). The amount of carbon released from peat and forest fires in Indonesia during 1997. Nature 420:61–5.
Pearce GH, Mullan AB, Salinger MJ, Opperman TW, Woods D, Moore JR (2005) Impact of Climate Change on Long-term Fire Danger. Prepared for New Zealand Fire Service Commission. National Institute of Water & Atmospheric Research Ltd, and Forest Research Ltd, Auckland. 69 pp.
Pyne SJ (1995) World fire. The culture of fire on earth. Henry Holt and Co. New York. 379 pp.
Pyne SJ, Andrews PL, Laven RD (1996) Introduction to Wildland Fire. 2nd Edition. John Wiley and Sons. New York. 769 pp.
Pyne, S.J., Goldammer, J.G., de Ronde, C., Geldenhuys, C.J., Bond, W.J. and Trollope, W.S.W. 2004. Introduction. In Goldammer , J.G. and de Ronde, C. (eds) 2004. Wildland firemanagement handbook for Sub-Sahara Africa. Global Fire Monitoring Centre (GFMC). Pp1-8.
Reynolds JF, Stafford-Smith DM (eds). Global desertification. Do human cause deserts? Dahlem University Press, Berlin. pp 41-57
Roy DP, Trigg S, Bhima R, Brockett BH, Dube OP, Frost P, Govender N, Landmann T, Le Roux J, Lepono T, Macuacua J, Mbow C, Mhwan-dangara KL, Mosepele B, Mutanga O, Neo-Mahupeleng G, Norman M, Virgilo S (2006) The Utility of Satellite Fire Product Accuracy In-formation—Perspectives and Recommendations From the Southern Africa Fire Network. IEEE T Geosci Remote 44:1928-1930
Savadogo P, Sawadogo L, Tiveau D (2007) Effects of grazing intensity and prescribed fire on soil physical and hydrological properties and pasture yield in the savanna woodlands of Burkina Faso. Agr Ecosyst Environ 118: 80–92.
Sheuyange A, Oba G, Weladji RB (2005) Effects of anthropogenic fire history on savanna vegetation in northeastern Namibia. J Environ Manag 75:189–198
Shakesby RA, Wallbrink PJ, Doerr SH, English PM, Chafer CJ, Humphreys GS, Blake WH, Tomkins KM (2007) Distinctiveness of wild-fire effects on soil erosion in south-east Australian eucalypt forests assessed in a global context. Forest Ecol Manag 238:347–364
Smith SD, Huxman TF, Zitzer SF, Charlet TN, Housman DC, Coleman JS, Fenstermaker LK, Seemann, Nowak RS (2000) Elevated CO_2 increases productivity and invasive species success in an arid ecosystem. Nature 408:79–82.
Soja AJ, Cofer III WR, Shugart HH, Sukhinin AI, Stackhouse Jr PW, McRae DJ, Conard SG (2004) Estimating fire emissions and disparities in boreal Siberia (1998 through 2002). J Geophys Res 109 (D14S06). doi:10.1029/2004JD004570.
Soja AJ, Tchebakova NM, French NHF, Flannigan MD, Shugart HH, Stocks BJ, Sukhinin AI, Parfenova EI, Chapin FS, Stackhouse PW Jr (2007) Climate-induced boreal forest change: Predictions versus current observations. Global Planet Change. 23P. doi:10.1016/j.gloplacha.2006.07.028
Stocks BJ, van Wilgen BW, Trollope WSW (1997) Fire behaviour and dynamics of convection columns in African savannas. In: Brian W. van Wilgen, Andreae MO, Goldammer JG, Lindesay JA (Eds.) Fire in Southern African Savannas, Ecology and Atmospheric Perspective. Witwatersrand University Press. Johannesburg. pp. 4-55.

Stocks BJ, Fosberg MA, Lynham TJ, Mearns L, Wotton BM, Yang Q, Jin J-Z, Lawrence K, Hartley GR, Mason JA, McKennedy DW (1998) Climate Change and Forest Fire Potential in Russian and Canadian Bo-real Forests. J Clim Chang 38:1-3.

Styger E, Rakotondramasy HM, Pfeffer MJ, Fernandes ECM, Bates DM (2007) Influence of slash-and-burn farming practices on fallow succession and land degradation in the rainforest region of Madagascar. Agric Ecosyst Environ 119 :257-269

Tews J, Jeltsch F (2004) Modelling the impact of climate change on woody plant population dynamics in South African savanna. BMC Ecology 4:17 doi:10.1186/1472-6785-4-17

Tews J, Esther A, Milton SJ, Jeltsch F (2006) Linking a population model with an ecosystem model: Assessing the impact of land use and climate change on savanna shrub cover dynamics. Ecol Model 1 9 5: 219–228.

Trollope WSW, de Ronde C, Geldenhuys CJ (2004) Fire behaviour. In: (Goldammer JG, de Ronde C ed.) Wildland fire management handbook for Sub-Sahara Africa. Global Fire Monitoring Centre (GFMC), pp 27-59.

UNCCD (1994) United Nations Convention to Combat Desertification. Nairobi (Kenya): UNEP.

Van de Vijver (1999) Fire and life in Tarangire. Effects of burning and herbivory on an East African savanna system. WAU dissertation no. 2664. Wageningen University PhD theses. Unpublished// http://library.wur.nl/wda/abstracts/ab2664.html.

Van Wilgen, BW, Biggs HC, O'Regan SP, Mare N (2000) A fire history of the savanna ecosystems in the Kruger National Park, South Africa, between 1941 and 1996. South Afr J Sci 96:167-183

Van Wilgen BW, Govender N, Biggs HC, Ntsala D, Funda XN (2004) Response of savanna fire regimes to changing fire management policies in a large Africa National Park. Conserv Biol 18:1533-1540

Van Wilgen BW, Scholes RJ (1997) The vegetation and fire regimes of Southern Hemisphere Africa. In: Brian W. van Wilgen, Andreae MO, Goldammer JG, Lindesay JA (Eds.) Fire in Southern African Savannas, Ecology and Atmospheric Perspective. Witwatersrand University Press. Johannesburg. pp 27-46

Van Wilgen B, Andreae MO, Goldammer JG, Lindesay JA (1997) Fire in Southern African Savannas. Ecology and atmospheric Perspective. Witwatersrand University Press. Johannesburg. 255 pp.

Vogel CH, Smith J (2002) Building social resilience in arid ecosystems. In: Reynolds JF, Stafford-Smith DM (eds). Global desertification. Do human cause deserts? Dahlem University Press, Berlin. pp 148-166

Wade DD, Brock BL, Brose PH, Grace JB, Hoch GA, Patterson III WA (2000) Fire in eastern ecosystems. In: Brown, J.K., Smith, J.K. (Eds.), Wildland Fire in Ecosystems: Effects of Fire on Flora. USDA Forest Services Gen. Tech. Rep. RMRS-42, pp. 53–96

Williams T (2001) INCITE. Burning Money: The press and politicians called fire season 2000 "a natural disaster." The fires were natural, but the "disaster" was how much the United States spent to fight them. Audubon Magazine, January-February, pp 1-5

WMO (2005) Climate and land degradation. WMO-No. 989. World Meteorological Organization, Geneva, Switerland. 32 pp.

Yeaton RI (1988) Porcupines, fires and dynamics of the tree layer of the *Burkea Africana* savanna. J. Ecol 76:1017-1029.

Importance of Drought Information in Monitoring and Assessing Land Degradation

Moshe Inbar

Abstract. Drought is a normal feature of climate, but also one of the most common and severe of natural disasters. In most world regions the economic damages caused by droughts are greater than those caused by any other events such as earthquakes and volcanic eruptions. World-wide population growth has intensified the pressure on water resources and increased the vulnerability to drought. Prolonged drought cycles are a major factor in land degradation processes and affect extensive geographical areas. While such a natural hazard may strike any climatic region, its occurrence is more frequent in arid and semiarid regions. According to long term rain measurements, Israel with its Mediterranean climate, has experienced three consecutive dry years for every 50 years period. The recent drought of 1998-2001 in northern Israel was the most extreme during the last 130 years. It affected the water flow of the Jordan River and brought the level of Lake Kinneret to its lowest point in historical periods. Changes in land-use, water pumping and flow diversion, have exacerbated the negative impact of droughts and caused land degradation, such as the drying of wetlands and salinization of freshwater aquifers. The increased use of urban treated waste water for irrigation, with its significantly higher salt content, is another cause of soil degradation, and has a major economic impact on irrigated farming schemes. Wetlands and aquatic environments around Lake Kinneret and other regions of the country, were practically dry for six consecutive years, affecting fish-breeding and endemic aquatic species. Various solutions have been applied: drip irrigation, recycling of wastewater, reduced allocations and increased pricing of water supplies, desalinization plants, etc. However, the failure by successive governments to introduce drought contingency planning and sustainable management of water resources, has already damaged agriculture and nature conservation. The imminent dangers of drought are liable to lead to a major crisis in the country's water resources and affect all sectors of society.

13.1 Introduction

Drought is a normal feature of climate, but also one of the most common and severe of natural disasters. It originates from a deficiency over an extended period of time, usually a season or more (National Drought Mitigation Center 1995). In most world regions the economic damages caused by droughts are greater than those caused by any other events such as earthquakes and volcanic eruptions. World-

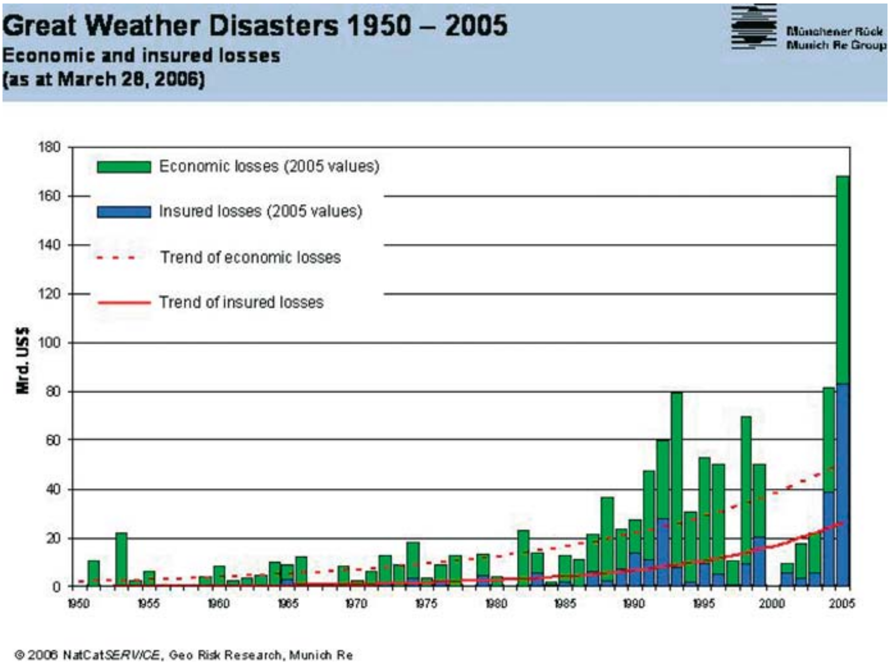


Fig. 13.1. Economic losses for natural disasters in the world, 1950-1999 (Munich Re Group 2000)

wide population growth has intensified the pressure on water resources and increased the vulnerability to drought.

Prolonged drought cycles are a major factor in land degradation processes and they affect extensive geographical areas. While such a natural hazard may strike any climatic region, its occurrence is more frequent in arid and semiarid regions. Extensive droughts have afflicted African countries causing major losses to their economies (Sivakumar et al. 2005).

The total economic loss from Natural Disasters increased from 5 U$S Billion/year in the 60's to more than 50 U$S Billion/year in the last decade of last century (Fig. 13.1). Droughts are among the most expensive disasters and the 1988 drought in the United States was the costliest natural disaster in the US history prior to the Katrina disaster (Fig. 13.2).

"*When God created the American West, to paraphrase Mark Twain, he provided plenty of whiskey to drink and just enough water to fight over*" is the quotation in the TIME magazine (1988) on the effects of the drought, reminding that the water shortage subject was also a major issue more than a hundred years ago in the US west. Water conflicts are dramatized even more in modern societies.

Droughts are known since early stages of human history: several quotations from the Bible stress the impact of drought on daily life and society:

Fig. 13.2. The 1988 Big Drought in the United States

Genesis, chapter 41:
30: but after them there will arise seven years of famine, and all the plenty will be forgotten in the land of Egypt; the famine will consume the land,
31: and the plenty will be unknown in the land by reason of that famine which will follow, for it will be very grievous.

Deuteronomy, chapter 11:
17: and the anger of the Lord be kindled against you' and he shut up the heavens, so that there be no rain, and the land yield no fruit, and you perish quickly off the good land drought for consecutive years drought for consecutive years was then as today a major natural disaster:

Samuel, chapter 212:
1:Now there was a famine in the days of David for three years, year after year; and David sought the face of the Lord.

Drought risks are escalating due to increasing and shifting populations that intensify pressure on water resources (Wilhite 2000).

13.2 Drought as a Natural Disaster

The total risk (R) or the expected number of injuries and lives lost and property damage, is a function of the hazard magnitude (H), the victims and affected elements (E), and vulnerability (V) (Bell 1999):

$$R= f (H, E, V)$$

Natural Disasters have following characteristics:

- They are caused by natural processes, and may be accelerated and aggravated by human activities, like large floods or landslides.
- High magnitudes, with scales for the magnitude
- They occur suddenly, usually last for a short time and unpredictably in some cases like earthquakes, or with short warning time like in volcanic eruptions. Droughts are an exception and are prolonged events.
- They produce serious human and economic losses.

Natural drought is a prevailing hazard in the Near East (Bruins 2000). The available resources of freshwater in the region are rather small in comparison with the world standard, and water stress is a problem if a country has less than 1700 m^3 $person^{-1}$ yr^{-1}. Israel resources are even below the figures for most neighboring countries (Table 13.1). Water withdrawn overcomes the renewable water resources by 110%.

Israel has large areas with a hyperarid climate (precipitation/potential evapotranspiration (P/ETP) <0.03) and arid climate (P/ETP=0.03-0.20). In the Northern Jordan basin, most of the area is semiarid (P/ETP=0.20-0.50). The average rainfall is 700 mm with an ETP of 1600 mm (P/ETP=0.41). Only the mountainous areas get more than 800 mm rainfall and have a subhumid climate.

The study defines the drought effects in Israel and other semi-arid countries in relation to land degradation and water resources management, and examines the

Table 13.1. Population and renewable fresh water in the Near East (Adapted from Soffer 1999 and World Population)

	Population (million)	Renewable fresh water (million m^3 y^{-1})	Fresh water per capita (m^3 y^{-1})
Turkey	72.6	105,000	1446
Egypt	80	60,000	750
Syria	19.2	10,500	547
Lebanon	3.9	3,700	949
Israel	7.1	1,600	225
Jordan	6.1	750	123

potential implications for the water resources in Israel, in order to provide information to the public and decision makers.

The public, and sometimes also decision makers, do not have long memories and there is a need to provide the scientific background and information to the drought problem.

13.3 Droughts in Israel

According to long term rain measurements series for Jerusalem (since 1846), Shechem-Nablus (since 1922), Beirut, (Lebanon, since 1876), Kfar Gil'adi (since 1921), Israel with its Mediterranean climate, has experienced consecutive three dry years every 50 years period (Table 13.2).

Severe and extensive hydrologic drought affected the majority of the streams in Israel (Ben-Zvi 1987). The recent drought of 1998-2001 in northern Israel was the most extreme during the last 130 years. It affected the water flow of the Jordan River and brought the level of Lake Kinneret to its lowest point in historical periods (Fig. 13.3) (Inbar and Bruins 2004). The Jordan river water flow was during the consecutive dry years below half of the average annual flow, causing the low levels of the Kinneret lake (Table 13.3). Droughts are a major component of the total disasters in Israel (Inbar 2004) (Figs. 13.4 and 13.5).

13.4 Human interference

During the recorded data period, different environmental conditions in the catchment changed significantly due to:

a. *Deforestation:* native forests were almost completely cut, specially for coal supply to the railway system at the beginning of the twentieth century. Since the establishment of the State of Israel an intensified program for aforestation was developed.

Table 13.2. Drought years in 30 years period, Northern Israel

Years	Drought years in 30 years periods	Std
1877–1900	(1887, 1888, 1889, 1890)	–0.94
1900–1930	no drought	
1930–1960	(1932, 1933, 1934) (1957, 1958, 1959, 1960, 1961, 1962)	–1.05 –0.75
1960–1990	(1989, 1990, 1991)	–0.84
1990–2003	(1999, 2000, 2001)	–1.30

b. Intensified agriculture, changing land use.
c. Water pumping and irrigation: most of the spring water flow in the dry season is used for agricultural purposes.
d. Water diversion: The National Water Carrier diverts since 1964 most of the Jordan flow to the central and southern parts of the country.
e. Drainage of Lake Hula: The lake and adjacent swamp areas were drained in order to gain land.
f. Overgrazing: The centuries overgrazing custom changed, and in the last decades there is a decrease in the traditional overgrazing herds into modern pasture systems.

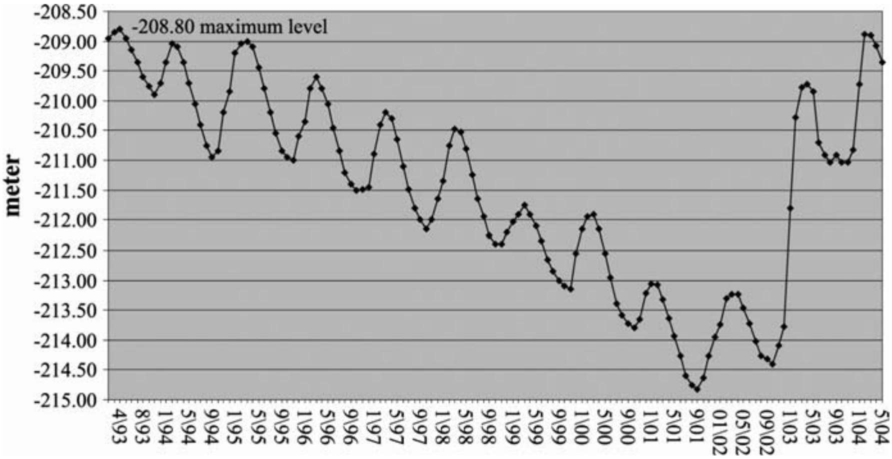


Fig. 13.3. Lake Kinneret level for the period 1993-2006. The extreme drought of 1998-2001 lowered the level to the lowest known level in history: -214.9m

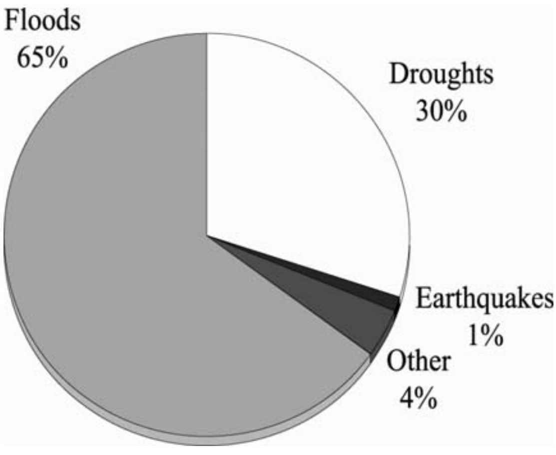


Fig. 13.4. Drought as a major component of total disasters in Israel

Fig. 13.5. Lake Kinneret (Lake of Galilee) is the major surface water reservoir of Israel, providing 30% of the total national water consumption

Table 13.3. Jordan River water flow during drought periods

Year	Q (10^6 m^3)	Std. value
1988/89	267	–0.93
1989/90	183	–1.52
1990/91	232	–1.18
1998/99	201	–1.39
1999/00	215	–1.30
2000/01	169	–1.62

These changes in land-use, water pumping and flow diversion, have exacerbated the negative impact of droughts and caused land degradation, such as the drying of wetlands and salinity of freshwater aquifers. The increased use of urban treated waste water for irrigation, with its significantly higher salt content, is another cause of soil degradation, and has a major economic impact on irrigated farming schemes (Table 13.4). Wetlands and aquatic environments around Lake Kinneret and other regions of the country, were practically dry for six consecutive years, affecting fish-breeding and endemic aquatic species.

13.5 Solutions

Various solutions have been applied: drip irrigation, recycling of wastewater, reduced allocations and increased pricing of water supplies, desalinization plants, etc. However, the failure by successive governments to introduce drought contingency planning and sustainable management of water resources, has already damaged agriculture and nature conservation. The imminent dangers of drought are liable to lead to a major crisis in the country's water resources and affect all sectors of society.

In order to cope with future drought periods, there is a need to have a reliable water reservoir in the aquifers and surface water reservoirs. Presently the figures are close to the red line and a basic need is for about two billion m^3.

There is uncertainty about the future. The most reliable figures are the increasing population and standard of living, and that means an increase in the demand for water. In Israel two main major water policies are defined (Gvirtzman 2002): first, the megaprojects, including import from foreign source (Turkey) by ship or pipe transport, the Mediterranean or Red Sea canal to the Dead Sea. Most of the projects are not viable under currently political factors (Soffer 1999). The second policy is based on local development, such as desalinization from the Mediterranean, desalinization of underground brackish water, increase of purification of domestic sewage water for agricultural purposes, aggressive water saving policy and increase of precipitation by cloud seeding.

13.6 Drought events in Mediterranean and South America countries

Other Mediterranean countries had experienced similar increase of drought periods (Conte et al. 2002). Since the beginning of the 20th century, Morocco had balanced phases of rainy and drought years. This balance seems to have broken since 1975, as the number of dry years has a tendency to exceed the humid ones. The 1980-1984 drought in Morocco was perhaps the most severe in the country over a period of 1000 years (Stockton 1988). A high mortality of trees was recorded.

In Algeria the frequency of the years of high drought is 10% on the coast and 20% in the continental areas. 11 drought sequences of more than one year were recorded in the 110 year old Tunis-Manoubia station (Laouina 1998). Drought in North Africa introduces severe constraints and can be catastrophic. It affects the whole economy, resulting in a deficit in the growth of meadow herbs, reducing replenishment of aquifers and increasing land degradation processes by overgrazing and water salinity.

Drought in South America is connected with the El Niño years. In Brazil the most affected area is the Northwest covering 800,000 km^2. For the period 1877 to 1995, drought affected 25 years, and three prolonged droughts of three consecutive years were registered (Nogueira de Souza and Vidal de Oliveira 2002). The effects were a drastic reduction in vegetation inducing famine and high mortality.

In Argentina in 1995 high temperatures were registered and a severe drought affected large areas of the "pampas" in the southern region. Drought affects the area every 10 years on average. The main effect is on agriculture, crops yielding only 600 kg ha^{-1} against an average of 1600 kg ha^{-1} (Piccolo et al. 2002).

13.7 Discussion and Conclusions

Global circulation models are inaccurate for relatively small basins because they have a spatial resolution of about 80,000 km^2. Lake Kinneret watershed area is 2,700 km^2. Globally the potential evapotranspiration will increase by 4% for every increase of 1 °C in temperature, leading to a decrease in the available water resources.

The largest impact will probably be the recurrence or more frequent extreme events like droughts and floods, leading to natural disasters. Water resource managers assume that the future resource base will be the same as that of the past. However, new components must be considered: climate change and human interference in water resources availability. There is uncertainty in the effects of both of them and different operational scenarios must be developed. Following topics demand further research and public involvement:

1. The two multi-year drought periods in the last 13 years are either a fluctuation in a long term range of cycles, or a climatic change towards a drier average.
2. Is the impact of the extreme drought irreversible? This is a complex issue due to:
   - Irreversible salinity processes in aquifers.
   - Negative ecological conditions in Lake Kinneret (blue algae)
   - Drying of wetlands
   - Socio-economic impact on rural populations: shift to agro-tourism and industrial sectors and migration to urban centers.
3. *Solutions.* Water management towards efficiency in water consumption in the agricultural sector by several methods and technologies:
   - Drip irrigation (Figs. 13.6 and 13.7)
   - Use of urban recycled waste water
   - Reducing water allocations (up to 50% in drought years)
   - Desalinization plants (400 MCM in 2010- increase of 25% of water resources)

   Saving in the domestic sector by educational means and probably also by increased pricing of water supply. Water leaking in the pipe systems may be a considerable amount of the total water use (Fig. 13.8).
4. *Water affairs.* The Israel centralized system is still under pressure of different sectors and various ministries, and there is a need of a comprehensive policy.
5. *Global change, Man-impact and drought.* Global climate change will increase the frequency of droughts, human impact will exacerbate their effect, and only a clear policy and comprehensive management may reduce the vulnerability to drought disasters. (Figs. 13.9 and 13.10).

In the Old World regions, rural land degradation generally is associated more with agricultural and pastoral activities than with other forms of land use. However, ur-

Fig. 13.6. Drip irrigation of a vineyard in the semi arid province of Mendoza-Argentina

Fig. 13.7. Drip irrigation of a cotton field in Israel, in the dry season. All water supply is by irrigation.

Fig. 13.8. Water shortage in the Israel map: cartoon showing the last drops left after a prolonged drought

ban industrial, mining and forestry land uses also have an important impact on the biophysical environment.

Soil erosion and soil degradation, involving changes in the physical, chemical and biological structure of the soil, has been a consequence of vegetation changes and exacerbated by irrigation agriculture. Soil degradation occurs as increasing of salinity, accumulation of nutrients associated with fertilizers and pesticides.

Countries faced with a growing population without increasing the total water resources will be affected by drought in all aspects of the economy. The failure by successive governments to introduce drought contingency planning and sustain-

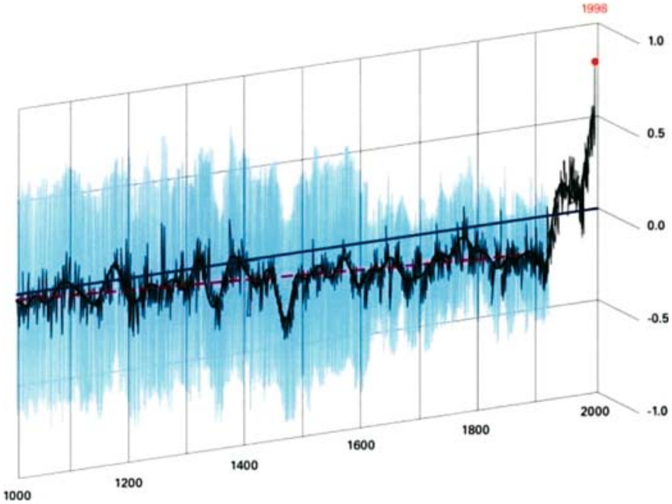


Fig. 13.9. Temperature development in the last 1000 years (Northern Hemisphere). The greenhouse gas concentrations alter the energy budget in the lower atmosphere

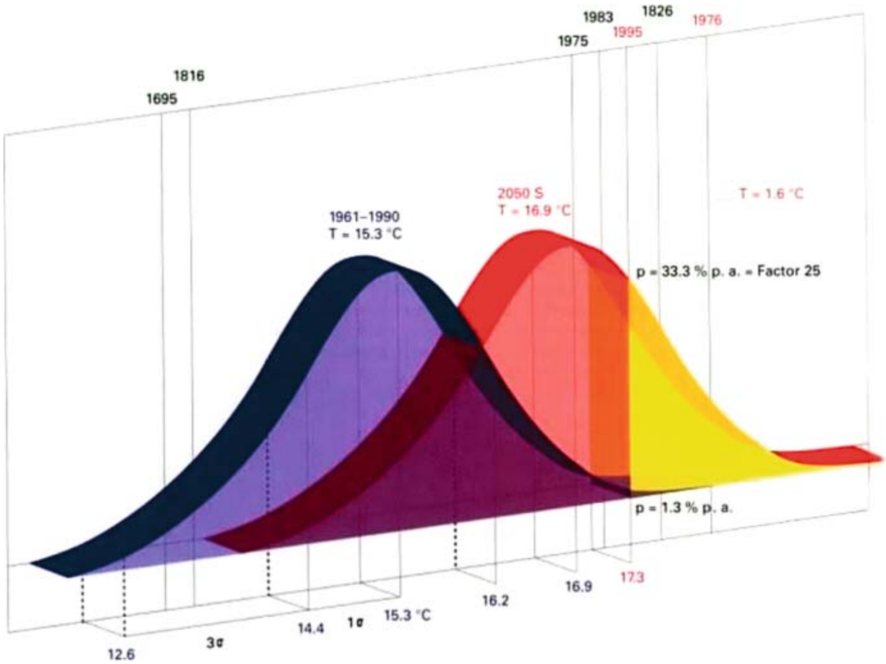


Fig. 13.10. Increase of extreme temperatures in the world

Table 13.4. Total water consumption in Israel by sectors: 1993-2003 (after Schwartz et al., 2004)

Year	Total	Agriculture				Industrial	Domestic
		Total	Fresh water	Sewage	Brackish and Floods		
1993	1762.4	1125.0	846.4	199.7	79.3	110.0	527.0
1994	1813.0	1143.6	841.4	219.3	82.9	113.9	555.5
1995	1981.0	1273.8	896.8	250.0	127.0	119.4	588.1
1996	2012.7	1284.3	892.3	270.0	122.0	124.4	604.0
1997	2007.8	1263.8	854.1	255.4	154.3	122.8	621.2
1998	2165.8	1364.9	918.3	271.0	175.6	129.2	671.7
1999	2072.9	1204.6	824.3	285.0	155.3	126.5	681.8
2000	1923.7	1137.4	729.1	260.0	148.3	124.2	662.1
2001	1800.4	1021.9	563.1	265.0	193.8	120.1	658.4
2002	1830.7	1007.0	540.0	287.0	180.0	121.8	688.4
2003	1859.6	1045.1	562.5	285.0	197.6	116.5	698.0

able management of water resources, has already damaged in Israel the agricultural economy sector and nature conservation. The dangers of drought are liable to lead in Israel and many other countries in the climatic semiarid belt to a major crisis in the country's water resources and affect all sectors of society. Science has to provide the background for the understanding of the present situation and may develop the future scenarios of drought contingency.

References

Bell FG (1999) Geological Hazards. Spon Press, London and New York.

Ben-Zvi A (1987) Indices of hydrological drought in Israel. J Hydrol 92: 179-191

Bruins HJ (2000) Drought hazards in Israel and Jordan: policy recommendations for disaster mitigation. In: Wilhite DA (ed.) Hazards and Disasters Series, vol. II. Routledge, London. pp. 178-193

Conte, M, Sorani R, Piervitali E (2002) Extreme Climatic Events over the Mediterranean. In: Geeson NA, Brandt CJ, Thornes JB (eds.) Mediterranean Desertification, John Wiley & Sons, pp. 15-31

Gvirtzman H (2002) Israel Water Resources. Yad Ben-Zvi Press, Jerusalem, Israel (in Hebrew).
Inbar M, Bruins HJ (2004) Environmental Impact of Multi-Annual Drought in the Jordan Kinneret Watershed, Israel. Land Degrad Dev 15:243-256
Inbar M (2004) Natural Hazards in Israel, 1948-2004: A Temporal and Spatial Analysis. In: Maos JO, Inbar M, Shmueli DF (eds.) Contemporary Israeli Geography, University of Haifa, Israel, pp. 139-146
Laouina A (1998) Drought, water shortages and water quality. In: Conacher AJ, Sala M (eds.) Land Degradation in Mediterranean Environments of the World. John Wiley, pp. 218
Munich Re Group (2000) Topics 1999. Annual Review of Natural Catastrophes. Munich, pp. 46
National Drought Mitigation Center (1995) Understanding and Defining Drought. www.drought.unl.edu
Nogueira de Souza MJ, Vidal de Oliveira VP (2002) Semi-arido do Nordeste do Brasil e o fenomeno da seca. In: Lugo Hubp J, Inbar M (eds.) Desastres Naturales en América Latina, Fondo de Cultura Económica, México, pp. 207-221
Piccolo MC, Capelli de Steffens A, Campo de Ferreras AM (2002) La sequía de 1995 en la region pampeana argentina.In: Lugo Hubp J, Inbar M (eds.) Desastres Naturales en América Latina, Fondo de Cultura Económica, México, pp. 189-206
Schwartz D, Nussboim Sh, Schor U (2004) Water in Israel- consumption and production. Water Authority, Ministry of Infrastructure, Tel Aviv, pp. 40 (Hebrew).
Sivakumar MVK, Das HP, Brunini O (2005) Impacts of Present and Future Climate Variability and Change on Agriculture and Forestry in the Arid and Semi-Arid Tropics. In: Salinger J, Sivakumar MVK, Motha RP (eds.) Increasing Climate Variability and Change, Springer, pp. 31-72
Soffer A (1999) Rivers of Fire. Rowman & Littlefield Publishers: Lanham, Boulder, CO.
Stockton CW (1988) Current research progress toward understanding drought. In: Drought, water management and food production. Conf. Proceedings, Agadir, 21-24 November 1985, pp. 21-36
TIME Magazine (1988) Just Enough to Fight Over, July 4, 1988, p.16.
Wilhite DA (ed.) (2000) Drought: A Global Assessment. Vol. I and II. Routledge, London.

CHAPTER 14

The Role of Land Degradation in the Agriculture and Environment Nexus

Anna Tengberg and Svanhild-Isabelle Batta Torheim

Abstract. The relationship between agriculture and environment could be viewed as conflicting (win-lose) or as synergistic (win-win). A win-lose situation is occurring when agricultural activities such as clearing forest for cultivation is leading to environmental degradation or when environmental protection prevents agricultural activity. A synergistic approach, on the other hand, assumes that sustainable environmental management and agricultural production can be achieved simultaneously. One central goal of the Global Environment Facility (GEF) and UNEP is to mainstream sustainable land management into sectors such as agriculture and forestry, thus assuming that win-win situations are possible. The different conceptual frameworks that UNEP has applied and developed in its GEF-funded land degradation projects highlight different aspects of the relationship between agriculture and environment.

The paper draws on 10 years of UNEP/GEF experience in working at the environment-agriculture nexus starting with the People, Land Management and Environmental Change Project (PLEC). PLEC illustrates the potential for synergies between environmental and developmental objectives by developing sustainable and participatory approaches to biodiversity management and conservation based on farmers' technologies and knowledge within agricultural systems. The Land Use Change, Impacts and Dynamics Project (LUCID) developed a model on how to use land use change analysis in combination with social and economic variables as a tool to assess biodiversity loss and land degradation across landscapes. The Millennium Ecosystem Assessment (MA) assessment framework offers a mechanism for decision-makers to: (1) identify options that can better achieve core human development and sustainability goals; and (2) better understand the trade-offs involved in decisions concerning the environment. The Land Degradation Assessment in Drylands (LADA) uses the *Driving Forces-Pressures-State-Impact-Responses* (DPSIR) framework in analysing the environment-agriculture nexus in drylands.

This overview shows how the relationship between agriculture and environment can be analysed using different models and approaches depending of scale and level of analysis. The PLEC model is useful at the local level in reconciling environmental and livelihood goals. Land use change analysis is a useful tool at the landscape level in analysing drivers of land degradation and biodiversity loss. The ecosystem services approach by the MA provides a tool for decision-makers at national level to make informed decisions about trade-offs between agriculture/human well-being and the environment. Finally, LADA will use the DPSIR framework for integration of information collected at different scales, from the local to the global.

14.1 Introduction

Land degradation is a global problem associated with desertification, loss of biological diversity and deforestation in arid, semi-arid and dry sub-humid zones. 'Desertification' is defined as land degradation in drylands, which covers some 47 percent of the globe's surface (UNEP 1997). However, land degradation is considered by many observers to be highly variable, discontinuous, arising from different causes and affecting people differentially according to their economic, social and political circumstances (Mortimore 1998; Swift 1996; Leach and Mearns 1996b; Thomas and Middleton 1994; Beinart 1996). Estimates as to the extent and impact of land degradation are conflicting and have in an increasing number of cases been proved to be based on false assumptions, as in the case with forest islands in the Guinean zone of West Africa (Fairhead and Leach 1996; Fairhead and Leach 1998) and soil erosion in East Africa (Tiffen et al. 1994). Due to this complexity, several actors have advocated for a reorientation of the United Nations Convention to Combat Desertification (UNCCD) from how to combat environmental problems in drylands to how to improve people's livelihoods in drylands (e.g. Movik et al. 2003).

It has been argued that the United Nations Environment Program (UNEP) has perpetuated the desertification narrative through its major role in organising the UN Conference on Desertification in Nairobi in 1977 and its follow up on the Plan of Action to Combat Desertification (Swift 1996; Lonergan 2005). The Action Plan resulted in the report of the Executive Director to the UNEP Governing Council in 1984, which stated that "The scale and urgency of the problem of desertification as presented to the Desertification Conference and addressed by the Plan of Action have been confirmed. Desertification threatens 35 per cent of the earth's land surface and 20 per cent of its population," (sited in Swift 1996). In the 21st Century, UNEP has taken on board new scientific evidence and understanding of the environment in drylands and supported the publishing of a special issue of the Journal of Arid Environments on the "greening" of the Sahel in 2005 (e.g. Herrmann and Hutchinson 2005). UNEP has also developed a new Strategy on Land Use Management and Soil Conservation (UNEP 2004) that stresses the need to adopt an ecosystem approach to integrate the management of land, water and living resources. Thus, a direct link is made between environment, land and soil issues and sustainable development and poverty reduction.

The interactions between humans and the environment are complex and driven by land use and land-use change, climate variability as well as policy and institutional factors. This paper will attempt to shed light on these interactions by examining the conceptual approaches and results of some UNEP projects that were co-funded by the Global Environment Facility (GEF). The first part of this paper explores the potential links between agriculture and environment in terms of the existence of conflicts or synergies. A comprehensive understanding of this nexus is a prerequisite for proper decision-making in regard to necessary interventions to promote sustainable development. Thus, the second section introduces four different frameworks for examining the agriculture and environment nexus as they are developed and used by UNEP projects. These frameworks highlight different conflicting and synergic aspects of the relationship between agriculture and environment.

14.2 Agriculture and environment – conflicts and synergies

Land degradation is caused by human-induced or natural processes which negatively affect the capacity of land to function effectively within an ecosystem. When examining the role of land degradation in the agriculture and environment nexus, it is essential to understand the human induced impact on the productive capacity of the land. However, the relationship between agriculture and environment is far more complex than simply assuming that agriculture causes land degradation. The causal relationship between agriculture and land degradation also goes in the other direction as the degradation of land severely hampers agricultural productivity (e.g. Biggelaar et al. 2003) as also demonstrated by economic valuation of loss in productivity due to soil erosion in East Africa (Ellis-Jones and Tengberg 2000).

Perspectives on the relationship between agriculture and environment can broadly be grouped in two, the 'Malthusian camp' versus the 'Boserup camp'.[1] The former camp sees a *conflict* between humans, population growth, agricultural activities and the environment. They stress the inherent degenerative impact of agriculture on the environment. Rapid population growth is seen to be associated with increased poverty and natural resource degradation, caused by, amongst other things, land scarcity, reduced fallow periods, deforestation, cultivation of marginal lands and underdeveloped human capital (Tiffen et al. 1994).

Arguably, there is a conflict between agriculture and the environment in at least two ways: (1) agricultural activities can lead to environmental degradation. Examples of this include the overgrazing of rangelands, cultivation of land that is inappropriate for agriculture or use of inappropriate land management techniques leading to e.g. soil erosion, salinisation and water logging, soil nutrient depletion, soil compaction, etc; (2) another conflicting side of the agriculture and environment relationship is the cases where environmental conservation prevents agricultural activity, as, for example, in protected areas where agriculture is prohibited.

The other perspective on the agriculture-environment nexus assumes that the goals of environmental conservation and agricultural activities can be achieved simultaneously. Such a *synergy approach* is therefore in line with the 'Boserup camp' that looks at population growth as a trigger of technological innovation that increases production. The goal to create synergies is obvious in the operations of UNEP (2004) and of the Global Environment Facility (GEF) – the financial mechanism of the Multilateral Environmental Agreements (MEAs) in e.g. Biodiversity, Desertification and Climate Change. Both institutions support efforts to main-

[1] For a longer introduction to this debate, Brookfield (1995) and Tiffen et al. (1994) provide a perspicuous overview of the two 'camps'. We apply a simplified interpretation of the original texts of Malthus and Boserup in order to highlight the essence in different theoretical approaches to the agriculture and environment nexus.

stream sustainable environmental management into sectors such as agriculture and forestry.

The notion of human-induced desertification is linked to the conflict perspective on the relationship between agriculture and the environment. It has its origin in the French colonial administrators in West Africa, who thought that the Sahara desert was enlarging thanks to unsustainable land management practises including extensive use of fire for clearing of vegetation as well as overgrazing (Stebbing, 1937 in Swift, 1996). Swift (1996) argues that the received narrative of desertification provided a convenient point of convergence for the interests of three main constituencies: national governments in Africa, international aid bureaucracies, especially United Nations agencies and some major bilateral donors. The dominance if this narrative resulted in the adoption of approaches that actually reinforced the conflict between agriculture and environment. This was for example the case with the agrarian reforms introduced in Ethiopia in the mid-1970s, whose net effects was to lessen farmers' incentive for good natural-resource management by decreasing both the security of land tenure and the profitability of agriculture (Hoben 1996). According to Hoben (1996), the neo-Malthusian narrative's denigration of indigenous agriculture has lead experts and planners to overlook and filter out much information about the strengths of indigenous resource-management practices. The worst thing about this narrative, he continues, is that it fostered a major investment in technologies and activities that did little to address environmental degradation or farmers' needs.

Well-known desertification narratives have been challenged by findings by long-term studies on environmental and agricultural change in the Sahel in West Africa of which many are collected by Leach and Mearns (1996a). As Hutchinson and Herrmann (2005) summarise, these studies have found evidence of significant transitions from degraded land-use trajectories to more sustainable and productive production systems. These include increases in cereal yields, higher densities of trees, improved soil fertility management, locally higher groundwater tables, reductions in rural poverty, and decreased out-migration. Hence, many local or indigenous land management practises capitalise on the complexity of the environments in which they operate to develop diverse and ecologically resilient land management systems adapted to variability and non-linear processes (Beinart 1996), while commercial and intensive agriculture tends to seek order and uniformity.

Land degradation can cause problems at three levels (Pagiola 1999): At the *field level*, land degradation can result in reduced productivity; at the *national level*, land degradation can cause problems such as flooding and sedimentation; while at the *global level*, land degradation can contribute to climate change, and damage to biodiversity and international waters. Thus, land degradation is a cause of concern for everybody although the impacts differ at different scales. The next sections will outline different frameworks for understanding the agriculture and environment nexus at these different levels with a focus on the role of land degradation. These frameworks are hence a good starting point to assess the different aspects of the nexus to identify where there are conflicts that need to be addressed and where there are synergies that can be utilised. The differentiation of levels for interventions is a prerequisite for applying proper approaches and to avoid the fallacies of the past where there was an assumed conflict, but in reality the interventions created a conflict.

14.3 PLEC – a local level framework to link environment and agriculture

The People, Land Management and Environmental Change Project (PLEC) was a global project co-funded by GEF through UNEP from 1998-2002 and led by the United Nations University. The main objective was to develop sustainable and participatory approaches to biodiversity management and conservation based on farmers' technologies and knowledge within agricultural systems at the community and landscape levels.

PLEC studied the impact of population and development on agricultural land resources and biodiversity (Brookfield 1995). It focused on small farmers in the tropics and subtropics, on their own innovations and adaptability, and on the reasons why some manage their resources sustainably, while others fail to do so. The PLEC philosophy was summarised by one of its members as: "The important question now is not which traditional practices, as practiced in the past, are sustainable, but rather which conditions cause people to conserve their resources, and which conditions favour their destruction, or over-exploitation, of local resources" (cited in Brookfield 1995). Thus, PLEC assumed that both conflicts and synergies can emerge in the relationship between agriculture and environment. Using a bottom up approach by taking farmers as the entry point, PLEC set out to identify factors that determine when conflicts will happen and when synergies can occur. Initially, PLEC was a research project focusing on methods of farmers' management of their resources, especially biodiversity resources. The research soon revealed that a minority of farmers managed their resources better than others and thus gained greater production while at the same time conserving or creating biodiversity and reducing environmental degradation. PLEC referred to these farmers as 'expert farmers' (Brookfield 2003).

Based on the expertise of these expert farmers, PLEC developed a replicable methodology to allow locally adapted solutions to biodiversity and land management emerge and be taken up by scientists and policy makers. The concept of *agrodiversity* was central in this work, which is a broader term than the more commonly used concept of agrobiodiversity (Brookfield et al. 2003; Brookfield 2002). While the latter refers to the diversity of plants and animals used for food and agriculture, agrodiversity is a broader concept as it captures the interlinkages between the environment, both natural and modified, and agricultural activities typically found in small-scale farming systems in developing countries. It is also related to development issues such as demography, macro-economy and livelihoods. Farmers of traditional and low input agricultural systems have long favoured diversity on the farm (Pretty 1995). By maintaining diversity and developing a variety of strategies, farmers are spreading risk. For example, Pretty (1995) refers to surveys of non-irrigated rice systems in south east Asia where farmers described different combinations of landscape position, soil type, hydrology, and flood and drought risk, and showed how they matched these to different combinations of rice varieties and management practices. PLEC identified different elements of agrodiversity that conceptually capture the diversity not only in the farmers' fields, but also how they organise themselves and utilise that diversity.

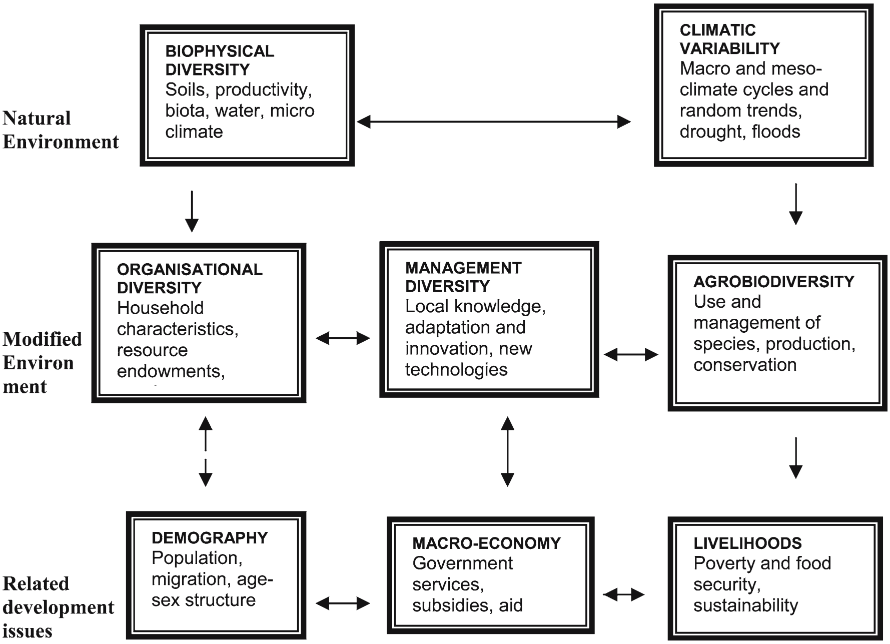


Fig. 14.1. The different elements that together constitute Agrodiversity (Adapted from Brookfield and Stocking 1999)

According to Brookfield and Stocking (1999), agrodiversity is composed of the following elements (see Fig. 14.1): *Agrobiodiversity*, which is the diversity of useful plants in managed ecosystems. It refers to all crops and other plants used by or useful to people. The term *Management diversity* includes all methods of managing the land, water and biota for crop production and maintaining soil fertility and structure. Local knowledge, constantly modified by new information, is the foundation of management diversity. *Organisational diversity* is often called the socio-economic aspects of agriculture and includes diversity in the manner in which farms are owned and operated and in the use of resource endowments and the farm workforce. Elements include labour, household size, the differing resource endowments of households, and reliance on off-farm employment. Also included are age group and gender relations in farm work and differences between farmers in access to land. Organisational diversity thus embraces management of all resources, including land, crops, labour, capital and all other inputs. Farmers with different resource endowments organise differently in accordance with their specific circumstances.

All these three elements belong to a modified environment. *Biophysical diversity* is part of the natural environment and refers to soil characteristics and their qualities and the biodiversity of natural plant life and the faunal and microbial biota. It takes account of both physical and chemical aspects of the soil, surface and near-surface physical and biological processes, and hydrology. Climatic variability and change, including macroclimate and microclimate, are also part of the natural environmental factors that affect farm management outcomes. Agrodiversity is the sum of all these elements and can be defined as "the dynamic variation in cropping systems, outputs and management practice that occurs within and between agroecosystems. It arises from bio-physical differences, and from the many and changing ways in which farmers manage diverse genetic resources and natural variability, and organise their management in dynamic social and economic contexts" (Brookfield 2001).

The agrodiversity framework of PLEC has some parallels to the better known Sustainable Rural Livelihood (SRL) approach developed in the late 1990s (e.g. Carney 1998a or Ellis 2000). Carney (1998b) adopts the following definition of SRL: "A livelihood comprises the capabilities, assets (including both material and social resources) and activities required for a means of living. A livelihood is sustainable when it can cope with and recover from stresses and shocks and maintain or enhance its capabilities and assets both now and in the future, while not undermining the natural resource base". Central to SRL is the analysis of five different types of assets upon which individuals draw to build their livelihood. These are natural, social, human, physical and financial assets. PLEC was adopting a SRL approach to address the issue on how farmers use and conserve biodiversity. Agrobiodiversity and biophysical diversity in the PLEC framework resemble the term natural capital of the SRL framework.

The importance of the SRL approach is to direct attention to the links between assets and the options people possesses in practise to pursue alternative activities that can generate the income level required for survival (Ellis 2000). This resembles the PLEC approach of agrodiversity where the way farmers utilise the agrobiodiversity resources at hand differs according to diversity in management and organisation as illustrated in the PLEC framework. Stocking (2002) situates agrodiversity and land degradation in the sustainable rural livelihood debate and global environmental agenda. He presents a 'win-win' scenario for sustainable rural livelihoods, with components involved in land degradation and biological diversity. Environmental protection is essentially part of the global agenda, enshrined in two global conventions (i.e. the UN Convention to Combat Desertification and the Convention on Biological Diversity). According to Stocking (2002), many land users also wish to protect their environment, but this is in the context of their primary goal of maintaining production rather than for environmental protection *per se*. PLEC recognised these links and its demonstration sites showed how the enhancement of biodiversity can be combined with improvements in production and livelihood (see the case studies in Brookfield et al. 2002).

PLEC was organised in five ecosystem clusters and its project sites in Africa, Asia and Latin America were selected based on the particular agrodiversity conditions found in those areas. One of the best PLEC examples of synergies between agricultural and environmental concerns is from China, where an expert farmer converted a rocky and sloping 0.5 ha plot into an agroforest with over 100 species with a mixture of timber, fruit, medicinal plants, and wild species (Dao et al. 2003). The agroforest generated a stable and growing income, and served as an attractive model for other village farmers to reforest the upper slope near the state nature reserve and to diversify their sources of income as well as the landscape. This approach is in sharp contrast to monoculture of coffee and sugar plantations being promoted by companies in the area.

Examples of how agrodiversity can improve resilience in the face of land degradation and climate change can be found within each of the principal elements of agrodiversity. To ensure farmers' cooperation in agrodiversity management, it is necessary to seek ways of linking conservation with development. This synergistic approach adopted by PLEC was successful in combining the local agenda of sustainable rural livelihoods with the global agenda of environmental conservation, i.e. combating land degradation and preserving biodiversity while sustaining livelihoods. An important lesson from PLEC is that interventions intended to address land degradation in the agriculture and environment nexus at the local level should take into consideration the diversity among local natural resource users. Furthermore, by recognising farmers' skills and knowledge the chances of creating synergies increase.

14.4 LUCID – a landscape level framework

The *Land Use Change, Impacts and Dynamics Project* (LUCID) is an example of how to examine the agriculture-environment nexus at the landscape level. LUCID is a network of scientists at leading national and international institutions who have been studying land-use change in East Africa and its implications for land degradation, biodiversity, and climate change for many years. LUCID received GEF funding from 2001 to 2004 via UNEP and was led by the International Livestock Research Institute (ILRI). The main objective was to analyse new and existing data concerning the linkages between the processes of change in biodiversity, land degradation and land use in order to design a guide on how to use land use change analysis to identify spatial and temporal trends, and linkages.

An important tool for LUCID was the use of spatial and temporal analysis of land use change over the last 50 years in project sites in Kenya, Tanzania and Uganda. The way people use land has changed dramatically over the last half-century in East Africa (Maitima et al. 2004a). Several of the trends identified by LUCID indicate a conflicting relationship between agriculture and environment. Two of the largest changes have been the expansion of mixed crop-livestock systems into former grazing and other more natural areas, and an intensification of agriculture. Land use change from bush to grazing has tended to reduce soil organic carbon content, soil moisture, pH, bulk density and nitrogen (Kamau 2004). Land use change from grazing to continuous cropping rapidly impacts soil properties because former methods to maintain soil productivity such as shifting cultivation and fallowing are no longer practiced.

LUCID also identified rising levels of human-wildlife conflict (Campbell et al. 2002; Githiga et al. 2003; Reid et al. 2004). This includes injury and loss of life, and crop damage. Many farmers have responded by fencing land. With increased individual tenure, the impact of fencing upon livestock management and upon wildlife dispersal will increase. The overall picture emerging from LUCID is that conflicts between agriculture and environment related priorities are on the rise. Based on its several case studies in Kenya, Tanzania and Uganda (Maitima et al. 2004a; Maitima et al. 2004b), LUCID developed a model for Land Use Change analysis (Fig. 14.2).

This model of land-use change suggests that in pastoral areas without cultivation, the sequence of land cover as a result of land-use change is as follows: woodlands are transformed to bush land, which then become grassland which today provide pasture for livestock.

In wetter, cultivated areas, LUCID came up with a more complicated sequence of land-use changes. In the process of change from forest to grassland, a subsequent change in land-use takes place from grazing to cultivation. The land can be used intensively through either high-intensity grazing, intensive monocropping or intensive mixed cropping. The different land uses have different impacts on the environment. However, the results of intensive land use is negative for the environment resulting in degraded ecosystems (e.g. reduced species numbers and plant cover), eroded soils, depleted soil nutrients, loss of native species and poor crop productivity.

The LUCID framework integrates ecological, socio-economic and land use data and theory. In summary, the principal findings of LUCID are the expansion of farming, grazing and settlements at the expense of native vegetation over the last 20 years, and the loss of biodiversity and plant cover accompanying the loss of na-

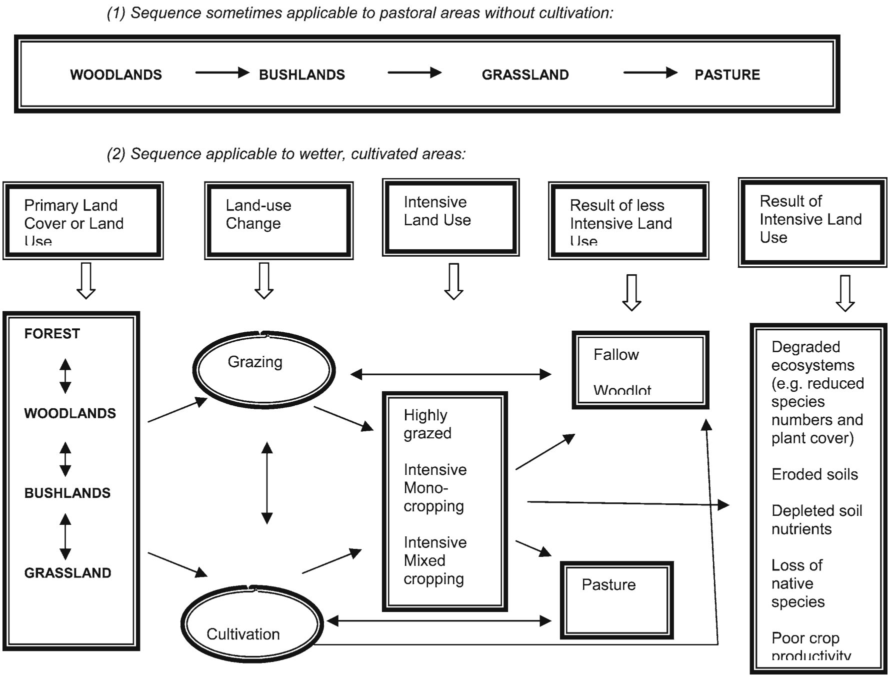


Fig. 14.2. Land-Use Change Model developed based on the last fifty years of development in East Africa (adapted from Maitima et al. 2004a). The top sequence (1) is applicable to changes in pastoral areas, the bottom (2), more complex sequence is applicable to wetter, cultivated areas

tive vegetation due to cultivation and overgrazing, leading to the destruction of habitats, with particular consequences for large mammals and local extinction. In addition, the significant changes in land cover over large areas observed by LUCID could have negative feedbacks on the local and regional climate. Although LUCID did not explicitly analyse the links between land-use change, land degradation and climate change, the project found that there was a grave concern in the region with climate change, and a perception that extreme weather events, such as droughts and floods were becoming more frequent. A recommendation from the project was therefore that there is a need for further research on regional climate change trends and interactions between climate change and land cover and land-use change.

14.5 The Millennium Ecosystem Assessment and LADA – global frameworks

14.5.1 The Millennium Ecosystem Assessment

The *Millennium Ecosystem Assessment* (MA) was a global project with many partners co-funded by GEF through UNEP. The main objective was to contribute to improved decision-making concerning ecosystem management and human well-being, and to build capacity for scientific assessments of this kind. The assessment focused on ecosystem services, which are the benefits people obtain from ecosystems, such as food, water and climate regulation, how these services have affected human well-being and how such changes may affect people in the future. It also focused on the responses that might be adopted at local, national, or global scales to improve ecosystem management and contribute to human well-being and alleviate poverty.

The Ecosystem Services Approach, developed by the MA, is bridging environment and human well-being concerns, and is therefore a valuable framework for analyzing the linkages between people and their environment. The MA identified land use patterns and practises as one of the major causes of desertification (MA 2005). For example, irrigation has led to increased cultivation and food production in drylands, but in many cases this has been unsustainable without extensive public capital investment. When analysing how future development paths will affect desertification, the MA concludes that population growth and increase in food demand will drive expansion and intensification of cultivated lands (MA 2005). It argues that if unchecked, desertification and degradation of ecosystem services in drylands will threaten future improvements in human well-being and possibly reverse gains in some regions.

The Assessment is operating with different categories of ecosystem services (MA 2003):

- *Provisioning Services*, which are products obtained from ecosystem such as food, fresh water, fuel wood, fibre, biochemicals and genetic resources.
- The *Regulating Services* are benefits obtained from regulation of ecosystem processes including climate regulation, disease regulation, water regulation, water purification and pollination.

- The *Cultural Services* are non-material benefits obtained from ecosystems, and refers for example to spiritual and religious benefits, educational benefits or cultural heritage.
- The *Supporting Services* are services that are necessary for the production of all other ecosystem services such as soil formation, nutrient cycling and primary production.

Changes in these services are driven by direct and indirect driving forces and these changes have consequences for human well-being. The indirect drivers of change, which include changes in demography, economy, socio- political context, science and technology as well as culture and religion, influence the direct drivers of change and also affect human well-being. The direct drivers of change of ecosystem services can be changes in local land use and cover, species introduction or removal and climate change. Further, the direct drivers of change influence human well-being. Human well-being and poverty reduction is measured in terms of basic material for a good life, health, social relations, security and freedom of choice and action. The degree of human well-being is influencing the indirect drivers of change, but is affected by all the three other components in this model.

How can the ecosystem services approach contribute to an enhanced understanding of the agriculture-environment nexus? Agricultural activities are captured in the box of figure 14.3 of direct drivers of change. For example, changes in

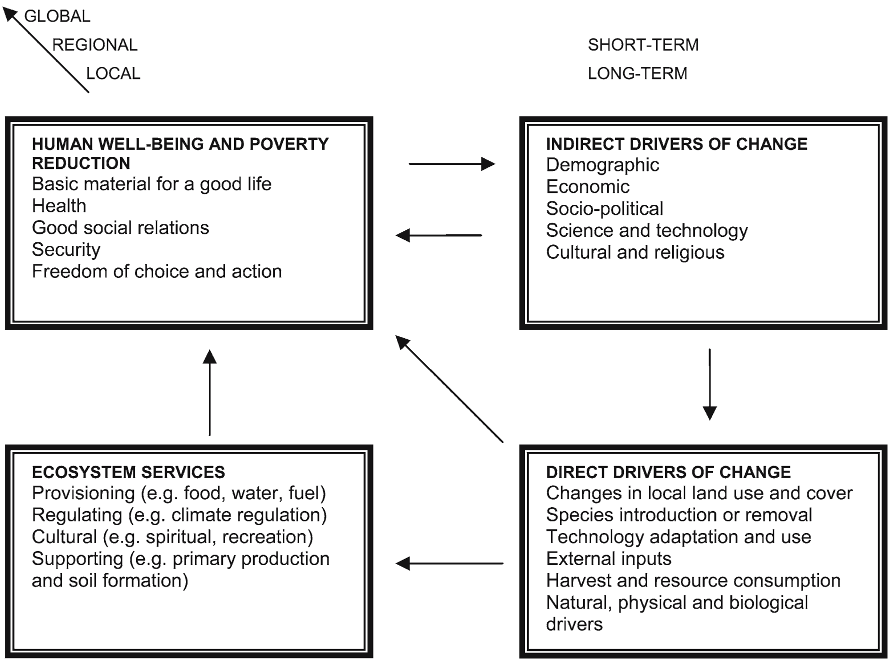


Fig. 14.3. The MA framework (adapted from the MA 2003)

local land use and cover are often associated with agriculture. From another perspective, agriculture could also be seen as part of human well-being as it provides basic material for a good life, which is highly influenced by ecosystem services. To what degree harvests will be good depends on water, climate, and nutrient cycling. Hence, the MA assessment framework offers a tool for decision-makers to identify options that can better achieve core human development and sustainability goals. All decision-makers must balance economic growth and social development with the need for environmental conservation. In cases of conflict between agriculture and environment, this framework can assist the analysis of consequences of different choices, so that agricultural development does not happen in a haphazard way at national level, as seems to have been the case in East Africa over the last 50 years, as documented by LUCID.

The assessment framework can also help decision-makers to better understand the trade-offs involved in decisions concerning the environment. Progress towards increasing food production, for example, has often been at the cost of progress towards other objectives such as conserving biological diversity or improving water quality. The MA complements sectoral assessments with information on the full impact of potential policy choices across sectors and stakeholders. A country can increase food supply by converting a forest to agriculture, but in so doing, it decreases the supply of services that might be of equal or greater importance, such as clean water, timber, ecotourism destinations, or flood regulation and drought control.

Impacts of human activities such as overgrazing or soil salinaztion, and climate variables such as inter-annual variability in rainfall and drought events, on vegetation productivity are difficult to distinguish. Thus, the MA recommends that long-term monitoring to distinguish between the role of human actions and climate variability in vegetation productivity be undertaken (MA 2005).

14.5.2
Land Degradation Assessment in Drylands

The *Land Degradation Assessment in Drylands* (LADA) builds on the recommendations of the MA for new and reliable data on the extent and impacts of desertification (MA 2005). LADA is an on-going project that is receiving GEF funding from 2006 to 2010 through UNEP and is led by United Nations Food and Agriculture Organisation (FAO). The main objective of LADA is to assess causes, status and impact of land degradation in drylands in order to improve decision making for sustainable development in drylands at local, national, sub-regional and global levels.

LADA will conduct a global assessment of the extent and magnitude of land degradation using data derived from remote sensing and climate data to produce maps of changes in Normalised Difference Vegetation Index (NDVI) and rain-use efficiency over the past 20 years. It will also work with six pilot countries to develop tools and methods for national-level assessment. These countries are South Africa, Senegal and Tunisia in Africa, Argentina and Cuba in Latin America and the Caribbean and China in Asia. In addition, a number of other countries and regions,

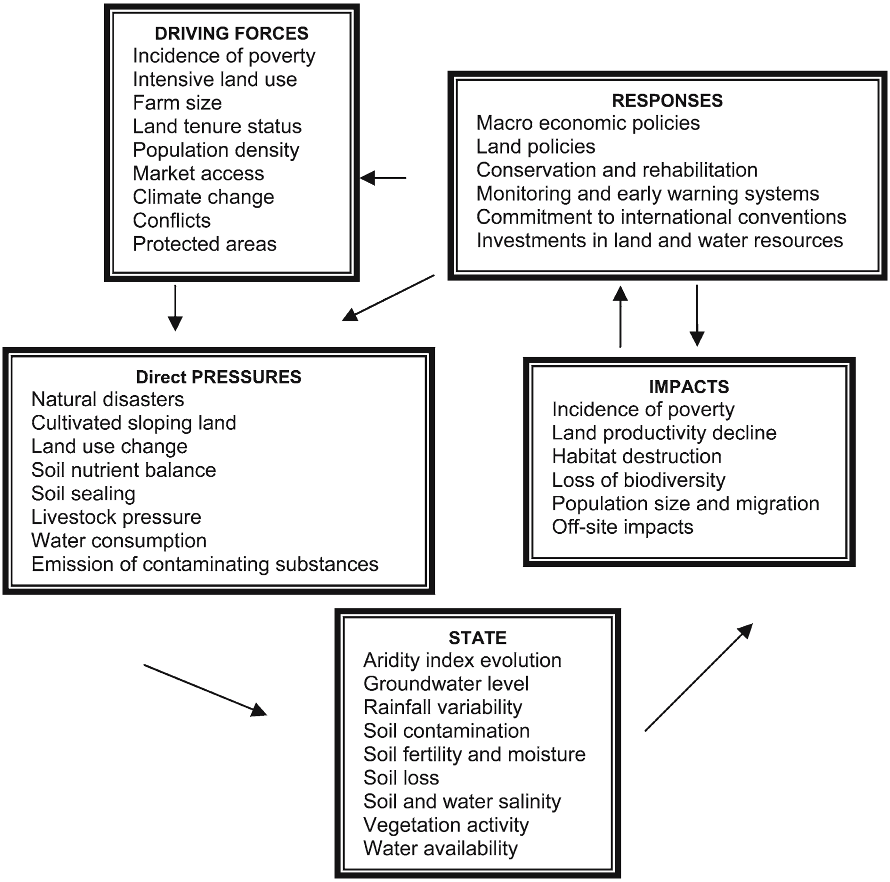


Fig. 14.4. DPSIR Framework with LADA Indicators (adapted from FAO 2006)

such as Central Asia, have expressed interest in the LADA methodology. Assessments are designed to ensure the transfer of benefits of capacity building and reduced land degradation accrued nationally or regionally, to the local level where, degrading land use activities and the costs of land degradation are incurred.

LADA will use the Driving-Force, Pressure, State, Impact and Response (DPSIR) framework, which is already in wide use in e.g. the EU and UN. The DPSIR framework will be used for integration of data from the local to the global level. However, one of the weaknesses with the framework is that it does not consider interactions between variables in each box (Fig. 14.4) and LADA will therefore try to identify aggregated indicators. LADA has reduced the key set of indicators from the original 120 to 20-30, as illustrated in Fig. 14.4.

14.6 Conclusions

The different theoretical frameworks discussed in this paper are contributing to enhancing the understanding of the agriculture-environment nexus in different ways and our examples have shown that different scales of analysis require different models and approaches. At the *local level* it is crucial to identify synergy situations and approaches that improve rural livelihoods while at the same time conserving the environment. The Agrodiversity approach of PLEC is a useful tool for conducting this type of analysis. It is an adaptation of the more generally known Sustainable Rural Livelihood framework that is often used in development circles.

At the *national and regional level* an important goal with the analysis is to identify long-term trends and whether there are conflicts between agricultural development and environmental sustainability. If this information is used to inform policy and planning, situations like the one described by LUCID in East Africa with growing conflicts between different types of land use threatening the long-term environmental sustainability of the region, could hopefully be avoided. The LUCID framework provides a tool for such analysis.

To gain a *global overview* of environmental changes brought about by agriculture, integration of information at different scales and across sectors is essential and here both the MA and DPSIR frameworks can be used depending on the nature of the data and the target audience. The MA framework can also be used at national level to analyse trade-offs between different land-use scenarios. In this context, it is also important to consider the potential value of all ecosystem services. Traditionally, decision-makers only used to consider the more obvious provisioning services of ecosystems, such as production of food and fuel. However, for a long-term sustainable management of natural resources, trade-offs between provisioning services on the one hand and regulating, supporting and cultural services of ecosystems on the other hand, should also be considered before decisions that affect the agriculture and environment nexus are taken.

The scale sensitiveness of these frameworks can facilitate the development of more efficient and effective policy and programmes for addressing land degradation. Thus, they represent a tool for decision-makers and actors engaged in development interventions directed towards the agriculture-environment nexus to design locally adopted solutions that trigger synergies and prevent conflicts.

With regard to the role of climate in understanding the agriculture and environment nexus, there is a need to understand the long-term trends in climate and land-cover change and how they interact. This is exemplified by the LUCID project as well as long-term studies of rainfall and land cover changes in the Sahel (e.g. Olsson et al. 2005). Olsson et al (2005) argue that the 'greening' of the Sahel is largely caused by increased rainfall from the 1980 until today. Moreover, different types of land-use have different potentials for storing carbon below and above ground, but better methods for quantifying carbon stocks are required in order to enhance the understanding of the interactions of climate, agriculture and the environment (e.g. Milne et al. this issue). Integration of climate information with analysis of long-term trends in land-cover change is therefore necessary in order to understand the drivers of change at the agriculture and environment nexus, an aspect that needs further strengthening in the frameworks analysed in this paper.

Acknowledgements

The authors wish to thank all the partners in the reviewed UNEP/GEF projects. Special thanks to Michael Stocking for useful comments on the manuscript.

References

Beinart W (1996) Soil Erosion, Animals and Pasture over the Longer Term. Environmental Destruction in Southern Africa. In: Leach M and Mearns R (eds) The Lie of the Land. Challenging Received Wisdom on the African Environment. The International African Institute, London, in association with James Currey Ltd, pp. 54-72.

Biggelaar C, Lal R, Wiebe K, and Breneman V (2003) The Global Impact of Soil Erosion on Productivity, Adv Agron 81:1-96

Brookfield H (1995) Postscript: the 'population-environment nexus' and PLEC, Global Environ Chang 5:381-393.

Brookfield H (2001) Exploring Agrodiversity. Colombia University Press, New York.

Brookfield H (2002) Agrodiversity and agrobiodiversity. In: Brookfield H, Padoch C, Parsons H and Stocking M (eds) Cultivating Biodiversity. Understanding, Analysing and Using Agricultural Diversity. ITDG Publishing, London, pp. 9-14

Brookfield H (2003) The evolution of PLEC's work, 1992-2002. In: Brookfield H, Parsons H, Brookfield M (eds) Agrodiversity. Learning from Farmers across the World. United Nations University Press, Tokyo, pp. 5-20

Brookfield H and Stocking M (1999) Agrodiversity: definition, description and design, Global Environ Chang 9:77-80

Brookfield H, Padoch C, Parsons H, Stocking M (eds) (2002) Cultivating Biodiversity. Understanding, Analysing and Using Agricultural Diversity. ITDG Publishing, London

Brookfield H, Parsons H, Brookfield M (2003) How PLEC worked towards its objectives. In: Brookfield H, Parsons H, Brookfield M (eds) Agrodiversity. Learning from Farmers across the World. United Nations University Press, Tokyo, pp. 21-42

Campbell DJ, Gichohi H, Reid R, Mwangi A, Chege L, Sawin T (2002) Competition and Conflict between People and Wildlife In Kajiado District, Kenya, LUCID Working Paper Series Number: 18, International Livestock Research Institute (ILRI), Addis Ababa, Ethiopia

Carney D (ed) (1998a) Sustainable Rural Livelihood. What contribution can we make? Papers presented at the Department for International Development's Natural Resources Advisors' Conference, July 1998. London: DFID

Carney D (1998b) Introduction. In: Carney D (ed) Sustainable Rural Livelihood. What contribution can we make? Papers presented at the Department for International Development's Natural Resources Advisors' Conference, July 1998. London: DFID, pp. 3-26

Dao Z, Guo H, Chen A, Fu Y (2003) China. In: Brookfield H, Parsons H and Brookfield M (eds.) Agrodiversity. Learning from farmers across the world, United Nations University Press, Tokyo, pp. 195-211

Ellis F (2000) Rural Livelihoods and Diversity in Developing Countries, Oxford University Press, Oxford, UK.

Ellis-Jones J, Tengberg A (2000) The Impact of Indigenous Soil and Water Conservation Practices on Soil Productivity: Examples from Kenya, Tanzania and Uganda, Land Degrad Dev 11:19-36

Fairhead J, Leach M (1996) Misreading the African Landscape. Society and ecology in a forest-savanna mosaic. Cambridge University Press, Cambridge, UK
Fairhead J, Leach M (1998) Reframing Deforestation. Global analysis and local realities: studies in West Africa. Routledge, London and New York.
FAO (2006) Land Degradation Assessment in Drylands (LADA) project, presentation by FAO LADA team at LADA meeting 29 November 2006, Rome, Italy.
Githiga JM, Reid R, Muchiru A, Dijk S (2003) Survey of Water Quality Changes with Land Use Type, in the Loitokitok Area, Kajiado District, Kenya, LUCID Working Paper Series Number: 35, International Livestock Research Institute (ILRI), Addis Ababa, Ethiopia
Herrmann SM, Hutchinson CF (2005) The changing contexts of the desertification debate, J Arid Environ 63:538-555
Hoben A (1996) The Cultural Construction of Environmental Policy. Paradigms and Politics in Ethiopia. In: Leach M, Mearns R (eds) The Lie of the Land. Challenging Received Wisdom on the African Environment. The International African Institute, London, in association with James Currey Ltd, pp. 186-208.
Hutchinson CF, Herrmann SM (2005) Introduction: The "Greening" of the Sahel, Editoral, J Arid Environ 63:535-537
Kamau P (2004) Forage Diversity and Impact of Grazing Management on Rangeland Ecosystems in Mbeere District, Kenya, LUCID Working Paper no. 36, available at http://www.lucideastafrica.org/publications.htm
Leach M, Mearns R (eds) (1996a) The Lie of the Land. Challenging Received Wisdom on the African Environment (African Issues), The International African Institute, London, in association with James Currey Ltd
Leach M, Mearns R (1996b) Challenging Received Wisdom in Africa. In: Leach M, Mearns R (eds) The Lie of the Land. Challenging Received Wisdom on the African Environment (African Issues), The International African Institute, London, in association with James Currey Ltd, pp. 1-33
Lonergan S (2005) The role of UNEP in desertification research and mitigation, Preface. J Arid Environ 63: 533-534.
MA (Millennium Ecosystem Assessment) (2003) Ecosystems and human well-being: a framework for assessment, Island Press
MA (Millennium Ecosystem Assessment) (2005) Ecosystems and Human Well-being: Desertification Synthesis. World Resources Institute, Washington, DC.
Maitima J, Reid RS, Gachimbi LN, Majule A, Lyaruu H, Pomeroy D, Mugatha S, Mathai S, Mugisha S (2004a) Regional Syntheses Paper: The Linkages between Land Use Change, Land Degradation and Biodiversity across East Africa. LUCID Working Paper Series Number 42, International Livestock Research Institute (ILRI), Addis Ababa, Ethiopia
Maitima J, Reid RS, Gachimbi LN, Majule A, Lyaruu H, Pomery D, Mugatha S, Mathai S, Mugisha S (2004b) A methodological guide on how to identify trends and linkages between changes in land use, biodiversity and land degradation, LUCID Working Paper Series Number: 43, International Livestock Research Institute (ILRI), Addis Ababa, Ethiopia
Milne E, Sessay MF, Easter M, Paustian K, Killian K (2007) Sustainable Land Management Through Soil Organic Carbon Management and Sequestration – The GEFSOC Modelling System. In: Sivakumar MVK, Ndiang'ui N (eds) Climate and Land Degradation, Springer Verlag, Berlin Heidelberg, pp. xx-xx
Mortimore M (1998) Roots in the African Dust: Sustaining the Sub-Saharan Drylands. Cambridge Univ. Press, Cambridge, UK
Movik S, Dejene S, Synnevåg G (2003) Poverty and Environmental Degradation in the Drylands: An overview of the Problems and Processes. Noragric Working Paper No. 29, July 2003, Noragric, Agricultural University of Norway
Olsson L, Eklundh L, Ardo J (2005) A recent greening of the Sahel – trends, patterns and potential causes, J Arid Environ 63:556-566

Pagiola S (1999) The Global Environmental Benefits of Land Degradation Control on Agricultural Land. World Bank Environment Papers Series Number 16. The World Bank, Washington D.C.

Pretty JN (1995) Regenerating Agriculture. Policies and Practice for Sustainability and Self-Reliance. Earthscan Publications Ltd, London, UK

Reid RS, Gachimbi LN, Worden J, Wangui EE, Mathai S, Mugatha SM, Campbell DJ, Maitima JM, Butt B, Gichohi H, Ogol E (2004) Linkages between Changes in Land Use, Biodiversity and Land Degradation in the Loitokitok Area of Kenya, LUCID Working Paper Series Number: 49, International Livestock Research Institute (ILRI), Addis Ababa, Ethiopia

Scoones I (1996) Range Management Science and Policy. Politics, Polemics and Pasture in Southern Africa. In: Leach M, Mearns R (eds) The Lie of the Land. Challenging Received Wisdom on the African Environment (African Issues), The International African Institute, London, in association with James Currey Ltd, pp. 34-53

Stocking M (2002) Agrodiversity, environmental protection and sustaining rural livelihoods: the global view. In: Brookfield H, Padoch C, Parsons H, Stocking M (eds) Cultivating Biodiversity. Understanding, Analysing and Using Agricultural Diversity. ITDG Publishing, London, pp. 26-40.

Swift J (1996) Desertification. Narratives, Winners & Losers. In: Leach M, Mearns R (eds) The Lie of the Land. Challenging Received Wisdom on the African Environment (African Issues), The International African Institute, London, in association with James Currey Ltd, pp. 73-90.

Thomas DSG, Middleton NJ (1994) Desertification. Exploding the Myth. John Wiley & Sons, Chichester

Tiffen M, Mortimore M, Gichuki F (1994) More People, Less Erosion. Environmental Recovery in Kenya. John Wiley & Sons, Chichester

UNEP (2004) UNEP's Strategy on Land Use Management and Soil Conservation. A strengthened Functional Approach, UNEP Policy Series, No. 4.

UNEP (1997) World Atlas of Desertification. Editorial commentary by N. Middleton and D.S.G. Thomas. Edward Arnold, London.

CHAPTER 15

Using Weather and Climate Information for Landslide Prevention and Mitigation

Roy C. Sidle

Abstract. Landslides are significant natural hazards that degrade the productivity of soils, harm humans, and damage property. Extended and intense rainfall is the most common triggering mechanism of landslides worldwide. Sites are most susceptible to landsliding during wet antecedent conditions. Typically deep-seated, slow moving landslides (e.g., earthflows, slumps) are triggered or reactivated by an accumulation of precipitation over several days or weeks. In contrast, shallow, rapid landslides (debris avalanches, debris flows) usually initiate during individual intense or large storm events. Successfully predicting landslide hazards in large regions greatly depends on our ability to link meteorological conditions with various types and extents of slope failures. Four available methods for linking available weather and climate information to landslide initiation are discussed: (1) simple rainfall – landslide relationships; (2) multi-factor empirical assessment methods; (3) distributed, physically-based models; and (4) real-time warning systems. Each of these methods has certain strengths and weaknesses related to landslide hazard assessment. Of the land use practices that exacerbate landsliding, roads/trails and forest conversion to agriculture (typically associated with burning) exert the greatest impacts. Climate change scenarios that promote higher intensity storms, more rainfall, and vegetation with weaker root structure or less root biomass will likely increase landslide susceptibility; however, such impacts are currently speculative and will be difficult to unravel from anthropogenic effects.

15.1 Background

Landslides contribute to land and water degradation by stripping nutrient-rich soil mantles from hillslopes (Sidle et al. 1985; Page and Trustrum 1997; Knapen et al. 2006) and depositing excessive sediments in streams (Nakamura et al. 2000; Roghair et al. 2002). Although landslides are natural geomorphic processes that shape landscapes, the magnitude and particularly frequency of these mass movements can be greatly affected by land use activities (e.g., Sidle and Ochiai 2006). In developing regions of Africa, Asia, and Latin America, widespread changes in land cover are occurring associated with forest conversion to cultivated agriculture, exotic plantations and pastureland; shifting cultivation; urban and residential sprawl; and networks of poorly designed roads and paths. These land uses exacerbate the potential for landslide initiation by reducing rooting strength in soils, reducing evapotranspiration and increasing soil water content, and creating unstable cuts and fills on hillslopes (Sidle et al. 2006; Sidle and Ochiai 2006). Unfortunately, these effects of landslides on land degradation are often overlooked for two reasons: (1) awareness of landslides is often limited to cases where lives are lost and buildings are damaged and (2) landslides occur episodically, and the long-term significance of these processes are typically disregarded if such failures have not occurred in recent years (e.g., Sidle and Ochiai 2006). The disregard of landslide potential can be unintentional, as in the case of many rural areas in developing countries, or 'blindly intentional', as in the case of developers in urban areas (Smyth and Royle 2000; Kamai and Shuzui 2002; Sidle et al. 2005).

The most common triggering mechanism of landslides is extended and intense rainfall. Thus, landslides are very different from many types of land degradation processes because they are most likely to occur in periodically wet sites. Earthquakes also trigger spectacular landslides; these occur very unexpectedly and thus can inflict heavy casualties (Keefer 1984). However, earthquake-triggered landslides are much less widespread than rainfall-induced slope failures (Sidle and Ochiai 2006). Mountainous regions with heavy snowfall also experience landslides during the melt season, sometimes accompanied by rain-on-snow (Megahan 1983). Antecedent soil moisture greatly affects the stability of hillslopes during individual rainfall events, extended sequences of storms, and during earthquakes, depending on the type of potential landslide (Crozier and Eyles 1980; Crozier 1999; Sidle and Ochiai 2006). Typically deep-seated, slow moving landslides (e.g., earthflows, slumps) are triggered or reactivated by an accumulation of precipitation over several days or weeks (Iverson and Major 1987). In contrast, shallow, rapid landslides (debris slides, debris avalanches, and debris flows) usually initiate during individual intense or large storm events that may be preceded by wet conditions (Sidle and Swanston 1982; Fuchu et al. 1999). Successfully predicting landslide hazards in large regions greatly depends on our ability to link meteorological conditions with various landslide types and the magnitude and frequency of these failures. Four available methods for linking available weather and climate information to landslide initiation are described in this chapter: (1) simple rainfall – landslide relationships; (2) multi-factor empirical assessment methods; (3) distributed, physically-based models; and (4) real-time warning systems. Each of these methods has certain strengths and weaknesses related to landslide hazard assessment. Additionally, various scenarios of climate change and land degradation will be discussed related to these landslide prediction and forecasting methods. While the emphasis herein will be on land degradation, it is not practical to separate the more catastrophic issue of potential casualties from this discussion, especially for developing nations. Thus, to some extent, vulnerability related to landslides will be covered.

15.2 Overview of factors and processes related to climate-initiated landslides

The timing (relative to pre-existing climate conditions) and spatial patterns of rainfall and snowmelt are closely associated with landslide initiation (e.g., Starkel 1976; Keefer et al. 1987; Hardenbicker and Grunert 2001). Due to orographic effects, higher mountain elevations usually experience larger volumes of rain and snowfall. In dry regions, rainfall-initiated landslides may also occur due to intense precipitation associated with convective storm cells (e.g., Caine 1976; Rapp and Nyberg 1981). Climate attributes that directly affect landslide initiation include: (1) total storm rainfall; (2) short-term intensity; (3) antecedent storm precipitation and the distribution of this precipitation prior to the landslide-triggering event; (4) storm duration; (5) snow accumulation and water content; and (6) snowmelt rate (associated with radiation and wind). These attributes all influence the generation of pore water pressure in unstable hillslopes (Sidle and Swanston 1982; Fernandes et al. 1994). While many studies in mountainous regions have implied a correlation of long-term precipitation with shallow landslide occurrence (e.g., Eyles 1979; Glade 1998; Pasuto and Silvano 1998), other studies where more detailed precipitation data have been collected (e.g., Sidle and Swanston 1982; Keefer et al. 1987; Larsen and Simon 1993; Finlay et al. 1997; Fuchu et al. 1999) have concluded that short-term rainfall intensity is a more important triggering factor. Unfortunately in developing nations where the consequences of landslides are the most daunting, the availability of short-term (hourly) rainfall data is uncommon. Thus, while the more typically available daily rainfall data are useful indicators of susceptible landslide areas, short-term rainfall intensity data obtained from continuous rainfall records are much more applicable to prediction of landslides (e.g., Wu and Sidle, 1995; Baum et al. 2002) and real-time landslide/debris flow warning systems (e.g., Reid et al. 1999).

15.2.1 Shallow, rapid landslides

Shallow, rapid landslides on hillslopes consist of debris slides, debris avalanches, and debris flows in order of increasing water content and speed of movement. Debris flows also occur as in-channel phenomena and may be directly associated (in time) with landslides or may occur independently of landslides following a progressive in-filling of landslide sediment and other erosion/bioturbation materials (Trustrum and DeRose 1988; Benda and Dunne 1997; Sidle and Ochiai 2006). Oftentimes, a debris slide or avalanche on a hillside will proceed rapidly downslope to a channel, where, after incorporating more water, it becomes a debris flow (Sidle and Chigira 2004; Chen 2006). Such combination slide-flows often entrain additional materials as they move downslope and thus can be very deadly (Figure 15.1). These generally shallow landslides typically occur on steep slopes with low-cohesion soil mantles where either the underlying bedrock or some other low permeability substrate facilitates the buildup of a perched water table during storms or snowmelt events. The most susceptible slopes are concave in plan form (Massari and Atkinson 1999; Palacios et al. 2003), but these rainfall-initiated landslides may also occur on planar or even convex slopes.

During large rainfall or snowmelt events, shallow groundwater accumulates in the soil mantle above a low permeability layer (e.g., Sidle and Swanston 1982; Harp et al. 1990; Dai et al. 1999). In some cases, the influx of subsurface water can occur from fractures in the underlying bedrock (Montgomery et al. 1997; Sidle and Chigira 2004). A common meteorological sequence for triggering shallow landslides is

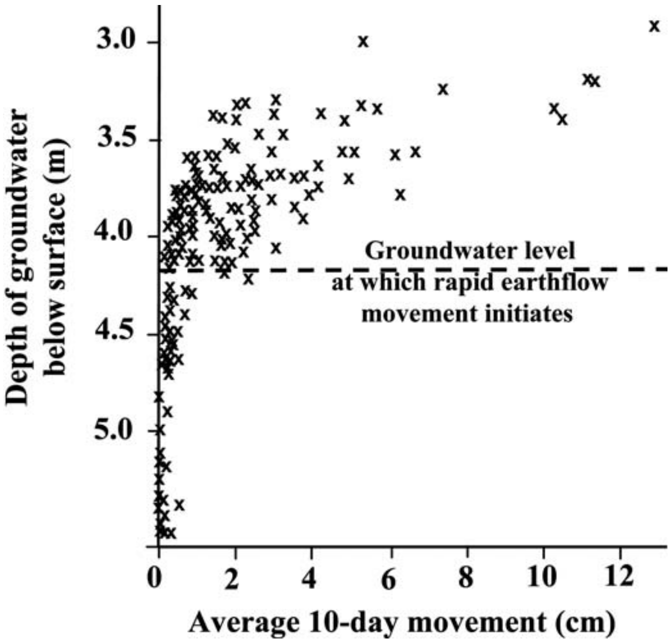
Fig. 15.1. Shallow debris avalanche that transformed into a debris flow and moved downslope, Okaya, Japan, July 2006

wet antecedent conditions followed by a prolonged period of rainfall with a burst of high intensity (e.g., Okuda et al. 1979; Sidle and Swanston 1982; Keefer et al. 1987). Because shallow, rapid landslides are triggered by individual rain (or snowmelt) events, the availability short-term rainfall records (and temperature records for snowpack ripening) are essential for prediction purposes. Antecedent rainfall data are also an important determinant of shallow rapid landslides, but they can not be used in exclusion of storm data. Deeper-seated, rapid landslides (oftentimes debris avalanches and flows) may require an extended period of rainfall and generally initiate in the latter period a moderate to large storm. Such failures include a significant proportion of weathered or fractured bedrock within the slide mass, but the materials are typically not clay-rich as in slow moving deep-seated landslides (Sidle and Ochiai 2006).

15.2.2
Slow, deep-seated slope failures

In contrast to shallow, rapid landslides which are triggered by individual storms or snowmelt events, slow, deep-seated landslides typically occur after a critical accumulation of subsurface water. These deeper slope failures occur on gentler slopes

Fig. 15.2. Groundwater dynamics related to earthflow movement; Chausuyama landslide, Nagano, Japan (data from Oyagi, 1977)



in highly weathered or altered clay-rich regoliths which undergo plastic deformation over a wide range of soil water conditions (Swanson and Swanston 1977; Sidle and Ochiai 2006). Typically an extended rainy or snowmelt period, several weeks or longer, is required to initiate slope movement (Wasson and Hall 1982; Coe et al. 2003). Thereafter, movement continues through the rainy or melt season and then subsides when water inputs are sporadic. Examples of such landslides are rotational slumps, earthflows, and slump-earthflow combinations. Soil creep, while not a landslide *per se*, is a plastic deformation of the hillslope soil mantle and behaves much in the same manner as earthflows (Sidle and Ochiai 2006). Although slow, deep-seated mass movements generally do not kill people, they can inflict heavy property damage and are responsible for the transport of large volumes of sediment to streams and rivers in certain regions (Dietrich and Dunne 1978; Sasaki et al. 2000).

Usually deep-seated slope failures respond non-linearly to accumulations of soil water. During dry seasons, little if any movement may occur during sporadic rainfall events. However, once the soil mantle is recharged to a critical threshold, mass movement responds to further rainfall or snowmelt inputs (Swanson and Swanston 1977; Bechini 1993), as shown in an example of earthflow movement and groundwater response for the huge Chausuyama landslide in Nagano Prefecture, Japan (Oyagi 1977) (Figure 15.2). This phenomena of a marked increase in earthflow movement following a threshold accumulation of soil water supports the observations of seasonal surging of earthflows recorded in many areas (e.g., Wasson and Hall 1982; Iverson and Major 1987; Coe et al. 2003). Due to the complex hydrology within the soil mantles of these deep-seated mass movements, responses to precipitation or snowmelt inputs vary greatly from site to site. Thus, it is difficult to generalize about threshold triggering climate conditions and it is often necessary to obtain groundwater data in specific movement sites to ascertain dynamic behavior. Localized features on these mass movements, such as sag ponds, terraces, and tension cracks, store or route water and exacerbate episodic movement (Swanson and Swanston 1977; Coe et al. 2003).

15.2.3 Surficial mass wasting

Dry ravel and dry creep are technically not landslides, however they involve the downslope movement by gravity of individual soil grains, aggregates, and coarse fragments and are therefore classified as mass wasting processes (Sidle and Ochiai 2006). Evidence of dry ravel can often be seen as talus cones or accumulations at the base of steep, sparsely vegetated hillslopes or behind obstructions (Figure 15.3). Ravel is strongly affected by freezing-thawing and wetting-drying cycles in soils (Sidle and Ochiai 2006). As such ravel responds to quite different climate characteristics compared to other mass wasting processes. Changes in diurnal tem-

Fig. 15.3. Extensive dry ravel occurring on steep hillsides during active freeze-thaw conditions; Kumanodaira, Japan

perature regimes within a range just above and below 0°C, as well as short-term changes in soil moisture content (affected by temperature, wind, and precipitation), greatly affect ravel rates. Although dry ravel generally transports far less sediment than other mass wasting processes, it can be significant in steep sites with sparse vegetative cover, especially where soils have been disturbed (e.g., road cuts and fills, burned sites, regarded soils) (Megahan 1978; Florsheim et al. 1991; Sidle et al. 1993).

15.3 Methods to link weather and climate data to landslide initiation

Several methods of assessing landslide hazard are available, including terrain stability mapping, rainfall-landslide relationships, multi-factor, empirical landslide hazard assessments, distributed, physically-based models, and real-time warning systems. Of these methods, terrain stability mapping typically does not use weather and climate except in a very broad way (e.g., Kienholz et al. 1984; Howes and Kenk 1988), thus it is not included in this discussion. Typically, increasing specificity in the spatial and temporal resolution of landslide predictability is accompanied by increasing demands for weather and climate data.

15.3.1 Simple rainfall-landslide relationships

Mean storm intensity – duration relationships for landslide triggering events have been developed for global data sets (Caine 1980) as well as for regional applications (Canuti et al. 1985; Larsen and Simon 1993; Wieczorek et al. 2000; Fiorillo and Wilson 2004). When such simple relationships are coupled with real-time rainfall data, such analyses can provide the basis for early warning systems for shallow landslides (Keefer et al. 1987; Iiritano et al. 1998). Using a global data set of 73 shallow landslides and rainfall data, Caine (1980) developed a log-log relationship between average rainfall intensity during storms and storm duration (Figure 15.4). The lower threshold of this relationship, which should indicate the lower limits for average storm intensity and duration that can trigger shallow landslides are given as:

$$I = 14.82\ \mathrm{D}^{-0.39}$$

where, I is the mean intensity of the rainstorm (mm h^{-1}) and D_s is the storm duration (h). Thus, in principle, if at any time during a storm when the average rainfall intensity exceeds the threshold value (I), shallow, rapid landslides may occur.

More regional application of this mean intensity – duration method of establishing threshold triggering conditions for shallow landslides has been accomplished in many areas. Larsen and Simon (1993) focused on a set of 256 tropical storms in Puerto Rico that triggered landslides over a 32-yr period (in contrast to Caine's earlier data which were mostly from temperate regions). For storms with durations <

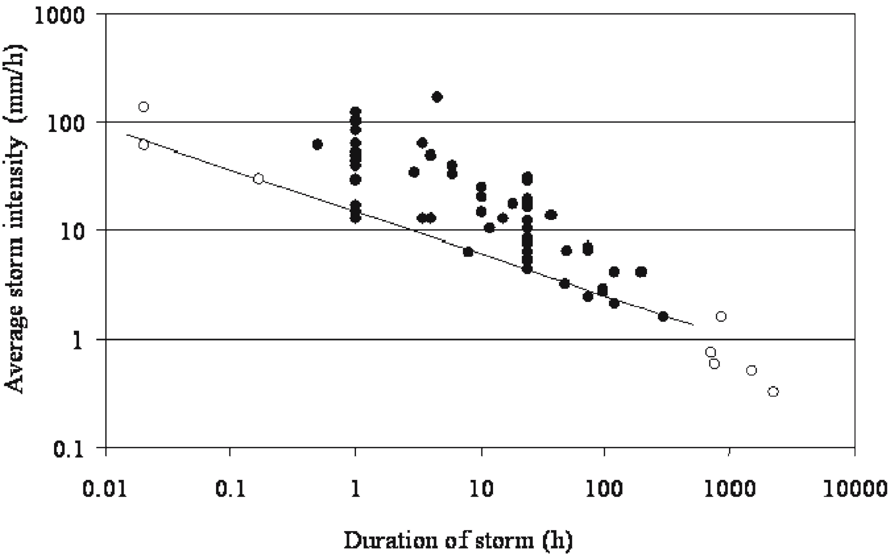


Fig. 15.4. Rainfall intensity – duration relationship based on the global data set of Caine (1980); open circles represent data in the original set that may not be reliable or based on in-channel debris flows

10 h, almost three times the rain intensity was needed to trigger landslides in Puerto Rico compared to temperate regions; after ≈ 4 days duration, the rainfall necessary to trigger landslides converged with Caine's global threshold. Two studies in Italy yielded contrasting results, suggesting the need for detailed regional specification. In Campania, intensity-duration thresholds all plotted well above Caine's global threshold, partly because selected data were excluded during smaller events in which only single debris flows occurred in these pyroclastic deposits (Fiorillo and Wilson 2004). In the Piedmont Region of northwest Italy, the intensity-duration threshold that captured 90% of the landslides from four events plotted just below Caine's threshold for long-duration storms (> 10 h); for shorter duration storms, the thresholds were similar (Aleotti 2004). In the Santa Cruz Mountains of California, Wieczorek (1987) found that the intensity-duration threshold, based on 7 yrs of climate data in which individual landslides were mapped, fell well below Caine's threshold. In Carnation Creek catchment in Vancouver Island, British Columbia, Dhakal and Sidle (2004a) modeled the occurrence of shallow landslides during the 86 most significant storms from 1972 to 1990 and compared their characteristics to Caine's global threshold; 65 storms produced only one landslide and 36 of these storms were below Caine's threshold; all 21 storms that produced 2 or more landslides fell above the threshold. Cannon and Ellen (1985) divided the San Francisco Bay region into areas of low (≤ 660 mm) and high (> 660 mm) mean annual precipitation. Based on antecedent moisture conditions and intensity – duration data, thresholds were delineated for abundant landslide initiation. Keefer et al. (1987) utilized these relationships together with geological indicators of instabil-

ity and real-time rainfall data to develop a warning system for landslides during major storms in the region. Because these thresholds were derived for abundant landslides, the precipitation threshold is above Caine's threshold; however, the dry precipitation threshold is similar.

In regions where rainfall intensity-duration-frequency relationships are well documented, they may be overlain on mean storm intensity – duration thresholds to identify return periods for various combinations of intensity and duration of precipitation that may trigger shallow landslides (Sidle et al. 1985). Such applications are complicated because these threshold relationships are based on landslides triggered by minimal rainfall inputs under almost saturated soil conditions. Thus, it may be necessary to add an index of antecedent soil moisture or at least wet and dry antecedent soil moisture conditions to better utilize such simple intensity-duration relationships for shallow landslide prediction (Sidle et al. 1985; Sidle and Ochiai 2006).

To apply even the simplest relationships between rainfall and landslide occurrence, it is obvious that daily rainfall values will generally not suffice. The minimum climate data required needs to be of a resolution that average storm intensity can be accurately calculated and that storm duration can be established. Generally this would require hourly rainfall data.

15.3.2
Multi-factor, empirical landslide hazard assessments

Numerous examples of landslide hazard assessment that use multi-factor overlays can be found in the literature. These assessments produce maps of potential landslide hazards or decision tools that can be used for land use planning in unstable regions. As such, they typically do not address dynamic environmental conditions that affect landsliding and thus often do not consider weather and climate data. Nevertheless, this methodology is included here because of the potential to improve this approach by including more detailed meteorological data. Early investigations that predated sophisticated Geographic Information Systems (GIS) utilized basically the same concepts as incorporated in the more advanced processing systems of today. For example, a conceptually advanced slope hazard assessment was developed for the San Francisco Bay region almost 30 years ago using detailed information derived from maps of slope gradient, previous landslide deposits, and surficial and bedrock geology (Nilsen et al. 1979). A key to the success of this stability mapping was the intensity of field data that had been compiled over many years in this urban region.

The factors incorporated in empirical landslide assessments are usually selected based on characteristics of existing landslides. In most empirical landslide analyses, it is assumed that landslides are more likely to occur under conditions similar to those of previous failures (Brabb 1984; Varnes 1984). Both univariate and multivariate statistical analyses are used to determine the relationships of various factors to the presence or absence of landslides (Soeters and van Westen 1996; Dhakal et al. 1999). Because there has been a proliferation of empirical landslide analyses in various regions, only a few representative examples are presented for Himalaya region, which is one of the most susceptible landslide areas in the world (Starkel 1972).

Because of the high loss of life, property destruction, and damage to natural resources associated with landslides in the Himalayas, numerous empirical landslide hazard assessments have been conducted in this region (e.g., Kienholz et al. 1984; Gupta and Joshi 1990; Anbalagan 1992; Pachauri and Pant 1992; Pachauri et al. 1998; Dhakal et al. 1999, 2000). The assessments of Dhakal et al. (1999, 2000) and Pachauri and Pant (1992) have been at the medium scale (1:25,000–1:50,000) for total areas ranging from about a hundred to several hundred km^2, while the study by Gupta and Joshi was conducted in a much larger area at a less detailed scale. The investigation by Kienholtz et al. (1984) in Kakani, Nepal, was conducted at a more detailed (1:10,000) scale in an area of 60 km^2. In this general region landslides are triggered by both earthquakes and rainfall; however, because of very limited spatially distributed data in this mountainous area, these causative factors are not directly included in these empirical analyses of landslide hazard potential.

Gupta and Joshi (1990) employed a very simple landslide hazard assessment in the Ramganga catchment of the Lower Himalayas by mapping recent and old landslides from aerial photographs and overlaying this information on geologic maps, remotely sensed maps of land use, and maps of major faults and thrust zones. Four criteria were selected for this univariate analysis of landslide hazards: (1) five general lithology groups; (2) five categories of land use; (3) eight distance ranges from major tectonic features; and (4) eight slope aspect classes. The distribution of landslides in various slope aspects is a surrogate for the influence of rock structure and physiography on landslide occurrence. Landslides tend to be more frequent in the direction of the dip of the bedrock. Since the hazard assessment only incorporated recent and older failures (i.e., not potential failures), slope gradient was not included in the analysis. This important parameter would obviously improve the GIS hazard zonation especially if inferences on future land use changes and predictive capabilities are desired. Percentages of landslide occurrence in all criteria classes were computed and compared to the average landslide incidence; subcategory values >33% higher than the overall average were weighted as high risk (2), values <33% lower than the average were weighted as low risk (0), and values in the range of ± 33% of the mean were weighted as moderate risk (1) (Gupta and Joshi 1990). All criteria were equally weighted in this preliminary analysis. Areas where vegetation was either sparse or totally removed were most susceptible to landslides. More detailed hazard analysis should consider the potential of weighting each of the criteria based on local knowledge and relationships of parameters to landslide initiation. The methodology is illustrated in Figure 15.5 along with suggestions for improvement, such as including general patterns of rainfall data.

An example of a rather sophisticated multivariate analysis of landslide potential in the Kulekhani catchment (124 km^2) of central Nepal is presented by Dhakal et al. (1999, 2000). They employed a detailed distributional map of landslides produced from aerial photo interpretation and later field reconnaissance together with data derived from a digital elevation model (DEM), geology, and land use/cover maps to analyze the factors and sub-factors influencing landsliding by discriminant (Quantification Scaling Type II; QS-II) analysis. Eight terrain factors were selected, partly based on availability of data: slope gradient, slope aspect, eleva-

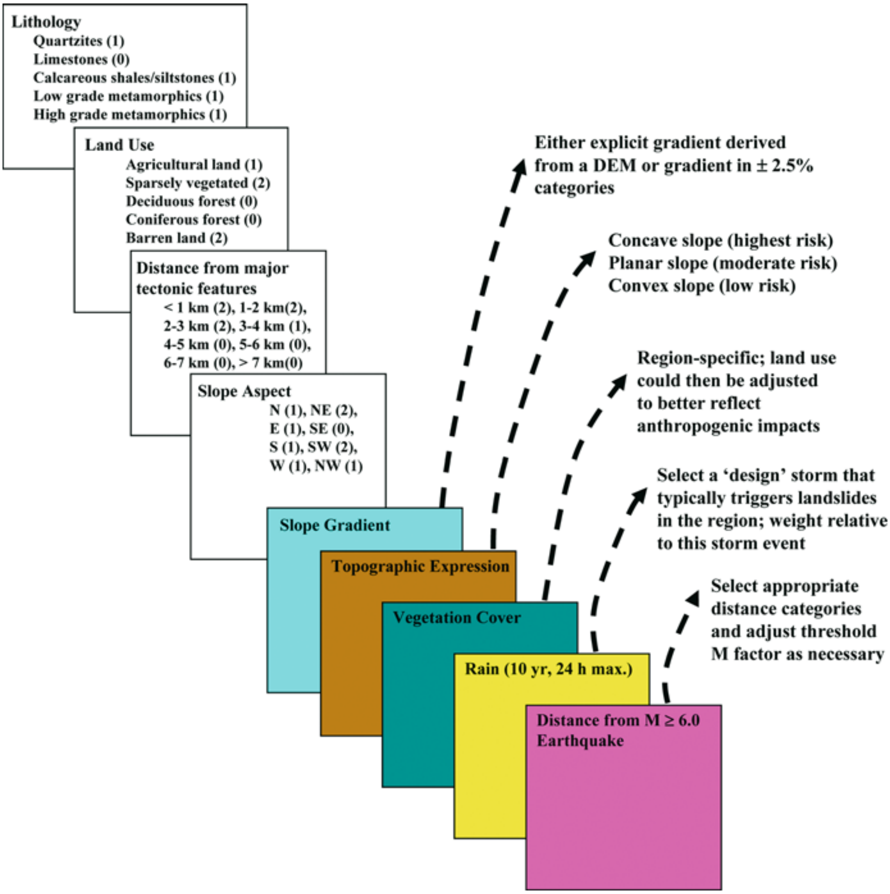


Fig. 15.5. A multi-factor empirical landslide assessment by Gupta and Joshi (1990) for the Ramganga catchment in India. Recommendations are included for improvement (colored panels)

tion, drainage basin order, distance from the ridge, distance from the valley, land use/cover, and geology; three to seven subclasses were designated for each factor with geology being the most detailed. For each grid-cell of the landslide and non-landslide groups, class codes of the eight terrain factors are assigned for the Q-S II analysis. The Q-S II method was deemed suitable for landslide hazard assessment because nominal variables (factors) such as geology or land use/cover are often most important to discriminate between landslide and non-landslide groups. The quantification of classes of the factors is accomplished such that the proportion of variance between the groups to the total variance is maximized (Dhakal et al. 2000). The scores derived from the Q-S II analysis can then be used to produce a map showing five different relative categories of landslide hazard. For the Kulekhani catchment, geology was the most important factor affecting landslide hazard with elevation, land use, slope gradient, and slope aspect contributing progressively lesser to the hazard assessment (Dhakal et al. 1999). As with the other empirical methods, this analysis does not directly consider landslide triggering factors (i.e., rainfall and earthquakes) although certain factors may serve as surrogates for these. This multivariate analysis has the advantage of assessing various combinations of factors (Dhakal et al. 2000).

The landslide hazard zonation for the Kathmandu-Kakani area of Nepal (Kienholz et al. 1984) is more detailed and based on extensive field investigations. This analysis includes information on regolith thickness, slope length and gradient, topographic expression, hydrogeology, and certain land use practices in addition to geologic and land use/vegetation indicators. Deep and shallow landslides were differentiated as were other erosion types. Land use played a significant role in this assessment, with terraces, converted forest areas, and roads all highly susceptible to landslides. Such land use assessments are difficult at scales of 1:50,000 or more general. Nonetheless, specific triggering factors (e.g., rainfall amount, rain intensity, seismicity) could not be included in this more detailed assessment due to lack of distributed data.

15.3.3
Distributed, physically-based models

Distributed, physically-based landslide models require extensive data inputs, but represent the most accurate methodology for incorporating climate dynamics into landslide hazard assessments. Design storm scenarios or long-term synthetic sequences of climate can be incorporated into these models to examine such important system functions as: (1) timing of landslide occurrence related to rainfall inputs; (2) effects of land cover change (both short and long-term); and (3) effects of various site parameters on slope stability. Distributed physically-based models are potentially the most powerful tools in landslide hazard analysis, particularly when they incorporate DEM data based on Lidar (Dietrich et al. 2001), actual rainfall inputs (Baum et al. 2002; Dhakal and Sidle 2004a), and long-term land use scenarios (e.g., Dhakal and Sidle 2003). However, widespread application of these models has been limited because they require distributed input data (including DEM's) and expertise with GIS and computer modeling. Additionally, all of the dynamic, physically-based landslide models developed to date can be applied only to shallow, rapid failures.

A distributed, physically based landslide model (dSLAM) that was developed to examine the spatial and temporal impacts of vegetation changes on shallow landslide probability was developed by Wu and Sidle (1995) and later extensively modified (IDSSM) by Dhakal and Sidle (2003, 2004a,b). The model incorporates an infinite slope analysis (based on factor of safety), continuous temporal changes in root cohesion and vegetation surcharge (Sidle 1991, 1992), and the stochastic influence of rainfall on pore water pressure. As such, the model simulates the actual process of landslide initiation rather than just the factors affecting landslides. Rainfall is input as actual storm sequences, events generated from historical data, or records synthesized using Monte Carlo techniques (Wu and Sidle, 1995; Sidle and

Wu, 1999; Dhakal and Sidle 2004a). The catchment is first divided in to a series of "TOPOTUBES" (perpendicular bisectors of slope contours), based on the stream-tube topographic model (Moore et al. 1988) to simplify shallow groundwater modeling (Dhakal and Sidle 2004b). Subsurface water is routed through TOPOTUBES via a kinematic wave equation. Dynamic pore water pressures calculated in each grid cell are used to calculate factor of safety for slope failure based on the infinite slope equation. The model has been tested with good results in both the Cedar Creek basin of coastal Oregon (Wu and Sidle 1995; Sidle and Wu 1999) and a sub-basin of Carnation Creek on Vancouver Island, British Columbia (Dhakal and Sidle 2004a,b). An example of the simulated temporal distribution of landslide volumes in the Carnation Creek sub-catchment is shown for a 200-yr period with a series of 50-yr clear-cuts and partial-cuts (90 overstory removal) (Dhakal and Sidle 2003) (Figure 15.6).

Spatially distributed data on soil properties is necessary to ensure accurate representation in distributed models. Particularly soil depth and cohesion are important (Wu and Sidle 1995); however, these parameters may be difficult to obtain for many sites of interest, especially in developing countries. Additionally, hourly rainfall data are required due to the demands of the dynamic, shallow groundwater model (Dhakal and Sidle 2004b). These dilemmas pose limitations on the application of distributed models, although certain algorithms that relate these properties to topographic attributes and more readily available data (e.g., soil texture) may prove useful. Nevertheless, a major advantage of such distributed models is their ability to simulate long-term scenarios of changing land use.

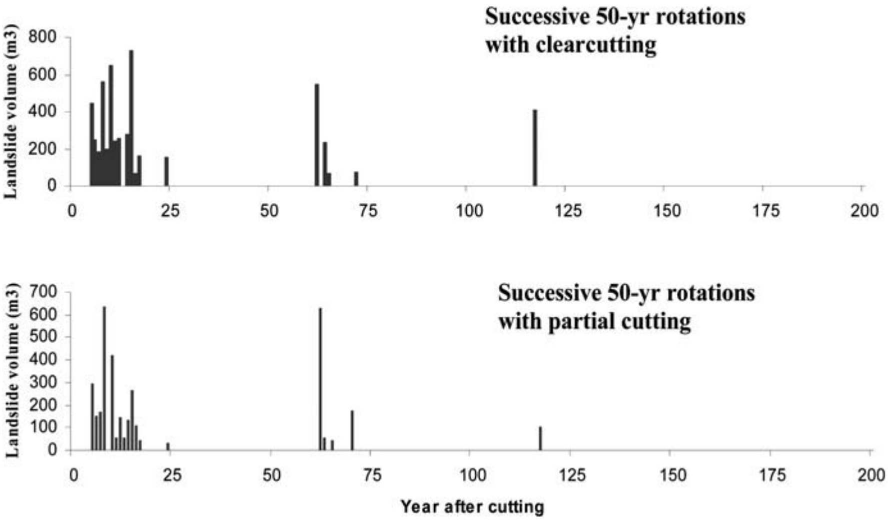


Fig. 15.6. Simulated landslide volumes for long-term scenarios of clearcutting and partial cutting (90% stand removal), each with a 50-yr rotation cycle, using the distributed landslide model ID-DSM (adapted from Dhakal and Sidle, 2003)

15.3.4 Real-time warning systems

Real-time warning systems for landslides typically rely on telemetered rainfall information that is subjected to a relatively simple set of algorithms to activate either an 'alert' or 'evacuation' of an area. Because of the expense associated with telemetered rainfall data and the subsequent rapid processing of these data, such methods are typically in the privy of developed nations and applied only in highly populated or traveled regions. A rather sophisticated landslide warning system has been installed along several unstable portions of U.S. Highway 50 in northern California (Reid et al. 1999). Real-time data on ground motion and pore water pressure are telemetered to computers, and graphs of these responses are directly supplied via the internet to local officials, geotechnical engineers, and emergency managers. Similar warning systems have been used along railway corridors in Seattle, Washington and along unstable roads in Hong Kong, California, and Oregon. In Japan, alarms are issued based on rainfall forecasts in susceptible mountainous areas; following alarms, if a designated threshold of total rainfall occurs, the road is closed (Yoshimatsu 1990). Warning systems for debris flows that would impact downslope residents have employed 'trip-wire' and video systems; however, such systems necessitate rapid evacuation plans due to the high velocities of debris flows.

The ability to link real-time climate data to physically-based landslide models should be highly beneficial for the assessment of landslide hazards in high risk areas. The application of real-time rainfall data along with antecedent moisture and geological indicators of instability to the development of a landslide warning system for the San Francisco Bay region is an excellent example (Keefer et al. 1987). While such an advanced warning system depends on spatially distributed, accurate, and timely disseminated rainfall data, it is possible that similar applications could be successful in densely populated regions of developing countries where local governments and international donors support regional telemetered networks of rain gages. Further advances in such warning systems may be possible in the future with advanced forecasting using improved Doppler radar systems, although problems exist related to orographic effects in mountainous terrain (Gysi 1998). As more of these radar networks come on line worldwide, the potential to use such data in landslide forecasts will increase.

Certain limitations exist related to landslide warning systems based strictly on rainfall characteristics. Such systems cannot discriminate landslide potential amongst different geologic materials or different land uses. The utility of telemetered rainfall data to predict landslides depends strongly on the density of rainfall gauges, particularly in dissected mountainous terrain or in areas that receive convective storms. In spite of these limitations, landslide warning systems based on a combination of rainfall forecasts, real-time rainfall data, antecedent precipitation, and ground motion could save lives and reduce damages if properly implemented in populated areas of developing nations. However, most mountainous terrain in both the developed and developing world is far too remote for accurate, real-time warning systems to be employed in the next few decades.

15.4 Effects of land degradation and climate change in landslide

Most landslides contribute to land and water degradation, and land use activities associated with various types of land degradation (e.g., forest clearing, roads and paths, fire, grazing) can exacerbate the occurrence of landslides. Climate change may exert variable effects on different types of landslides depending on the changes in seasonal and short-term precipitation. The greatest impacts of climate change on landslide occurrence are likely via modification of evapotranspiration and root strength of vegetation. Oftentimes the interactions between climate change impacts and anthropogenic effects are difficult to unravel.

15.4.1 Land degradation

Of the land management practices that increase the susceptibility of hillslopes to landslides, roads and forest conversion (including the effects of fire) usually exert the greatest effects (Sidle et al. 2006). While much emphasis has been placed on forest logging practices, particularly in the tropics, the practice of forest harvesting with subsequent secondary forest regeneration needs to be clearly distinguished from forest conversion to agriculture, pasture or exotic plantations. Forest harvesting with subsequent regeneration increases landslide potential in a 3 to 15 yr 'window' after logging, while the increases related to forest conversion are essentially permanent (Sidle and Ochiai, 2006).

Roads and trails cut into steep hillsides decrease the stability of the natural terrain by: (1) adding weight to the slope in the embankment fill; (2) steepening the slope in both the cut and fill surfaces; (3) removing support in the cutslope; and (4) rerouting and concentrating road drainage water (Sidle et al. 1985, 2006). The relative importance of these destabilizing factors depends on the design and construction standards (if any) of the road and associated drainage system. Additionally, road location is very important; midslope roads in steep terrain have the greatest destabilizing effect, while valley bottom and ridgeline roads have progressively lower influences on slope stability (Sidle and Ochiai 2006). Numerous studies worldwide have found that forest roads increase landslide erosion by approximately two orders of magnitude as compared to undisturbed forest land, with average landslide erosion rates from road right-of-ways in unstable terrain of about 50 t $ha^{-1}yr^{-1}$. However, such increases are highly variable; in North America these increases range from 25 to 350-fold in unstable terrain (Sidle et al. 1985; Sidle and Ochiai 2006). In developing countries mountain roads, even those used for vehicular traffic, may produce much higher rates of landslide sediment. A recent investigation along a new mountain road in Yunnan, China, found that landslide erosion was approximately 9,600 t ha^{-1} yr^{-1} during the first four years after construction. Most of this sediment was directly transported into the headwaters of the Mekong River.

Progressive forest clearing/conversion and associated land degradation in developing countries of Africa, Asia, and Latin America have been associated with general increases in landslides (Haldemann 1956; Harwood 1996; Fischer and Vasseur

2000) although specific rates of increase have not been reported. The major effect of conversion of forest land to agriculture on landslide erosion can be attributed to a permanent loss in rooting strength compared to previous forest or brush vegetation (Sidle et al. 1985; Sidle and Dhakal 2002). Shallow rooted crops and grasses have negligible rooting strength compared to deeper-rooted trees and shrubs (Rice et al. 1969; Marden and Rowan 1993; Bergin et al. 1995). Such long-term reductions in rooting strength following forest conversion are associated with increases in landslide probability (Sidle et al. 2006). Studies of forest conversion and related land degradation have generally not persisted long enough to capture landslide erosion. Terraces constructed on steep converted hillsides exacerbate landsliding, especially those that impound water (Johnson et al. 1982; Kienholz et al. 1984; Billard et al. 1993; Sidle and Ochiai 2006), even though many practitioners view such practices as generally beneficial for erosion control. Conversion of forest or brushland to pastureland has accelerated landslide erosion in many regions of the world. Widespread conversion of mixed evergreen forests of North Island, New Zealand, during the development of pastoral hill country between 1860 and 1920 caused severe landslide erosion and reduced productivity of the land (Ministry of Works and Development, 1970; Garrett, 1980; Trustrum et al., 1983). In addition to increased landsliding in pastureland due to weak root systems of grasses, trampling and destruction of vegetation along streambanks by cattle contribute to bank failures (Sidle et al. 2006). Agroforesty may reduce the incidence of landslides on steep slopes compared to forest sites converted to agriculture or grass because of the greater rooting strength of planted trees, albeit less than rooting strength of mature forests.

Fire is often used in conjunction with forest clearing and its role in promoting landslides and debris flows is quite complicated and poorly understood. Debris accumulation in headwater channels can be greatly enhanced by burning and resultant surface erosion and dry ravel (Florsheim et al., 1991; Wohl and Pearthree, 1991; Meyer et al., 1992). Such accelerated loading of these channels immediately after fire can increase the probability of a debris flow. Additionally, fires consume large woody debris in channels and thus may destabilize stored sediment and decrease channel roughness (Cannon and Reneau, 2000). If a moderately large rainstorm occurs after burning, a debris flow may result in these overloaded channels (e.g., Wells 1987; Cannon and Reneau 2000). In contrast, the susceptibility of hillslope landslides increases after burning because of the gradual decay in rooting strength. Superficially, it may appear that the immediate effects of fire may decrease the susceptibility of landslides due to increased surface runoff and reduced water inputs into the soil (Sidle et al., 1985). Rice (1977) concluded that although burning may initially reduce landsliding, as rooting systems decay and new vegetation restores the infiltration capacity of soils, the burned sites become more vulnerable to slope failure. Rice et al. (1982) estimated that landslide erosion would increase 3-fold when a 15-year prescribed burning interval was used in brushland. With such a burning interval, the age distribution of brush is clustered in the period of minimum rooting strength and the site is this sensitive to large landslide-producing rainstorms. Typically the effects of burning on dry ravel production are short-lived; as sites revegetate, ravel decreases markedly (Sidle and Dhakal, 2002).

15.4.2
Climate change

Although certain types of landslides may be influenced by increases in mean air temperature and changes in regional annual and seasonal precipitation, the initiation and persistence of slope failures are more related to the timing and short-term rates of rainfall and snowmelt. Long-term changes in average temperature and precipitation as well as shifts in the frequency of extreme events are anticipated. Such climate changes will affect landslide scenarios throughout the world (Evans and Clauge 1994; Wyss and Yim 1996). The effect of climate change on other environmental factors, such as vegetation and soil, may introduce more complex interactions related to landslide occurrence (Sidle and Dhakal 2002).

Landslides triggered by snowmelt in the Northern Hemisphere will likely decline south of latitude 60°N because of decreases in snowfall (Rowntree 1993). However, those landslides that do occur will probably occur earlier in the year because thinner snowpacks will ripen more quickly and release meltwater earlier in the spring (Sidle and Dhakal 2002). The effects of possible changes in rain-on-snow on landslide initiation cannot be estimated in current climate-change forecasts. Shallow, rapid landslides will only increase in scenarios of increasing rain event intensity, whereas, deep-seated mass movements will increase with seasonal increases in precipitation. Thus, the former will require spatially explicit information on changes in rainfall intensity during individual storms, which is not yet reliable in climate change forecasts. Data on seasonal precipitation changes that affect deep-seated mass movements (slumps, earthflows, soil creep) are more reliable from climate change predictions, but the spatial resolution of such data leaves much to be desired. With predicted increases in winter rainfall in northern latitudes, rates of deep-seated landslide movement may increase in some areas; however, the actual period of this movement may decrease due to shorter winters. Dry ravel may respond more directly to long-term climate warming, increasing as vegetation cover becomes sparse and with increasing frequency of fire. The predicted longer, drier summers (Loaiciga et al. 1996) would exacerbate fire hazard and increase rates of ravel on burned sites.

An important long-term consequence of climate change is the redistribution of vegetation and even entire ecosystems as the result of sustained warming and altered patterns of rainfall and snow accumulation. Because vegetation rooting strength depends on species and below ground root biomass (Sidle, 1991; Sakals and Sidle, 2004), vegetation cover changes will affect landslide susceptibility. As growing seasons increase in warmer climates, the resultant increases in evapotranspiration may reduce landslide potential. The effects of climate change in the tropics on landslide initiation are believed to be less than in temperate regions because of the smaller projected changes in temperature and precipitation; however, any long-term changes in vegetation cover could especially influence deep-seated landslide rates.

15.5 Summary related to weather and climate information needs

Weather and climate information are important for predicting the spatial and temporal distribution of landslides as well as developing realistic long-term scenarios for assessing impacts of anthropogenic practices on landslide magnitude and frequency. In predicting landslide occurrence, a clear distinction must be made between the methods and climate information needed for the more commonly studied surface erosion compared to landslides. For real-time predictions of shallow, rapid landslides it is imperative to have hourly rainfall data. Such intensity data are generally required in physically-based shallow landslide models and even simple rainfall-landslide relationships. Linking real-time climate data with physically-based landslide models may be one of the greatest challenges for developing improved landslide warning systems in the next decade. Given that most gauges in developing nations only collect daily rainfall, a high priority needs to be placed on more intense networks of recording rain gauges, not only near populations, but also at elevations where landslides typically originate that may impact people and property located downslope. Also, multi-factor empirical landslide analyses can be improved by including probability estimates for design storms (average intensities or maximum short term intensities) that are known to trigger different types of landslides. Such analyses need to focus on the different climate dynamics associated with shallow and deep landslide initiation. Currently, most analyses do not differentiate amongst various landslide types, and thus, different climatic triggering responses or thresholds. Additionally, there are currently no sufficient distributed physically-based models that address deep-seated landslides.

Existing daily precipitation records are useful to estimate the reactivation of existing deep-seated landslides based on historical knowledge of their behavior; however, such records need to be augmented by additional gauges located at appropriate elevations (i.e., not just on farms or in villages) to better reflect landslide initiation/reactivation mechanisms. Temperature records are less useful in landslide prediction although they can be used to assess the susceptibility of dry ravel. Long-term trends or future projections of temperature can suggest general patterns of vegetation redistribution and weathering rates, both of which affect landslides. The incorporation of climatic change scenarios into landslide hazard assessments and models appears to be a complex task given the inaccuracies in future temporal and spatial predictions (e.g., Buma and Dehn 1998).

Because the impacts of landslides in developing regions have been largely ignored except for cases where people or expensive property are directly affected, more emphasis needs to be placed on the distribution and extent of these mass movements in rural regions where they will degrade land productivity and water supplies. While many international donors have sponsored relatively short-term, plot-scale surface erosion studies in developing nations and subsequently developed expensive erosion control strategies and land use recommendations based on these findings, landslide processes and interactions with anthropogenic practices in these same regions have been largely ignored. Even in longer-term catchment studies, the occurrence of landslides and their influence on sediment budgets has only been documented in a few cases (Douglas et al., 1999; Chappell et al., 2004).

To fill this void, landslides must be quantified using *long-term* sediment budgets to adequately quantify erosion rates and sedimentation processes. Such information is crucial in formulating sustainable land management practices and developing appropriate prediction methods for such areas.

References

Aleotti P (2004) A warning system for rainfall-induced shallow landslides. Eng. Geol. 73: 247-265

Anbalagan R (1992) Landslide hazard evaluation and zonation mapping in mountainous terrain. Eng. Geol. 32: 269-277

Baum RL, Savage WZ, Godt JW (2002) TRIGRS – A Fortran program for transient rainfall infiltration and grid-based regional slope-stability analysis. Open-file report 02-424, 35 p. (2 appendices), U.S. Geol. Surv.

Bechini C (1993) Natural conditions controlling earthflows occurrence in the Eden Canyon area (San Francisco Bay region, California). Z. Geomorph. N.F., Suppl.-Bd 87: 91-105

Benda L, Dunne T (1997) Stochastic forcing of sediment supply to the channel network form landsliding and debris flow. Water Resour. Res. 33: 2849-2863

Bergin DO, Kimberley MO, Marden M (1995) Protective value of regenerating tea tree stands on erosion-prone hill country, East Coast, North Island, New Zealand. N.Z. J. For. Sci. 25(1): 3-19

Billard A, Muxart T, Derbyshire E, Wang JT, Dijkstra TA (1993) Landsliding and land use in the loess of Gansu Province, China. Z. Geomorph. N.F. Suppl. Bd. 87: 117-131

Brabb EE (1984) Innovative approach to landslide hazard and risk mapping. Proc. 4th Intern. Symp. on Landslides, Vol. 1, pp. 307-324, Toronto, Ontario, Canada

Buma J, Dehn M (1998) A method for predicting the impact of climate change on slope stability. Environ. Geol. 35: 190-196

Caine N (1976) Summer rainstorms in an alpine environment and their influence on soil erosion, San Juan Mountains, Colorado. Arct. Alp. Res. 8(2): 183-196

Caine N (1980) Rainfall intensity-duration control of shallow landslides and debris flows. Geograf. Ann. 62A: 23-27

Cannon SH, Ellen SD (1985) Rainfall conditions for abundant debris avalanches, San Francisco Bay Region, California. Calif. Geol. 38: 267-272

Cannon SH, Reneau SL (2000) Conditions for generation of fire-related debris flows, Capulin Canyon, New Mexico. Earth Surf. Process. Landforms 25: 1103-1121

Canuti P, Focardi P, Garzonio CA (1985) Correlation between rainfall and landslides, Bull. Int. Assoc. Eng. Geol. 32: 49-54

Chappell NA, Douglas I, Hanapi JM, Tych W (2004) Sources of suspended sediment within a tropical catchment recovering from selective logging. Hydrol. Process. 18: 685-710

Chen H (2006) Controlling factors of hazardous debris flow in Taiwan. Quaternary Int. 147: 3-15

Coe JA, Ellis WL, Godt JW, Savage WZ, Savage JE, Micheal JA, Kibler JD, Powers PS, Lidke DJ, Debrey S (2003) Seasonal movement of the Slumgullion landslide determined from Global Positioning System surveys and fields instrumentation, July 1998-March 2002. Eng. Geol. 68(1-2): 67-101

Crozier MJ (1999) Prediction of a rainfall-triggered landslide: a test of the antecedent water status model. Earth Surf. Process. Landforms 24: 825-833

Crozier MJ, Eyles RJ (1980) Assessing the probability of rapid mass movement, N. Z. Inst. Eng. Proc. Tech. Group 6, 1(G): 2.47-2.51

Dai FC, Lee CF, Wang SJ, Feng YY (1999) Stress-strain behaviour of a loosely compacted volcanic-derived soil and its significance to rainfall-induced fill slope failure. Eng. Geol. 53(3-4): 359-370

Dhakal AS, Sidle RC (2003) Long-term modeling of landslides for different forest management practices. Earth Surf. Process. Landforms 28: 853-868

Dhakal AS, Sidle RC (2004a) Distributed simulations of landslides for different rainfall conditions. Hydrol. Process. 18: 757-776

Dhakal AS, Sidle RC (2004b) Pore water pressure assessment in a forest watershed: simulations and distributed field measurements related to forest practices. Water Resour. Res., 40: W02405, doi:1029/ 2003WR002017

Dhakal AS, Amada T, Aniya M (1999) Landslide hazard mapping and the application of GIS in the Kulekhani watershed Nepal. Mountain Res. Develop. 19: 3-16

Dhakal AS, Amada T, Aniya M (2000) Landslide hazard mapping and its evaluation using GIS: an investigation of sampling scheme for grid-cell based quantitative method. Photogram. Eng. Rem. Sens. 66: 981-989

Dietrich WE, Bullugi D, Real de Asua R (2001) Validation of the shallow landslide model, SHALSTAB, for forest management, In: Wigmosta MS, Burgess SJ (eds.) Land Use and Watersheds, Human Influences on Hydrology and Geomorphology in Urban and Forest Areas, Water Science and Application 2, Am. Geophys. Union, Washington, D.C, pp. 195-227

Dietrich WE, Dunne T (1978) Sediment budget for a small catchment in mountainous terrain. Z. Geomorph. N. F., Suppl. Bd. 29: 191-206.

Douglas I, Bidin K, Balamurugan G, Chappell NA, Walsh RPD, Greer T, Sinun W (1999) The role of extreme events in the impacts of selective tropical forestry on erosion during harvesting and recovery phases at Danum Valley, Sabah. Phil. Trans. Royal Soc. London 354: 1749-1761

Evans SG, Clague JJ (1994) Recent climate change and catastrophic geomorphic processes in mountain environments. Geomorphology 10: 107-128

Eyles RJ (1979) Slip-triggering rainfalls in Wellington City, New Zealand, N.Z. J. Sci. 22: 117-121

Fernandes NF, Netto ALC, Lacerda WA (1994) Subsurface hydrology of layered colluvium mantles in unchanneled valleys – south-eastern Brazil. Earth Surf. Proc. Landforms 19(7): 609-626

Finlay PJ, Fell R, Meguire PK (1997) The relationship between the probability of landslide occurrence and rainfall. Can. Geotech. J. 34: 811-824

Fiorillo F, Wilson RC (2004) Rainfall induced debris flows in pyroclastic deposits, Campania (southern Italy). Eng. Geol. 75: 263-289

Fischer A, Vasseur L (2000) The crisis in shifting cultivation practices and the promise of agroforestry: a review of the Panamanian experience. Biodiversity and Conservation 9: 739-756

Florsheim JL, Keller EA, Best DW (1991) Fluvial sediment transport in response to moderate storm flows following chaparral wildfire, Ventura County, southern California. Geol. Soc. Am. Bull. 103: 504-511

Fuchu D, Lee CF, Sijing W (1999) Analyis of rainstorm-induced slide-debris flows on the natural terrain of Lanatu Island, Hong Kong. Eng. Geol. 51: 279-290

Garrett J (1980) Catchment authority work in the Rangitikei area. Aokautere Sci. Ctr. Int. Rep. 21: 23-26, N. Z. Ministry of Works and Develop.

Glade T (1998) Establishing the frequency and magnitude of landslide-triggering rainstorm events in New Zealand. Environ. Geol. 35(2-3): 160-174.

Gupta RP, Joshi BC (1990) Landslide hazard zoning using the GIS approach – a case study from the Ramganga Catchment, Himalayas. Eng. Geol. 28: 119-131

Gysi H (1998) Orographic influence of the distribution of accumulated rainfall with different wind directions. Atmosph. Res. 47-48 (1): 615-633

Haldemann EG (1956) Recent landslide phenomena in the Rungwe volcanic area, Tanganyika. Tanganyika Notes Record 45: 3-14
Hardenbicker U, Grunert J (2001) Temporal occurrence of mass movements in the Bonn area, Z. Geomorh. N. F. 125: 13-24
Harp EL, Wells II WG, Sarmiento JG (1990) Pore pressure response during failure in soils. Geol. Soc. Am. Bull., 102(4): 428–438
Harwood RR (1996) Development pathways toward sustainable systems following slash-and-burn. Agric., Ecosystems & Environment 58: 75-86
Howes DE, Kenk E (1988) Terrain classification system for British Columbia (revised edition), Ministry of Environment Manual 10, Ministry of Crown Lands, Victoria, BC, Canada
Iiritano G, Versace P, Sirangelo B (1998) Real-time estimation of hazard for landslides triggered by rainfall, Environ. Geol. 35(2-3): 175-183
Iverson RM, Major JJ (1987) Rainfall, ground-water flow, and seasonal movement at Minor Creek landslide, northwestern California: physical interpretation of empirical relations, Geol. Soc. Am. Bull. 99: 579-594
Johnson K, Olson EA, Manandhar S (1982) Environmental knowledge and response to natural hazards in mountainous Nepal. Mountain Res. Develop. 2: 175-188
Kamai T, Shuzui H (2002) Landslides in Urban Region, 200 p., Rikou-tosho, Tokyo (in Japanese)
Keefer DK (1984) Landslides caused by earthquakes. Geol. Soc. Am. Bull. 95: 406-421
Keefer DK, Wilson RC, Mark RK, Brabb EE, Brown WM, Ellen SD, Harp EL, Wieczorek GF, Alger CS, Zatkin RS (1987) Real-time landslide warning during heavy rainfall. Science 238: 921-925
Kienholz H, Schneider G, Bichsel M, Grunder M, Mool P (1984) Mapping of mountain hazards and slope stability. Mountain Res. Develop. 4(3): 247-266
Knapen A, Kitutu MG, Poessen J, Breugelmans W, Deckers J, Muwanga A (2006) Landslides in a densely populated country at the footslopes of Mount Elgon (Uganda): Characteristics and causal factors. Geomorphology 73: 149-165
Larsen MC, Simon A (1993) A rainfall intensity-duration threshold for landslides in a humid-tropical environment, Puerto Rico. Geograf. Ann. 75A: 13-23
Loaiciga HA, Valdes JB, Vogel R, Garvey J, Schwarz H (1996) Global warming and the hydrologic cycle. J. Hydrol. 174: 83-127
Marden M, Rowan D (1993) Protective value of vegetation on Tertiary terrain before and during Cyclone Bola, East Coast, North Island, New Zealand. N.Z. J. For. Sci. 23(3): 255-263
Massari R, Atkinson PM (1999) Modelling susceptibility to landsliding: an approach bases on individual landslide type. Trans. Jpn. Geomorphol. Union 20(3): 151-168
Megahan WF (1978) Erosion Processes on steep granitic road fills in central Idaho. Soil Sci. Soc. Am. J., 42(2): 350-357
Megahan WF (1983) Hydrologic effects of clearcutting and wildfire on steep granitic slopes in Idaho. Water Resour. Res. 19(3): 811-819
Meyer GA, Wells SG, Balling RC, Jull AJT (1992) Response of alluvial systems to fire and climate change in Yellowstone National Park. Nature 357: 147-149
Ministry of Works and Development (1970) Wise land use and community development. Report Tech. Comm. of Inquiry into the Problems of the Poverty Bay-East Cape Dist. of New Zealand, 119 p., Wellington, N.Z.
Montgomery DR, Dietrich WE, Torres R, Anderson SP, Heffner JT, Loague K (1997) Hydrologic response of a steep, unchanneled valley to natural and applied rainfall. Water Resour. Res. 33: 91-109
Moore ID, O'Loughlin EM, Burch GJ (1988) A contour based topographic model and its hydrologic and ecological applications. Earth Surf. Process. Landforms 13: 305-320
Nakamura, F, Swanson FJ, Wondzell SM (2000) Disturbance regimes of stream and riparian systems – a disturbance-cascade perspective, Hydrol. Process., 14(16-17): 2849-2860

Nilsen TH, Wright RH, Vlasic TC, Spangle WE (1979) Relative slope stability and land-use planning in the San Francisco Bay region, California. Prof. Pap. 944, 96 p., U.S. Geol. Surv

Okuda S, Ahida K, Gocho Y, Okunishi K, Sawada T, Yokoyama K (1979) Characteristics of heavy rainfall and debris hazard. J. Nat. Disaster Sci., 1(2): 41-55

Oyagi N (ed) (1977) Guide-book for excursions of landslides in central Japan. Jpn. Soc. of Landslide, Tokyo, Japan, 29 p.

Pachauri AK, Pant M (1992) Landslide hazard mapping based on geological attributes, Eng. Geol. 32: 81-100

Pachauri AK, Gupta PV, Chander R (1998) Landslide zoning in a part of the Garhwal Himalayas. Environ. Geol. 36(3-4): 325-334

Page MJ, Trustrum NA (1997) A late Holocene lake sediment record of the erosion response to land use change in a steepland catchment, New Zealand. Z. Geomorph. N.F. 41(3): 369-392

Palacios D, Zamorano J, Gómez A (2003) The impact of present lahars on the geomorphologic evolution of proglacial gorges: Popocatepetl, Mexico. Geomorphology 37: 15-42

Pasuto A, Silvano S (1998) Rainfall as a trigger of shallow mass movements. A case study in the Dolomites, Italy. Environ. Geol. 35(2-3): 184-189

Rapp A, Nyberg R (1981) Alpine debris flows in northern Scandinavia: morphology and dating by lichenometry. Geograf. Ann. 63: 183-196

Reid ME, LaHusen RG, Ellis WL (1999) Real-time monitoring of active landslides. Fact Sheet 091-99, 4 p., U.S. Geol. Surv.

Rice RM (1977) Forest management to minimize landslide risk. In: Kunkle SH, Thames JL (eds) Guidelines for Watershed Management, pp. 271-287, Food and Agric. Organ. of the UN, Rome, Italy

Rice RM, Corbett ES, Bailey RG (1969) Soil slips related to vegetation, topography, and soil in southern California. Water Resour. Res. 5: 647-659

Rice RM, Ziemer RR, Hankin SC (1982) Slope stability effects of fuel management strategies: Inferences from Monte Carlo simulations. Gen. Tech. Rep. PSW-58, pp. 365-371, For Serv., U.S. Dep. of Agric., Berkeley, CA

Roghair CN, Dolloff CA, Underwood MK (2002) Response of a brook trout population and instream habitat to a catastrophic flood and debris flow. Trans. Am. Fish. Soc. 131: 718-730

Rowntree PR (1993) Climatic models – changes in physical environmental conditions. In: Atkinson D (ed), Global climate change its implications for crop protection. BCPC Monograph No. 56, British Crop Protection Council, Surrey, UK, pp. 13-32

Sakals M, Sidle RC (2004) A spatial and temporal model of root strength in forest soils. Canadian J. For. Res. 34: 950-958

Sasaki Y, Fujii A, Asai K (2000) Soil creep process and its role in debris slide generation – field measurements on the north side of Tsukuba Mountain in Japan. Eng. Geol. 56: 163-183

Sidle RC (1991) A conceptual model of changes in root cohesion in response to vegetation management. J. Environ. Quality 20(1): 43-52

Sidle RC (1992) A theoretical model of the effects of timber harvesting on slope stability. Water Resour. Res. 28(7): 1897-1910

Sidle RC, Chigira M (2004) The July 20, 2003, landslides and debris flows in southern Kyushu, Japan. Eos, Trans. Am. Geophys. Union 85(15): 145-151

Sidle RC, Dhakal AS (2002) Potential effects of environmental change on landslide hazards in forest environments. In: Sidle, RC (ed) Environmental Change and Geomorphic Hazards in Forests, IUFRO Research Series, No. 9, pp. 123-165, CAB International Press, Oxen, UK

Sidle RC, Ochiai H (2006) Landslides: Processes, Prediction, and Land Use. Water Resources Monograph 18, Am. Geophys. Union, Washington, DC, 312 p.

Sidle RC, Swanston DN (1982) Analysis of a small debris slide in coastal Alaska. Can. Geotech. J. 19: 167-174

Sidle RC, Wu W (1999) Simulating effects of timber harvesting on the temporal and spatial distribution of shallow landslides. Z. Geomorphol. N.F. 43: 185-201

Sidle RC, Brown RW, Williams BD (1993) Erosion processes on arid minespoil slopes. Soil Sci. Soc. Am. J. 57: 1341-1347

Sidle RC, Kamai T, Trandafir AC (2005) Landslide damage during the Chuetsu earthquake, Niigata, Japan. Eos, Trans. Am. Geophys. Union 86(13): 133-140

Sidle RC, Pearce AJ, O'Loughlin CL (1985) Hillslope Stability and Land Use, Water Resources Monograph, Vol. 11, American Geophysical Union, Washington, DC, 140 p.

Sidle RC, Ziegler AD, Negishi JN, Abdul Rahim N, Siew R, Turkelboom F (2006) Erosion processes in steep terrain – truths, myths, and uncertainties related to forest management in Southeast Asia. For. Ecol. Manage. 224(1-2): 199-225

Smyth CG, Royle SA (2000) Urban landslide hazards: incidence and causative factors in Niterói, Rio de Janeiro State, Brazil. Appl. Geogr. 20: 95-117

Soeters R, van Westen CJ (1996) Slope instability recognition, analysis, and zonation, In: Turner AK, Schuster RL (eds) Landslides – Investigation and Mitigation., pp. 129-177, Special Report 247, Trans. Res. Board, National Res. Council, National Academic Press, Washington, D.C.

Starkel L (1972) The role of catastrophic rainfall in the shaping of the relief of the lower Himalaya (Darjeeling Hills). Geogr. Polonica 21: 103-147

Starkel L (1976) The role of extreme (catastrophic) meteorological events in the contemporary evolution of slopes. In: Derbyshire E (ed) Geomorphology and Climate, pp. 203-246, John Wiley

Swanson FJ, Swanston DN (1977) Complex mass movement terrains in the western Cascade Range, Oregon. In: Rev. Eng. Geology, Landslides. vol. 3, pp. 113-124, Geol. Soc. Am., Boulder, CO

Trustrum NA, DeRose RC (1988) Soil depth-age relationship of landslides on deforested hillslopes, Taranaki, New Zealand. Geomorphology 1: 143-160

Trustrum NA, Lambert MG, Thomas VJ (1983) The impact of sol slip erosion on hill country pasture production in New Zealand. Proc. 2nd Int. Conf. on Soil Erosion and Conserv., Univ. of Hawaii, Honolulu

Varnes DJ (1984) Landslide hazard zonation: a review of principles and practice. Natural Hazard No. 3, Commission on the Landslides of the IAEG, UNESCO, Paris

Wasson RJ, Hall G (1982) A long record of mudslide movement at Waerenga-O-Kuri, New Zealand. Z. Geomorph. N.F. 26: 73-85

Wells WG (1987) The effects of fire on the generation of debris flows in southern California, In: Costa JE, Wieczorek GF (eds) Debris Flows/Avalanches: Processes, Recognition, Mitigation, Rev. Eng. Geol. 7, Geol. Soc. Am., Boulder, CO

Wieczorek GF (1987) Effect of rainfall intensity and duration on debris flows in central Santa Cruz Mountains, California. Rev. in Eng. Geol., vol. 7, pp. 93-104

Wieczorek GF, Morgan BA, Campbell RH (2000) Debris-flow hazards in the Blue Ridge of Central Virginia. Environ. Eng. Geosci. 6(1): 3-23

Wohl EE, Pearthree PP (1991) Debris flows as geomorphic agents in the Huachuca Mountains of southeastern Arizona. Geomorphology 4: 273-292

Wu W, Sidle RC (1995) A distributed slope stability model for steep forested hillslopes. Water Resour. Res. 31: 2097-2110

Wyss W, Yim S (1996) Vulnerability and adaptability of Hong Kong to hazards under climatic change conditions. Water Air Soil Poll. 92: 181-190

Yoshimatsu H (1990) A large rock fall along a coastal highway in Japan, Landslide News (Jpn. Landslide Soc.) 4: 4-5

CHAPTER 16

Drought Hazard and Land Management in the Drylands of Southern Africa

Juliane Zeidler and Reagan Chunga

Abstract. Significant climatic variability is a common phenomenon in southern Africa. Frequent and persistent dry periods, unpredictable and variable rainfall and temperatures are considered normal climatic conditions. Additionally predictions of long-term climate changes for the sub-region suggest that by 2050 temperatures will be significantly higher and rainfall greatly reduced over extensive areas of southern Africa. Innovative drought hazard and land management responses are being implemented in the southern Africa sub-region. Best practices and clear shortcomings that have been identified and lessons learnt can feed into future response development. The adaptive response capacities of farmers, pastoralists and natural resource managers for example have to be strengthened in anticipation of worsening climatic conditions for crops and livestock productivity, conservation and sustainable use of biodiversity and land management, as a matter of priority. Concurrently capacities at the regional and national decision-making levels need also to be addressed.

Case examples from the sub-region demonstrate that intensive support to individual farmers and communities can significantly improve land management practices, responsiveness to climatic variability and improve livelihood security. Furthermore, it is clear however that pilot approaches need to be "up-scaleable". Pilot studies may not be success stories if lessons learnt are not integrated in a wider systems context. It is also clear that local level interventions on their own will do little to address the issues of land degradation, desertification, sustainable land management, and drought hazard in an integrated way that reaches across to the regional and national decision making levels.

The cases selected provide examples of (i) an early warning system (EWS), and (ii) drought and/or desertification policy. These examples are being analysed based on experiences from southern Africa. Short narrative descriptions are provided and salient lessons learnt synthesised.

16.1 Introduction

Significant climatic variability continues to be a common phenomenon in southern Africa. Frequent and persistent dry periods, unpredictable and variable rainfall and temperatures are considered normal climatic conditions, especially in the drylands. Overall, southern Africa is considered a dry area, and two to three severe drought events can be expected somewhere in the region per decade (Tschirley et al. 2004). Additionally, predictions of long-term climate changes for the sub-region suggest that by 2050 temperatures will be significantly higher and rainfall greatly reduced over extensive areas of southern Africa (IPCC 2001). The Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report and subsequent studies (Scholes and Biggs 2004; Biggs et al. 2004) suggest that by 2050 temperatures in the sub-region will increase by 2°C to 4°C and precipitation will be 10% to 20% less than the 1961-1990 baseline. Increased frequencies and intensities of dry periods are consequently expected.

Although dry periods are considered "normal", extreme natural events put people, production and governance systems under pressure. Droughts can lead to emergencies through food shortages, enhanced pressures on natural resources and ecosystems, and testing and sometimes non-performance of service delivery and emergency responses.

The clear interlinkages between dry periods and land degradation will be depicted and explored in more detail in Section 16.2 of this paper. Overall, it is asserted that if reliable and relevant climate and weather data were more readily available to and applied by key user groups, i.e. farmers, other resource managers, extension officers, emergency response units, and policy and decision makers, countries would be more readily prepared for dealing with the dry periods and occasional disasters, droughts and related land degradation threats challenging the region. At the same time, adaptive capacities to predicted climate changes would be strengthened. Integration and cognizance of weather and climate data in land use planning and land management, as well as better understanding and acknowledgement of the interlinkages between land degradation and dry period would go a long way towards more sustainable land management in southern Africa.

Innovative drought hazard and land management responses are already being implemented in the southern African sub-region. Best practices, clear shortcomings and region specific challenges can be identified. These lessons learnt from previous and ongoing work can feed into improved future response development. This paper analyses cases selected to identify key issues to be addressed to improve strategies for more efficient use of weather and climate information and application for reducing land degradation. Examples of ongoing responses currently applied in southern Africa are presented focussing on (i) an early warning system (EWS), (ii) drought and/or desertification policies and (iii) local level responses.

16.2
Drought and land degradation: conceptual interlinkages

The interlinkages between normal dry periods, drought and land degradation are manifold – and two-directional. Drylands are considered to be "drought-adapted", i.e. dry periods and more severe droughts naturally occur and the ecosystem is adapted to its occurrence. The interlinkages are exacerbated, however, by the increasing population pressure, increased consumption expectations, as well as overall an increase of rural poor. Most countries in southern Africa, with rapidly growing populations, and the various ecosystems occurring across the region, including drylands and more humid ecosystems, experience droughts at least at certain

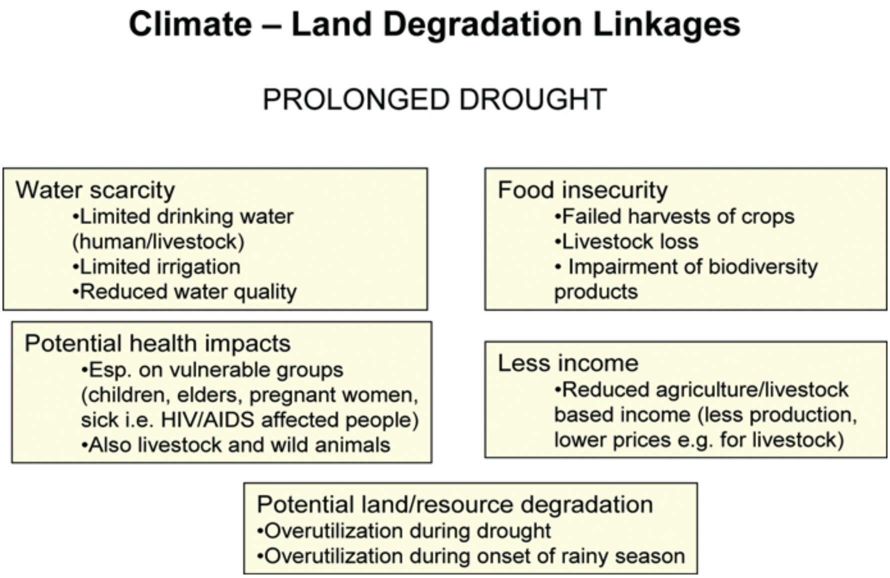


Fig. 16.1. Impacts on the bio-physical and socio-economic environment induced by prolonged drought. It is important to note that both bio-physical and socio-economic impacts can lead to increased land degradation risk (Fig. 16.2)

times. Although the impacts of dry periods in drylands which are considered to be more drought resilient (Behnke et al. 1990; Scoones 1995; Illius and O'Connor 1999), may differ from more humid areas, generally prolonged and severe droughts impact on the bio-physical and socio-economic environment (Figure 16.1).

Droughts, or even normal dry periods, may lead to water scarcity. Reduced or complete failure of rainfall impairs primary production and may lead to failures of harvests and livestock deaths, and ground water recharge can be significantly disturbed. Food insecurity and shortages are the frequent result. These directly affect human well-being, and especially already vulnerable groups, often those who depend directly on subsistence farming for their daily livelihood, poor people and those already exposed to health challenges, i.e. pregnant women, children, elderly people, ill people, for example suffering from HIV/AIDS and related symptoms (IECN 2006). Loss of agricultural produce and income derived therefrom, can severely threaten household economics and the ability to cope with the impacts of the extreme events. Prevailing dry periods and severe droughts often lead to the over utilization of natural resources, e.g. leading to overgrazing of rangeland, or the over harvesting of other biodiversity products such as natural foods ("veld foods[1]") and game. Land and related natural resource degradation can be the effect.

[1] "Veld foods" is a term widely utilized in southern Africa and refers to plant or animal food sources especially collected as alternative or additional food source during drought times.

Areas that are degraded are less resilient, and dry period and drought impacts can be expected to be more severe. The concept of ecosystem services is an important one in this context, and crucial work has been carried out by the Millennium Ecosystem Assessment. Especially relevant to this region is the Southern African Millennium Ecosystem Assessment (Scholes and Biggs 2004; Biggs et al 2004). It can be said that areas where ecosystem services are impaired, i.e. where degradation is evident, resilience, including for dry periods and drought, may be reduced.

Analysing in some more detail the three bottom impact areas of prolonged drought, i.e. potential health impacts, less income and potential land/resource degradation highlights how both bio-physical and socio-economic impacts can lead to increased land degradation risk see (Figure 16.2) below.

During prolonged drought the human resource capacities of farmers and other resource managers can be severely reduced. Reduced capacities to attend to agricultural and livestock husbandry activities can lead to unsustainable land management practices. It is already observed in southern Africa that households who have lost family members suffering from HIV/AIDS or are tending to people living with HIV/AIDS are more vulnerable and usually have less resources to properly manage land, crops and animals (IECN 2006; ABCG 2002; FAO and UNAM 2001; FAO 2003). Further, small-scale farmers often have no or few opportunities to accumulate savings for emergency situations, i.e. droughts or even normal dry periods. Thus if during such periods, there is no harvest or livestock herds perish,

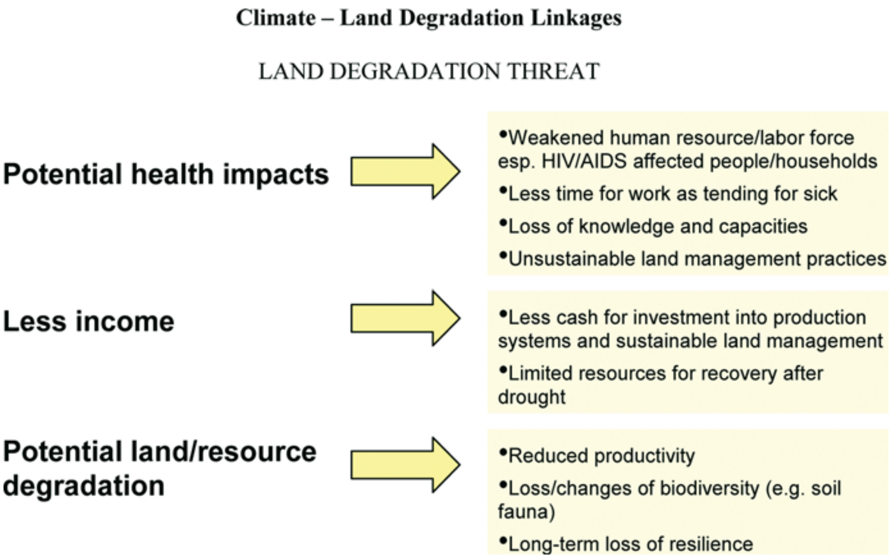


Fig. 16.2. Drought impacts lead to increased land degradation risk. Indirect impacts such as through effects on human resource capacities and house-hold economics, increase the vulnerability of farmers and farming systems, and consequently worsen the land degradation threat. Drought hazard and land management response actions have to be cognizant of these intricate interlinkages and interactions to be effective

such households may be driven into severe debt and poverty. Lack of cash to reinvest into herd re-establishment after the dry period or drought has passed, does, for example, push farmers to keep their herds even in times when de-stocking would be advisable as one way to prevent land degradation.

Although this deliberation is not all-inclusive, it makes a clear case of the issues at stake when considering the important two-directional interactions between normal dry periods, drought and land degradation, the economic impacts and consequences for development. Predicted climate change in the region will aggravate the situation, and thus it will become more important to examine the inter linkages and devise comprehensive strategies to address the need to apply climate and weather data more rigorously in development planning and adaptive resource management.

16.3
Response actions in the southern African region: what can we learn?

16.3.1
Early Warning Systems (EWS)

16.3.1.1
Mechanisms for ESW in Southern Africa: what works – what doesn't?

EWS exist for a variety of extreme events including droughts and floods, earthquakes and tsunamis, as well as fires and other events. These systems exist on a diversity of levels, including local level EWS, which often are based on indigenous knowledge and locally established management systems, and reach to sophisticated national, regional and global EWS. The Southern African Development Community (SADC), representing the southern African region, has established a strong EWS with a Regional Early Warning Unit and maintains a dedicated Drought Monitoring Centre situated in Harare, Zimbabwe[2]. This Centre is designated to assist with regional EWS information generation and dissemination, i.e. on drought hazards. The regional Centre works in close association with all SADC countries and intricate information flow chains have been established over the past decade (Nyenzi et al. 2006). The Centre is responsible for research and science, models and predictions; the southern African Regional Climate Outlook Forum (SARCOF) is composed of members of each SADC country, who, together with the Centre, produce consensus seasonal forecasts, which are then adapted to national conditions. SARCOF and the national institutions associated constitute part of the communication mechanism that reach out to planners and other forecast users. The set-up generally satisfies the request that EWSs should be people centred and have four elements to be effective (UN 2006):

- Knowledge of the risk faced
- Technical monitoring and warning service

[2] See www.sadc-fanr.co.zw; www.fews.net/south/ for details

- Dissemination of meaningful warnings to those at risk, and
- Public awareness and preparedness to act.

Early warning infrastructure in the region is linked to the SADC and existing national Food Security Networks and Emergency Response Institutions, usually constituted of multiple stakeholders.

In the context of land degradation management, the key issue is that not only emergency planners at the national and regional level have access to adequate weather and climate data for emergency responses in case of drought, but that the farmers and local level resource manager are prepared to deal with normal dry times and drought by applying appropriate response measures. For example, forecasts are needed to inform the choice of seed varieties for either higher productivity or drought resistance, the timing of planting, stocking rates and other. Application of and response to forecast information at this level is of highest importance. It is at this level that it is decided if sustainable land management practices are applied – or not. However, it is exactly at this level that a great number of obstacles to the acquisition and application of weather and climate data exist and workable strategies have to be employed to significantly impact on this level.

Considering the enormous impact dry periods and droughts place on national economies, is seems also important that relevant data and information on weather and climate, medium-and longer-term, are integrated more systematically throughout economic and development planning *per se*. A discussion paper prepared by the UNDP Drylands Development Centre in 2005 (UNDP 2005), eloquently describes the impact droughts can have on economies especially in developing countries. They make a strong case that not addressing drought in a development planning context can put severe limitations to options countries have, especially in those countries that can expect more frequent and severe droughts under climate change scenarios for the region. These observations and analysis should be expanded to consider normal dry periods as well.

16.3.1.2 Analysis & Synthesis: looking at different scales

Two different levels of EWS will be analysed in the context of this paper, concerning (i) information needs and challenges to successfully addressing such needs at the farmers' level, and (ii) an indicative analysis of capacity needs at the national and regional level for improved provision of weather and climate information.

16.3.1.2.1 Local level

Although climate forecast information may in general be available (even if they could be improved: see "national and regional level" analysis below) such information is not readily accessible to small scale farmers and rural communities in developing counties e.g. in southern Africa, and adequate response actions are not rigorously applied.

Pilot studies conducted in several parts of southern Africa have investigated the utility of climate information in agricultural management and farmers' information needs. The following types of information/predictions have been identified to be of particular use (Ziervogel 2001; Chikoore and Unganai 2001; Patt and Gwata 2002):

- Onset date of the main rains (as it differs from expected).
- Quality of the rainy season (rainfall amount).
- Cessation date of the main rains (as it differs from expected).
- Temporal and spatial distribution of the main rains.
- Timing and frequency of active and dry periods (wet and dry spells).
- Agronomic recommendations in terms of, for example, which crop varieties to grow.

The most useful forecast information according to farmers is early warning of a poor season, the commencement of the season and whether the rains would be adequate (Phillips et al. 2001). It is probable for people living in low rainfall zones, where rainfall is more variable, that seasonal forecasts for wetter years are of greater value than warnings of a poor season (Phillips 1998). An important consideration is that "the forecast needs to be stated in a language and in terms the user understands" (Unganai 2000).

Usually it is asserted that it is a matter of communication and outreach to the local levels that is needed, and governments are often criticised for not taking the necessary actions. However, it appears that the situation is more complex. Patt and Gwata (2002) undertook some in-depth research in Zimbabwe, analysing what type of weather and climate data are needed by local farmers, how such information should be provided and what the key constraints are for effective local level responses to take place. Generally they identify six constraints to forecast effectiveness: (1) credibility, (2) legitimacy, (3) scale, (4) cognition, (5) procedures, and (6) choices. Other sources (Phillips et al. 2001; Ziervogel 2001) add to this list both access and structure of decision set (Table 16.1). These authors analysed causes and effects of the constraints and made recommendations as to how to address the identified constraints.

From their analysis it is clear that weather and climate information needed at the local level has to go far beyond producing a forecast, and effecting the appropriate application of data so provided requires dedicated inputs. As Patt and Gwata (2002) point out, intense extension and outreach work, e.g. through training workshops, is required to actually get weather and climate information fully integrated into land management decision making.

The challenge is to reach out to the key target group concerned with land management decision making – critically, local farmers and resource managers. When discussing strategies for more efficient use of weather and climate information and its application for reducing land degradation, the role of these stakeholders cannot be overemphasised. Recommendations made from the case study in Zimbabwe pointed to the need to invest enormous human and financial resources into the capacity building and empowerment of the local resource manager. Currently, most international and multilateral instruments place responsibility for such local level outreach and devolution efforts to national governments. The enormous investments required to reach but a few people is indicative of the scale of efforts re-

Table 16.1. Constraints to effective communication of weather and climate data to the farmer and resource manager level based on case study research in Zimbabwe and Lesotho and recommendations made by the researchers (Patt and Gwata 2002; Phillips et al. 2001; Ziervogel 2001) in a UNDP/GEF proposal to the GEF 2006

Constraint	Cause	Effect	Recommendation
Access	Mode of information delivery not tailored to remote rural areas. No national radio coverage	Users resort to indigenous knowledge systems	Establish community radio stations and information centres
Relevance	Forecast generators do not interface with users to correctly define user needs	Forecasts not used	Strengthen forecaster – user interface
Credibility	Previous forecasts perceived as wrong: source not trusted	Users will do business as usual	Rely on trusted communicators
Scale/ geographic location	Forecasts tells users nothing about events in their local area	Forecast not incorporated in decision making	Work with users to analyze implications for local area
Cognition	Forecast is new, different and confusing/ difficult to understand	Users either do not use forecast or use it in a counterproductive way	Work repeatedly with the media and users to help them understand forecasts for their local area and to correct past mistakes
Legitimacy	Forecasts perceived as superseding local knowledge or hurting users	Both forecast and concomitant advice ignored	Incorporate local knowledge in forecast process; involve users in formulating advice
Procedures / lead time	Forecast arrives at the wrong time, to the wrong people or is unexpected	Forecast not incorporated	Repeat communication to resolve timing, relevant actors and consistency
Choices	Forecast does not contain enough new information to alter specific decisions	Users will not change decisions in response to forecast	Improve forecast skill; encourage users to make incremental decisions
Structure of decision set	Limited management options	Farmers will do business as usual	Create opportunities to diversify livelihoods

quired to up-scale and reach out to a majority of farmers and resources managers nation-wide. Politicians and decision makers are faced with the need for pragmatic solutions and it is not only their responsibility to devise more practicable strategies and response actions.

In Namibia, currently efforts are ongoing to establish a National Drought Risk Management Centre, which, through an intricately established multi-stakeholder mechanism would process and communicate relevant information to the end user level (Seely et al. 2006). Such a system would involve the extension services of the Ministry or Agriculture, Water and Forestry, and outreach and training for communities through approaches and programmes such as the Farming Systems Research and Extension (FSRE), Forum for Integrated Resource Management (FRIM) and Local Level Monitoring (LLM) piloted in Namibia (see also section 16.3.2, Policy Instruments). It is essential to make special efforts to connect successful community action and research (Seely and Moser 2004; Seely and Wöhl 2004).

In terms of EWS for drought occurrence, a recent UN report highlights and stresses the importance of traditional and indigenous knowledge systems, which are partially still applied and seem to be scientifically quite robust (UN 2006). It might be overall more practical and cost effective to promote such local systems instead of superimposing complicated and not fully appropriate top-down systems. Many of these indigenous and traditional knowledge systems are effective when population remains relatively constant and effective governance is in place. With rapidly growing populations and changing governance structures, these systems require combination with alternative systems.

16.3.1.2.2
National and regional level

The above described SADC Drought Monitoring Centre in Zimbabwe is an established institution. Relevant and relatively well functioning regional platforms have been established though SARCOF. Additionally, linkages to regional and national emergency response entities exist. However, there are constraints that hamper the efficient work of these institutions. For example, funding and technical support to the Centre are limited and new mandates and work responsibilities, e.g. that would emerge, from the aforementioned requirements on the local level, can not be met at current state. It is clear that currently existing EWS globally are not adequate and capacity gaps are pertinent. The Global Survey of EWS, published by UN (2006) looked at a comprehensive set of EWS, including for drought hazards. The survey identifies a suite of constraints relating to risk knowledge, monitoring and warning systems, dissemination and communication and response capacities. Drought monitoring, as well as environmental monitoring, including land degradation are covered in the study. Overall the need to establish better global linkages for sharing information and providing adequate early warning are noted, and existing capacity gaps ought to be addressed as a matter of priority. However, the survey places a strong emphasis on building and improving national people-centred EWS, and proposals for such capacity building are presented.

Supporting information is presented in the *Climate Africa Report* (Washington et al. 2004) commissioned by the UK Government. This document identifies capacity needs and potential support actions in the field of improving climate and weather information and the long-term response capacity to climate change in Africa. It is shown that African climate observing systems are in a worse state than that of any continent and shown to be deteriorating. Relative to many parts of the world, scientific understanding of the African climate system as a whole is low, although the southern African climate system is comparatively better understood than that of other areas in Africa. It is noted that traditionally the provision of climate services and information by many African National Meteorological and Hydrological Services (NMHSs) was developed around transport demands, with short-term forecasts, whilst longer-term climate concerns are a lower priority. However, as partially asserted above, seasonal forecasting and the provision of probabilistic climate information on time scales from months to a year have improved and could meet informational needs relevant to farmers and in the land degradation context.

An appraisal of the current weather and climate facilities within Africa reveals numerous gaps not only in the ability of Africa to satisfy international agreements but also to provide quality national climate services. A review of climate policy within Africa identifies important limitations in the use of climate within policy planning. The report further finds that international support for African climate activities is "diffuse and largely discontinuous". Based on the analysis the report suggests immediate issues for consideration in addressing the gaps, and options and cost-benefit information for implementation.

16.3.1.3
Salient points

The persistent dry periods and drought risk knowledge currently place inadequate emphasis on social, economic and environmental vulnerability. EWS need to be both more inter- and multi-disciplinary in their nature to address key management concerns. Competent capacities have to be strengthened and built in institutions which could provide more sophisticated research information and become more valuable for developing adequate response actions. For example, the currently provided drought early warning information could be further refined through an additional vulnerability element, which could be presented in an integrated manner, and targeted beyond the "food security" community.

Capacity gaps in Africa's (including southern Africa) weather and climate observatories exist and overall capacity bottlenecks need to be identified and overcome to ensure that weather and climate data are included in land use and management planning and implementation. Rigorous application of seasonal forecast information can contribute to preventing land degradation. It is recognised that it will be difficult for national governments to generate and allocate sufficient resources to building up a strong observatories system. Developing environmental observatories would provide a broader set of information, whilst at the same time serving a wider set of user groups and information needs while satisfying the requirements of more inter- and multi-disciplinary research.

The technical, scientific and financial capacities to produce rigorous information are limited and need to be improved and supported. Strong scientific research and knowledge generation is required to generate sufficiently accurate information. Although the SADC (Southern African Development Community) region has a competent authority dedicated to EWS, updated data from national sources is a major deficiency. The low number of observatories is evident and data quality is not always adequate. Even if the data foundation is being improved, technical capacities have to be developed that enable countries to process the data according to the local and national information needs. It has been observed that there is currently a major bottleneck in communicating the available weather and climate information and in synthesizing it in the most appropriate ways. Perhaps a new generation of professionals is needed to overcome these current capacity gaps. It seems that, for example, traditional "weather/climate professions" as well as profiles of extension officers do not suffice current demands and new profiles may be needed.

Local level outreach is effort- and resource-intensive and hence pragmatic and practical strategies and responses are needed which really reach out to the intended end user of weather and climate information. It becomes apparent that the communication of weather and climate data is a key bottleneck. Although certain mechanisms are being tested, two main questions are (i) who is responsible for the communication of the information, and (ii) how much does it cost to provide effective communication which is extremely resource intensive. Can we come up with more practical and pragmatic strategies?

16.3.2
Policy instruments

16.3.2.1
Drought Policy: empowering farmers to monitor rainfall and to take adaptive management actions: an example from Namibia

Drought and/or desertification/land degradation related policy instruments exist in most countries in the southern African region. However, drought risk as well as land degradation risk, are seldom integrated into other relevant policy instruments relating to agriculture, water and related food security and emergency management. In the context of this paper, there is a need for exploring if and how the use and application of weather and climate data could be integrated on a policy level to help curb land degradation, and contribute to drought preparedness in countries.

As an example, the Namibian *National Drought Policy and Strategy* can be used. Namibia has a drought policy as well as a desertification policy. Whilst the latter is relatively unknown and not widely applied, the drought policy and strategy is considered an important policy instrument fostering drought preparedness of farmers rather than emergency responses. An important element is the definition of drought which focuses on differentiating normal dry periods with 'disaster' droughts that occur on average 1 out of 20 years. This policy entails elements that require the farmer and resource manager to monitor the condition of the natural resource base and rainfall. In disaster drought situations only those farmers qualify for emergency relief and subsidies who can demonstrate that the conditions of the natural resource and rainfall base are indeed impaired due to prolonged drought and not just due to natural climatic variability. The farmer also must demonstrate that adequate management responses were applied, which would fall within a realistic framework of drought preparedness that could be expected at the farmers' level. The specific provisions made in the Namibian Drought Policy should:

- Prevent "relief fraud" which can cost the Government large sums of money;
- Reduce dependency on drought relief which may reduce coping abilities in future drought situations;
- Support the implementation of local level EWS, based on resource and rainfall tracking principles, and thus
- Empower the farmer and local resource manager to apply adaptive management practices, which would reduce land degradation and vulnerability to extreme events, and contribute to drought preparedness for natural dry periods and disaster droughts.

A "carrot and stick" incentive system is used to promote the active implementation of the provisions.

16.3.2.2
Analysis: What can be done at the policy level?

The example of the Namibian *National Drought Policy and Strategy* indicates how the use and application of climate and weather data can be promoted through national policy setting. Considering that Section 16.3.1 on EWS identified the devolution of information and management responses to the farmer and resource manager as a key bottleneck, this approach is novel. However, analysis of the Namibian case indicates additional shortcomings and constraints.

The Drought Policy is not widely implemented, although the Ministry of Agriculture, Water and Forestry (MAWF) has undertaken a number of serious attempts to promote the instrument. Most recently during its last Ministerial Planning a plan of action was devised that should foster application of the policy. Additionally the third phase of Namibia's National Programme to Combat Desertification (2000-2004), Namibia's equivalent to the National Action Programme (NAP) under the UNCCD, focused on promoting the policy and supporting implementation through a targeted communications strategy. The national policy was simplified into a small handbook for farmers and translated into vernacular languages.

[3] As part of Namibia's National Programme to Combat Desertification (NAPCOD) Desert Research Foundation of Namibia (DRFN) developed guidelines and systems for natural resource tracking targeting local farmers (Napcod 2003; Zeidler 2000); similar tools have been developed for application in conservancies, which integrate more information on wild-life and biodiversity (Stuart-Hill et al. unpublished).

Materials were disseminated and introduced during workshops at pilot sites of the programme. Where needed, the acquisition of raingauges was supported and a Local Level Monitoring scheme[3] was developed, targeting especially communal area farmers.

The Drought Policy and its provisions have been implemented more widely in the commercial farming sector[4] where agricultural extension services were historically more active and farmers have a relatively higher level of coping capacities compared to communal areas. Uneven capacity is evident in, for example, financial and infrastructural resources, human resource capacity and tenure arrangements (freehold versus communal or open access). Implementation of these instruments in communal areas has been much less successful to date, largely for the reasons and constraints outlined for EWS in the previous section. Outreach to remote villages and communities, and individual farmers is resource intensive and up-scaling efforts to a nation-wide level is hard to achieve in a country with low population density like Namibia. Enforcement of the policy is difficult to achieve alone as the human and financial resources of the extension services (i.e. of MAWF) are constrained.

It could be that the intricate and relatively sophisticated resource tracking and adaptive management systems advocated are not appropriate for the key target groups we are dealing with. There could be a stronger emphasis on recognising and utilising existing traditional and indigenous EWS/tracking systems including for weather and climate data; this would perhaps allow for wider applications of such methods. However, a challenge would be to recognise such systems, adapt them for application to changing conditions, and integrate them equitably into the drought policy context outlined above.

As long as dry periods and drought are dealt with as a standalone natural disaster without linking it to the overall development priorities of the country, e.g. to economic performance and trade relationships, the magnitude and importance of this policy will not be recognised and the necessary resources for the instruments' implementation will not be allocated. It is important to ensure that aridity and drought are not only a concern to the agriculture and water sector, but also food security. Environmental sustainability and the interlinkages between dryness, drought and land degradation are important, as are further expansions to health, trade, and poverty alleviation, mention a few. In the context of climate change adaptation considerations, such more encompassing relationships can potentially be elevated. It is notable that Namibia recently developed Climate Change Adaptation activities under the GEF-funded Pilot Partnership for Integrated Sustainable Land Management (CPP for ISLM), a medium term country programme that addresses land degradation and development in a cross-sectoral and integrative system. In this context, dryness, drought and land degradation, including the use and application of weather and climate information, are imbedded in a clear

[4] In Namibia historically a "commercial" or freehold farming sector is distinguished from the small-scale or subsistence farming sector primarily in the communal areas. This is a heritage of the apartheid era, which still to date is dominating many development and socio-political decisions and frame conditions.

development and management context. In such a context, immediate value-added information needs would fall into the realm of informing land use planning and land management with comprehensive climate scenarios that would identify best options for longer-term land use decisions as well as seasonal land management decisions (Zeidler 2006).

16.3.2.3
Salient points

National (development) policies should be informed by an understanding of policy options which integrate climate and land degradation considerations. For example, it should be systematically considered in which situation a specific policy increases or decreases the vulnerability to dry period and drought and potential risk of land degradation. If a designated drought policy is being developed it has to be ensured that it receives the justified level of priority – with its strong economic and development impacts.

Policy makers have to be pragmatic and take into account resources, constraints and opportunities associated with the instrument. It is important to design policy instruments in a way that they are implementable, whilst identifying the highest leverage and avenues through which a lasting and effective enabling environment can be created for positive action. In many countries good policies have been developed, however implementation is slow because many of the well-intended instruments are not practical. Often implementation is expensive and enforcement is complicated. Especially dealing with issues that may not obviously be national priorities (climate, land degradation), very well crafted instruments need to be developed to effect change.

Applying incentive systems that would promote the implementation of a policy may work. In the Namibian case, the tracking of natural resources including rainfall and/or the application of forecast data and practicing adaptive land and natural resource management based on such data are novel approaches which should be promoted. Linking performance to qualifying for drought relief thus developing a clear incentive linkage is a clever thought. However, it is clear that even if appropriate incentive measures can be identified, many implementation and enforcement obstacles remain.

Different people/groups have different approaches and capacities to assessing and managing drought risks, usually as a function of their opportunities, situation, experience and this variety needs to be taken into account when devising drought policies or other relevant policy instruments. In the context of using monitoring and tracking systems of natural resources and climate ie., in the Namibian policy context it is important to not disadvantage inclusion of traditional and indigenous knowledge systems as well as "western" scientific monitoring systems. Traditional and indigenous knowledge systems should be identified and promoted and equitably integrated into the policy context, where they are proven to be (scientifically) robust. This would potentially also improve on the level of "implementability" of the policy instrument, and allow more people to act on the instrument.

Land use options under different climate conditions should be identified and made known to farmers/ resource managers. This can be done both in terms of long term land uses (e.g. shifting from livestock to game-based meat production or nature tourism) or shorter-term options such as planting drought resistant crop varieties in a predicted drought year, de-stocking at an early stage, and providing incentives for de-stocking through maintenance of strong prices for meat, amongst others. An integrated analysis of climate and weather data and scenarios with other environmental and agricultural information as well as social and economic parameters would be called for.

16.4
Synthesis and conclusions

Based on the sections described earlier, a synthesis of the lessons learned from the case studies of ongoing work in terms of dry periods and drought hazard and land degradation management in southern Africa can be drawn (Figure 16.3). Such a synthesis is targeted at identifying opportunities to improve EWS to address, in particular, climate and land degradation needs.

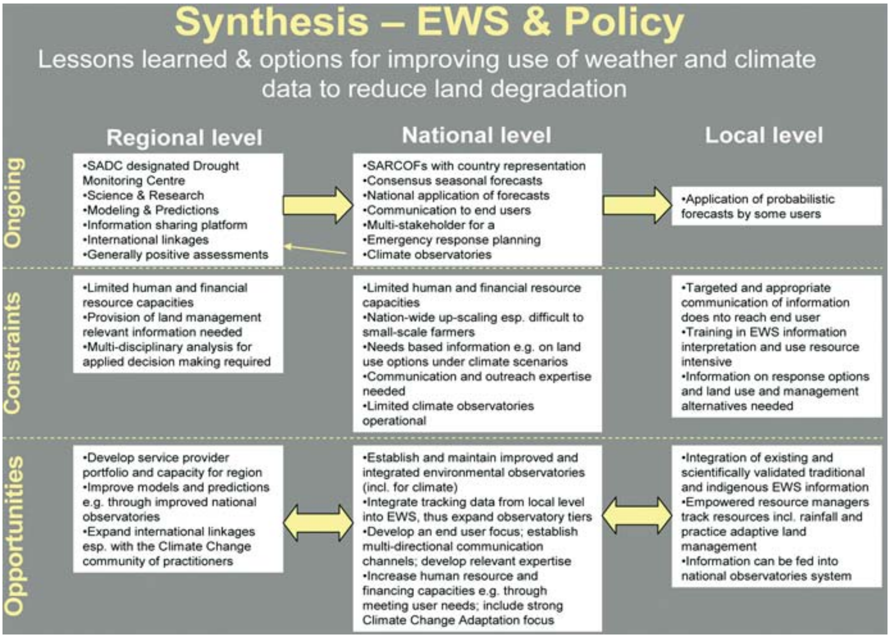


Fig. 16.3. Based on the analysis of drought hazard and land degradation management responses applied in southern Africa, a synthesis of (i) ongoing work, (ii) key constraints, and (iii) opportunities for improving the use and application of weather and climate data to reduce land degradation are derived

It is apparent that different needs, constraints and opportunities are identified at different scales of stakeholder target groups. It is opportune to address climate- and weather-related work on a regional and even broader international scale. The existing networks, institutions and mechanisms in the SADC region seem to be well situated to serve that role, and to potentially expand and improve the scope of work that is truly needs-driven. The potential to further establish inter- and multi-disciplinary working groups and fields of proficiency should be explored to better serve countries to address key environmental and development challenges which are emerging, in amongst other cases, the context of climate change adaptation.

It cannot be overemphasised that capacity constraints at the national and local scale impede the effective use of weather and climate data, especially as the much-needed forecast information is not effectively transmitted to the end user. This is not the result of bad will, but there are challenges that have to be recognised openly and honestly to be able to overcome this problem. While NMHSs are generally challenged to meet new and ever increasing needs, e.g. for more and better climate data, new customer services, modern technical and research fields, Governments in general face the enormous task of decentralisation and devolution of rights and responsibilities to the people. Considering that we are referring to a developing country situation, many of the end users can only be "reached" through an enormous effort of engagement, capacity building and infrastructure development. It is the responsibility of the science and research community as well as policy makers and practitioners to come up with pragmatic and practical solutions and strategies. Such strategies have to be implementable and effective in achieving more sustainable development. It is simply not good enough for the science and research community to provide information and "make it available", if the key end user groups have no means to tap and apply that information. It may mean that we have to look at developing an entire new cadre of practitioners who are able to work at the interface of the various levels. It may mean that we have to rethink the way we conduct research and apply science.

Acknowledgements

The authors would like to thank Dr. Mary Seely, Desert Research Foundation of Namibia, and Louisa Nakanuku, Carleton University, Ottawa, for their invaluable comments on a draft of this publication. Further we would like to acknowledge the review contributions of our colleagues Jessica Jones, Josephine Ashipala and Lydia Mlunga.

References

ABCG (Africa Biodiversity Collaborative Group) (2002) HIV/AIDS & Natural Resource Management linkages. Background materials from ABCG Workshop on the Impacts of the HIV/AIDS Pandemic on the Management and Conservation of Natural Resources in East and Southern Africa, 26-27 September 2002, Nairobi, Kenya. Available online at: www.frame.org/partnerpages/ABCG-hiv-NRM_Workshop.htm.

Biggs R, Bohensky E, Desanker PV, Fabricius C, Lynam T, Misselhorn AA, Musvoto C, Mutale M, Reyers B, Scholes RJ, Shikongo S, van Jaarsveld AS (2004) Nature Supporting People: The Southern African millennium ecosystem assessment. Council for Scientific and Industrial Research, Pretoria, South Africa

Behnke R, Scoones I, Kerven C (eds.) (1990) Range ecology at disequilibrium. ODI, London, UK, pp. 248

Chikoore H, Unganai L (2001) Integrating climate forecast information in agricultural management: A perspective from Southern Africa. Rio de Janeiro, Brazil

FAO and University of Namibia (UNAM) (2001) Impact of HIV/Aids on the different farming sectors in Namibia.

FAO (2003) HIV/AIDS and agriculture: impacts and responses: case studies from Namibia, Uganda and Zambia. World Agricultural Information Centre (WAICENT), FAO, Rome, Italy.

Houghton J, Ding T, Griggs Y (2001) Climate change 2001: The scientific basis. IPCC, Cambridge University Press, Cambridge, UK.

IECN (2006) Strategic Assessment of the Relationship between HIV/AIDS and Environment in Namibia. Vol 1: Synthesis Report; Vol 2: Status Report; Vol 3: Elements for an Action Plan; Vol 4: Action Plan; Vol 5: Extended Bibliography. For the Ministry of Environment and Tourism, Namibia by Integrated Environmental Consultants Namibia, Windhoek, Namibia

Illius AW, O'Connor TG (1999) On the relevance of non-equilibrium concepts to arid and semi-arid grazing systems. Ecol Appl 9:798-813

NAPCOD (2003) Local level monitoring – for enhanced decision-making – a tool for improved decision making in Namibia. Desert Research Foundation, Windhoek, Namibia

Nyenzi BS, Raboqha SP, Garanganga B (2006) Review of Regional Climate Outlook Forums: Meteorological aspects for Southern Africa. Harare, Zimbabwe

Patt A, Gwata C (2002) Effective seasonal climate forecast applications: examining constraints for subsistence farmers in Zimbabwe. Department of agricultural economics and extension, university of Zimbabwe, Harare, Zimbabwe

Phillips JG (1998) Comparing Optimal Use of ENSO Forecast Information in two socioeconomic contexts. Invited Talk at the American Association of Geographers Annual Meeting, Boston, MA

Phillips JG, Makaudze E, Unganai L (2001) Current and Potential Use of Climate Forecasts for Resource poor Farmers in Zimbabwe. In: ASA Special Publication No. 63, Impact of El Niño and Climate Variability on Agriculture, pp. 87-100.

Scholes RJ, Biggs R (eds.) (2004) Ecosystem services in Southern Africa: A regional assessment. Southern Africa Millennium Ecosystem Assessment, CSIR, Pretoria, South Africa

Scoones I (ed) (1995) Living with uncertainty: new directions in pastoral development in Africa. IIED, London, UK

Seely, M, Moser, P (2004) Connection community action and science to combat desertification: evaluation of a process. Environ Monit Assess 99:33-55

Seely, M, Wöhl, H (2004) Connecting research to combating desertification. Environ Monit Assess 99:23-32

Seely, M, Klintenberg, P, Kruger, A (2006) The unmet challenge of connecting scientific research with community action. Proceedings of the International Conference on Future of Drylands, 19-21 June 2006, Tunis, UNESCO, Paris *(In press)*

Stuart Hill G, Ward D, Munali B, Tagg J (Unpublished). Event book system. Namibia Nature Foundation, Windhoek, Namibia

Tschirley D, Nijhoff JJ, Arlindo P, Mwinga B, Weber MT, Jayne TS (2004) Anticipating and responding to drought emergencies in Southern Africa: Lessons from the 2002-2003 experience. Department of Agricultural Economics, Michigan State University (MSU), Nairobi, Kenya

UN (2006) Global survey of early warning systems: An assessment of capacities, gaps and opportunities towards building a comprehensive global early warning system for all natural hazards. United Nations

Unganai LS (2000) Application of long range rainfall forecasts in agricultural management: a review of Africa's experiences. In: Proceedings of the International Forum on Climate Prediction, Agriculture and Development, International Research Institute for Climate Prediction, Palisades, New York.

UNDO (2005) Discussion paper for the UNDP-DDC/BCPR & UN-ISDR expert workshop Drought risk and development policy. United Nations Development Programme, Nairobi, Kenya

Washington R, Harrison M, Conway D (2004) African climate report: A report commissioned by the UK government to review African climate science, policy and options for action. United Kingdom

Zeidler J (2000) Communities take the lead. Monitoring and management of natural resources in communal farming areas: case study from Namibia. In: B. Gemmill (ed.), People managing resources, ELCI, Nairobi, Kenya, pp. 27-29

Zeidler J (2006) Namibia: Land use planning and environmental sustainability. Contributions to an analytical framework for sustainable land management. Commissioned by the World Bank as a contribution to Namibia's Country Pilot Partnership for Integrated Sustainable Land Management, World Bank, Washington, US

Ziervogel G (2001) Global Science, Local problems: Seasonal climate forecast use in a Basotho village, Southern Africa. Environmental Change institute, University of Oxford, OXI 3TB, UK

CHAPTER 17

Climate Monitoring in the Southern Africa Development Community

Bradwell J. Garanganga

Abstract. The Drought Monitoring Centre (DMC) is a specialized institution in climate diagnosis, prediction and applications for the Southern African Development Community (SADC) comprising 14 member states with well over 220 million inhabitants. SADC is largely semi-arid to arid. The SADC countries, therefore, experience recurrent vagaries of climatic extremes such as droughts, floods, tropical cyclones and tsunamis. Consequently, there are far-reaching negative impacts on socio-economic development of the member states and the well being of most of the inhabitants of the region. Impacts can easily exacerbate land degradation. The main objective of the DMC is to contribute to minimizing negative impacts of the climatic extremes on the socio-economic development of the region; and for the rational use of natural resources. This is achieved through the monitoring and diagnosis of near real-time climatic trends, and generating medium-range (10-14 days) and long-range climate outlook products on monthly and seasonal (3-6 months) timescales. These outlook products are disseminated in timely manner to the communities of the SADC principally through the national Meteorological/Hydrological Services (NMHSs) regional organizations, relief and international development partner agencies. The provision of early warning for the formulation of appropriate strategies to combat the adverse effects of climate extremes affords greater opportunity to decision-makers for development of prudent plans for mitigating the negative impacts. The main activities of the DMC are described with suitable examples. The DMC is continuing to transform itself into a centre of excellence in climate analysis, prediction and applications with particular emphasis on the extremes across the SADC. It develops the capacity of the SADC NMHSs scientists on climate diagnosis and prediction; and users in climate applications.

17.1 Introduction

The Southern African Development Community (SADC) comprises 14 member states with well over 220 million inhabitants whose socio-economic development is intrinsically and inextricably tied to rainfed agricultural activity and utilization of other natural resources. SADC is a region of tremendous contrasts (Fig. 17.1): the 14 countries vary in size from 17,400 km² (Swaziland) to 2.3 million km² (Democratic Republic of Congo-DRC). Population ranges from 1.08 million (Swaziland) to 54.9 million (DRC); per capita income from US$ 110 (DRC) to US$ 4,500 (South

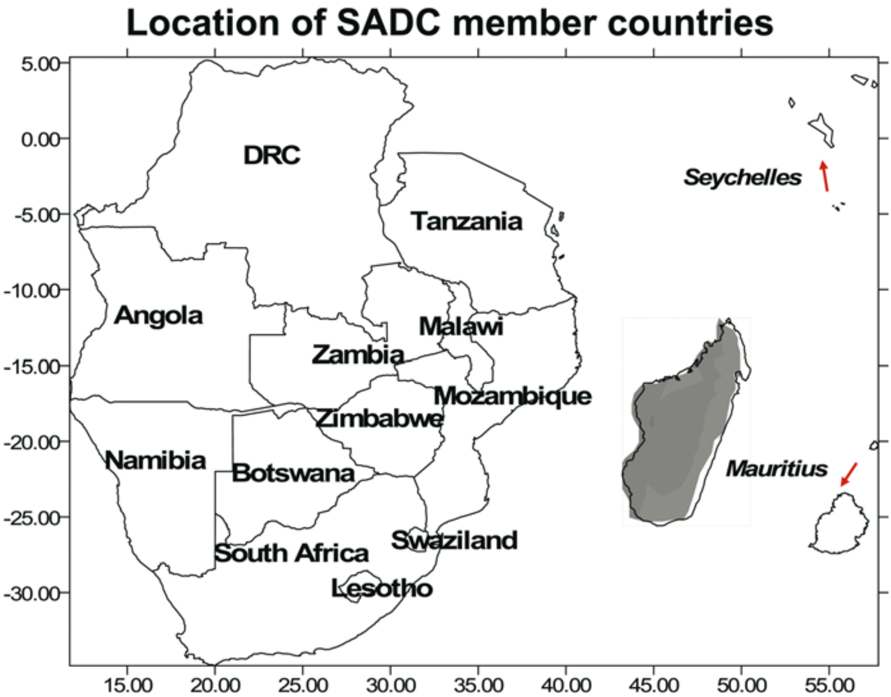


Fig. 17.1. Map of SADC countries

Africa); gross domestic product (GDP) from US$ 1.07 billion (Lesotho) to US$ 212.8 billion (South Africa) (SADC 2005).

Climatic extremes such as tropical cyclones, floods and droughts have led to losses of life, property and environment especially in developing countries. This has also been demonstrated in southern Africa during the recent spate of floods and droughts that affected the region. These climatic extremes not only have far-reaching implications on socio-economic development of the member states but also oftentimes wreak havoc on their ecological balance. An example of climate related disasters that occurred in the region are the devastating droughts of 1991-94 and the heavy floods of early 2000's that have had a negative and far-fetched bearing on socio-economic well being and land degradation of the SADC countries. Against this background of recurrent negative impact of vagaries of weather and climate and under the guidance of WMO, African countries formed Drought Monitoring Centres (DMCs) in Nairobi and Harare in 1989/90 for eastern and southern African subregions. These centres helped in mitigating the negative impacts of droughts from respective regional perspectives.

Each country must use climate information and prediction services to ultimately design its own set of policies to deal with the many challenges in these areas, which include:

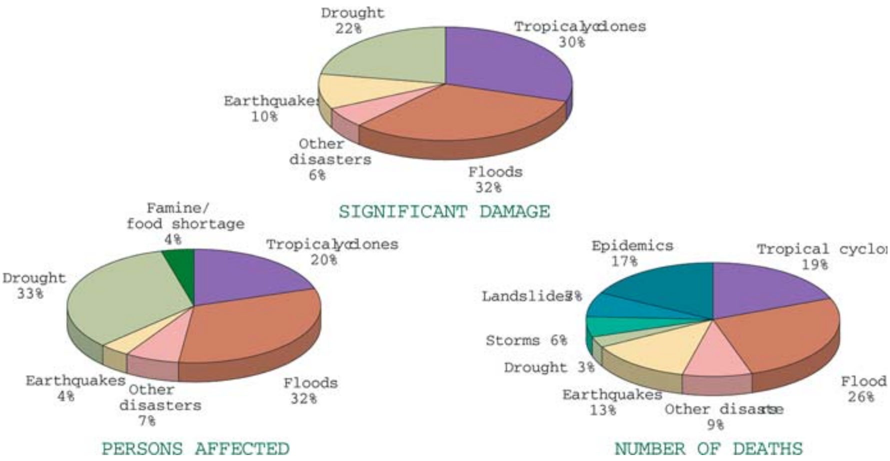


Fig. 17.2. Climate related natural disasters of the globe

- Land management
- Poverty and economic growth
- Human resource development
- Population growth, urbanization, and displacements
- Natural resources and agricultural inputs

Extremes in climate tend to exacerbate the ecological balance. This is in addition to direct land degradation caused by droughts and floods, because poor communities will over-exploit resources in order to sustain themselves when agriculture fails due to either drought or floods.

17.2 Climate related natural disasters including land degradation

About 80% of the world-wide natural disasters derive from extremes of climate (Fig. 17.2). These oftentimes lead to land degradation, especially in the developing economies. Tropical cyclones rank highest due to their direct impacts on the communities and their environments. The impacts due to droughts are indirect and evolve slowly. Recent years have amply demonstrated the vulnerability of SADC member states to the extremes in climate. Food unavailability has been one of the major problems over the past few years due tropical cyclones, floods, droughts, and at times hailstorms. Other sectors such as environment, water resource management, health and power utilities can easily be also at the mercy of extremes of climate variations.

Poor economic performance due to droughts or floods has in general negative consequences on employment availability. This leads to communities carrying out activities to sustain themselves during the duration of impacts of hostile climatic conditions. For instance, communities tend to engage in activities such as rampant cutting down of trees for re-sale as fuel wood in order to purchase food and other vital supplies. This invariably leads to land degradation. Application of climate system monitoring information and prediction products play an important role in minimizing negative impacts of climatic extremes.

17.3 Overview of the summer climate system of southern Africa

SADC is the region of Africa from the equator (DRC) all the way to the south shores of the subcontinent and the Island states of Madagascar and Mauritius out in the Indian Ocean. It lies between the South Atlantic and Indian Ocean subtropical high-pressure cells in a region subject to the interaction of tropical easterly and extra-tropical westerly airflows. Both these high pressure cells change their longitudinal positions during the Southern Hemisphere summer and winter. The seasonal longitudinal shifts of the subtropical high-pressure cells have a direct effect on the weather systems over southern Africa. Rainfall in southern Africa also comes from evaporation over the Indian Ocean. Moisture in the air is generally higher in the northeast of the region and lower in the southwest. Rainfall also increases towards the equator. Generally there tends to be more rain in DRC, Tanzania and northern Mozambique, and less in Namibia and Botswana.

Rainfall is seasonal throughout most of the region. A five to seven month wet season occurs during summer (roughly October to April). The main systems that result in the distribution of rain in both space and time in the subregion are the Inter-Tropical Convergence Zone (ITCZ) and transient westerly cloud systems associated with cold fronts that regularly traverse southern Africa and generally support the former. The ITCZ is a zone of intense rain-cloud development created when the southeast trade winds (from the southern part of the region) collide with the northeast Monsoons (winds from the north). The movement of the ITCZ southwards away from the equator marks the start of the main rainy season in the southern hemisphere.

Over the equatorial belt across the southwest Indian Ocean and within the influence of the ITCZ, tropical cyclones form and cause devastation in the communities, which is often quite dramatic. For instance, in 2000 the devastation caused by tropical cyclone Eline captured the attention of many due to the extensive media interest. The rain-producing westerly cloud bands rooted in the troughs emanating from mid latitude weather systems, at times pushes northwards to interact with ITCZ creating ideal conditions for widespread rains over southern Africa. This occurs more frequently in the good summer rainfall seasons.

An atmospheric anticyclone commonly referred to, as the Botswana Upper High, is disruptive of good rainfall distribution. This is a high-pressure cell generally centred over Botswana between three and six kilometers above sea level. Its frequent occurrence almost always results in drought in most countries of the region except the northeastern. In some instances, like an expanding balloon, it tends to push the rain-bearing ITCZ and active westerly cloud bands out of the region and over the Indian Ocean. This is part of the subtropical high-pressure system, which will have failed to migrate sufficiently southwards as is generally expected in the summer months.

17.4 El Niño-Southern Oscillation phenomenon

One of the major contributors to the extremes in the climate system world-wide is the El Niño-Southern Oscillation (ENSO) phenomenon. During the La Niña phase of ENSO, sea surface temperatures (SSTs) in the equatorial east Pacific Ocean up to the Ecuadorian and Peruvian coasts are colder than normal. During the El Niño phase of ENSO, the opposite is the case i.e. the equatorial east Pacific SSTs are warmer than usual. The impacts of El Niño on global scale are depicted in Fig. 17.3. Most of the countries in the SADC region experience acute food shortages due to failed agricultural production from El Niño induced droughts. These conditions are quasi-periodic. Both phases of ENSO cause disturbance to the steady global climate system. These extreme variations of the SSTs in the equatorial east Pacific Ocean occur every few years and last for approximately one year.

Empirical studies show that many regions of the global tropics and sub-tropics exhibit climate anomalies that correlate with the ENSO (Ropelewski and Halpert 1987,1989). In many regions influenced by the ENSO changes, the statistical relationships include zero and lagged correlations of sea-surface temperatures (SSTs)

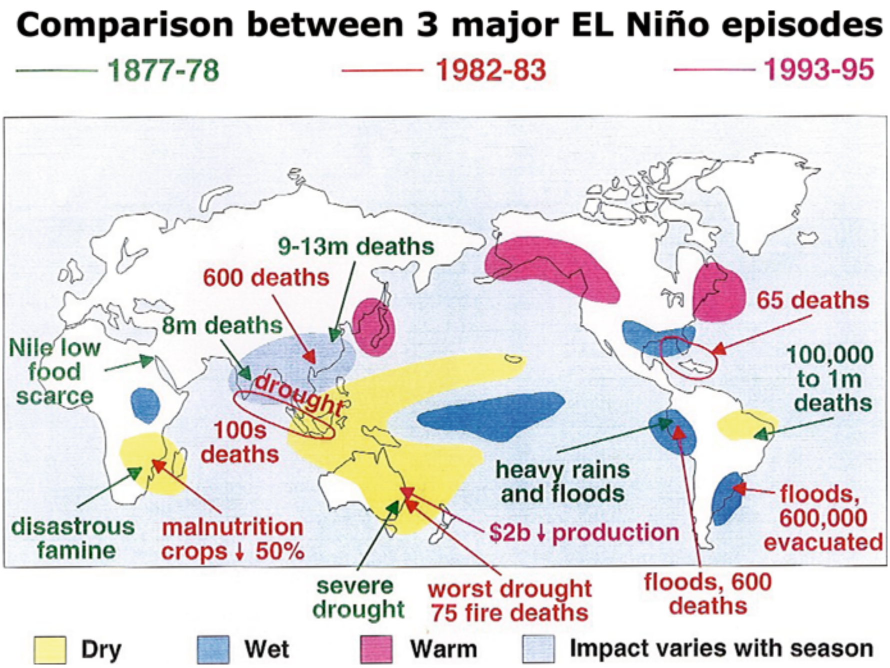


Fig. 17.3. Impacts of El Niño around the globe

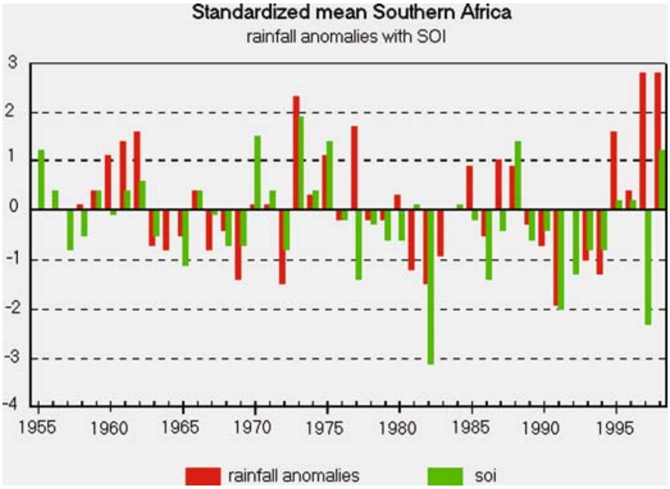


Fig. 17.4. Rainfall anomalies over southern Africa and SOI

and Southern Oscillation Index (SOI), which provide a basis for predictions. Rainfall anomalies juxtaposed on ENSO index, SOI, are shown in Fig. 17.4. Although many ENSO phases show closely timed oceanic and atmospheric responses, Deser and Wallace (1987) suggest that even El Niño and the Southern-Oscillation are not always as well linked and have occurred separately, often leading and lagging one another. Such fluctuations in ENSO could conceivably also explain failures of some correlations of ENSO with expected climatic anomalies.

17.5 Cycles of droughts in southern Africa

Droughts develop from a complex interaction of factors including land use, water management practices, weather and human activity. Extensive droughts have afflicted southern Africa from time to time, e.g. 1921-1930, 1946-47, 1965-66, 1972-73, 1982-83 and 1986-87 culminating in the most severe droughts in the period 1991-95 and 2001-02. These times were also major El-Nino years. It is important to note that the 2001/02 droughts occurred in a neutral ENSO phase that is there was neither pronounced El Niño nor La Niña. Wet years were rare during this period and drought was the norm for most of the continent. In 1981 drought was severe in the Sahel. In 1982, drought intensified and prevailed throughout much of subtropical Africa. By 1983 drought or below average rainfall affected nearly the whole continent. In southern Africa a severe drought that many describe as the worst in terms of the deficiency of rainfall and associated negative impacts ravaged the whole sub-region during 1991/92. These droughts contributed to negatively to ecosystems in the region.

The effects of drought are cross-cutting, with severe direct impacts on agriculture, water resources, and natural vegetation and indirect effects on health, and

Fig. 17.5. An example of impacts of droughts on flora and fauna in the SADC region

other sectors of the economy and institutions. The impacts of drought worsen environmental degradation, including soil erosion, water pollution, and deforestation. A single-season drought may not have a major impact on environment or livestock numbers as the latter can survive, though they may not put on weight or breed. However, a drought lasting two or three seasons, which sometimes happens, tends to more severely exhaust the available food resources, thereby decimating herds (Fig. 17.5). The 1991-92 drought, which ravaged most of southern Africa, killed more than one million cattle in Zimbabwe alone, while the 1962 drought killed nearly all the zebra in Botswana (SADC/IUCN/SARDC 1994).

Other impacts of drought are that they cause land degradation particularly of cultivated land and rangelands. There is a greater impact from wind after a long dry spell. Subsequently soil from the cultivated land is blown away. Further sheet erosion easily sets in particularly at the early stages of the rainy season. On the rangelands, there is depressed growth of vegetation. Animals tend to browse those species, which they normally do not eat. Thus, the ecosystem is greatly disturbed during drought periods. There is also concentration of animals among the few watering holes that will be available resulting in the trampling and loosening of the soil around these spots. Therefore, erosion will easily set in.

17.6 Cycles of floods over southern Africa

From historical data, southern Africa has had its share of flooding rains. Most of southern Africa gets extensive floods largely during the La Niña phase. However, flooding the northeastern parts is associated with El Niño. During 2000 floods, there was significant human suffering and infrastructural damage with bridges being broken and large sections of major roads rendered impassable across many countries in the southern portions of the subregion associated with the deluges that gripped the region. At the same time the northeasternmost areas of the subregion were reeling under drought conditions. The 1999-2001 seasons were dominated by active tropical cyclone activity, which caused considerable human suffering across parts of SADC. Tropical cyclone Eline had devastating effect in the region. Eline ravaged parts of southern Africa with the heaviest rains stretching from the bulk of southern half of Mozambique through parts of the Northern Province of South Africa into southeastern half of Zimbabwe. Over 200 mm of rains was registered within a period of less than 48 hours in many stations in the southeastern half of the Zimbabwe. Consequently people in this region experienced considerable suffering associated with flooding rains from Eline (Figs. 17.6 and 17.7). The 2000-2001 saw the southern portions registering flooding rains again although the devastation was less dramatic than the previous season. The financial costs are still to be fully assessed. Various media have shown how extensive and at times intense the calamity was.

Tropical cyclone Japhet has had its impacts over the subregion in 2003. This caused some damage in its wake. But as it weakened after landfall it also contributed to a reversal of some rainfall deficits that had affected the southeastern sections of the subregion. The other positive attribute of Japhet was contributing to recovery of some of the crops that were virtually wilting.

17.7 Climate extremes and ecosystems

Extended droughts and warmer temperatures in southern Africa lead to changes in biogeographic distributions and loss of biodiversity. Ecosystems that support a rich biological diversity and variety of trophic pathways display greater resilience to disease, pestilence and extreme environmental conditions.

Climate directly determines the nature and functioning of ecosystems. Sustained droughts and attendant higher temperatures can trigger biomal shifts and loss of terrestrial species. The perennial droughts threaten accelerated land degradation with possibility of increased aridification such that semi-arid areas are likely to become arid and dry sub-tropical areas could shift to semi-arid conditions. Permanent damage to natural wetlands is also likely to occur. Furthermore, increased temperatures, accompanied by reduced winter rainfall threaten the rare succulent flora that characterises the Sperrgebiet in Namibia, for example.

Thus, there is need for mitigating the effects of extremes in climate variability and climate change on local and regional wildlife populations and the water

Fig. 17.6. Example of gully erosion due to flooding in parts of the SADC region

Fig. 17.7. Aftermath of tropical cyclone Eline flooding in parts of Mozam-bique. (Source: Salvation Army)

resources and habitats that support them. They will require a reduction in land degradation, land clearing and other activities that cause a loss of natural habitats and ultimately increase the sensitivity of ecosystems, particularly those in arid and semi arid areas, to drought and other extreme climatic events.

Extremes in climate affect both energy production and energy consumption in the region. Due to limited hydropower output during droughts, communities will invariably supplement their energy requirements through fuelwood obtained through usually wanton deforestation. The extent of these effects is closely linked to economic development and will largely be determined by the regions future dependency on fuelwood and electricity produced from hydropower. Solar energy is currently underutilised in the region but has tremendous potential for mitigating drought induced power deficiencies.

17.8 Climate monitoring as a regional strategy to mitigate climate-related disasters and land degradation

Given the susceptibility of region to climate extremes, institutions such as the SADC Drought Monitoring Centre, under the guidance from WMO, have been established since the late 1980's in order to contribute to the mitigation of the negative impacts of drought or floods on the communities. This resulted from the realization that a regional approach was more cost-effective in dealing with large-scale phenomena such as droughts that are largely transboundary in nature. Over the years, these regional institutional structures have built partnerships with sister international institutions in order to be more effective in contributing to effective application of climate information and prediction services to the communities. SADC has been able to develop some mitigation measures to deal with impacts of extreme climate events on sustainable multisectoral socio-economic development and rational use of natural resources.

The DMC generates and disseminates important outputs such as 10-day forecast bulletins and seasonal rainfall outlooks, as a contribution to mitigation of negative impacts of extreme climatic anomalies. Consequently, many stakeholders are institutionally linked with the DMC. DMC has the responsibility of monitoring and prediction of the global and regional climate system including extreme variations in a timely manner. These extremes generally take the form of flood or drought, and whose description should be with respect to intensity, geographical extent and duration. It provides relevant early warnings for the formulation of appropriate strategies to combat adverse effects of climatic extremes. However, the level of socio-economic development in a particular country is oftentimes the limiting factor with respect to the amelioration of negative impacts of climatic extremes.

The DMC is continuing to transform itself into being a centre of excellence in climate analysis, prediction and applications with particular emphasis on the extremes across the subregion. It develops the capacity of the SADC National Meteorological/Hydrological Services (NMHSs) scientists in climate diagnosis, prediction and applications through secondment programmes. The DMC also conducts training workshops and seminars in climate analysis, prediction and applications. Through these processes the centre provides the scientists from NMHSs an opportunity to have a greater capability to:

- receive, analyse and archive global atmospheric and oceanic data needed to improve the scope and accuracy of the forecasts;

- accelerate applied research focused on climate predictability on seasonal to inter annual time scales in order to systematically produce useful climate forecasts on regional scale for several months;
- conduct systematic experimental forecasts of such climate variability and provide them to the appropriate agencies in participating countries; and
- assist participating countries in effectively using these experimental forecasts to meet their particular social and economic needs.

The development of a critical mass of climate practitioners in turn immensely benefits the users of climate services in the subregion, i.e. institutions from both public and private sectors.

17.9 Institutional linkages

Apart from the NMHSs, there are other beneficiaries of climate information and services offered by the DMC. The linkages between producers and users of climate information and products are shown in Fig. 17.8. The users can be categorised as the following decision makers:

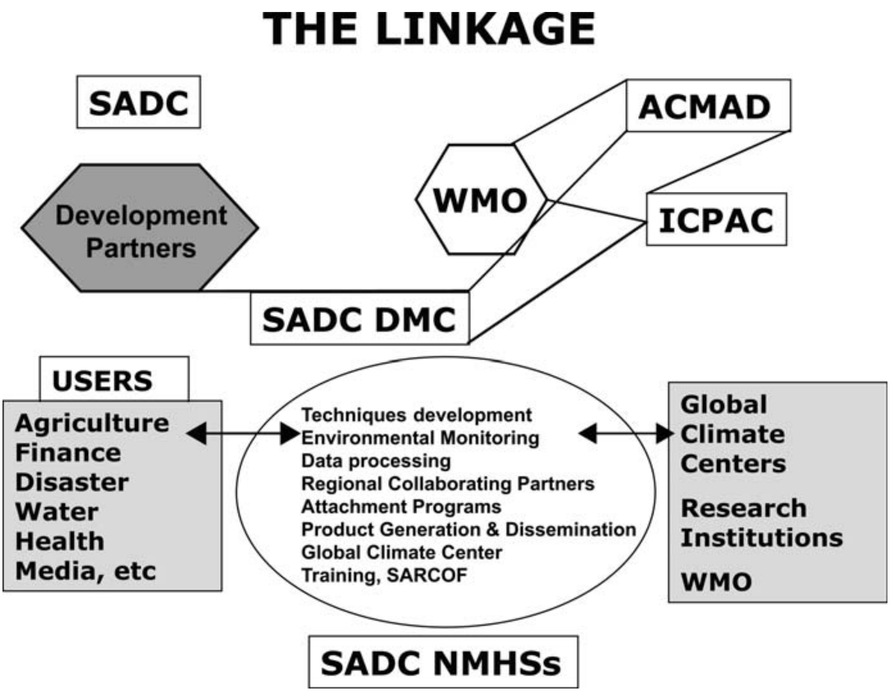


Fig. 17.8. Linkages of DMC with producers and users of climate products

17.9.1
International aid and development agencies

Information can help in determining the location and nature of greatest difficulties and the import, distribution and storage requirements for food and essential non-food commodities.

17.9.2
Government ministries and departments

Climate information is applied in policy making and strategic and tactical planning aimed at the overall national well being of individuals, consumers, and commerce and industry. Actions at Governmental level could be the optimisation of trading opportunities and control of import and exports, regulation of internal water and power supplies, strengthening of distribution systems, change of taxation and subsidies, and mitigation or adaptation to large scale potential disasters that could arise out of epidemics, seawater inundation, floods, drought and desertification.

17.9.3
Private sector

Climate information can also assist policy making in multi-sectoral matters (e.g. water for power or agricultural use). Specific measures of benefit would be increased national trade margins (or reduced gaps), reduced hazard related deaths, etc. The private sector also benefits by getting prediction products that serve as decision tools.

Sectoral interests, such as farming, forestry, fisheries, water resource management, environmental quality, energy, transport, health, leisure, retail, banking, insurance, legal, construction, urban design etc. do directly or indirectly benefit from products and other services from the DMC. The indirect benefit is through the NMHSs as the latter will have learned techniques to down-scale DMC products to country levels.

17.10
Southern African Regional Climate Outlook Forum

The Southern African Regional Outlook Forum (SARCOF) was initiated in Kadoma, Zimbabwe, in September 1997. This is part of a global effort to coordinate forecasting activities of respective regions for the benefit of the user community. Since then the Forums have brought together climate scientists, the user community and policy-makers, from SADC and other parts of Africa and from cooperating institutions in the region and overseas. This collective and inter-disciplinary process of training, technical analysis and preparedness forums to formulate appropriate

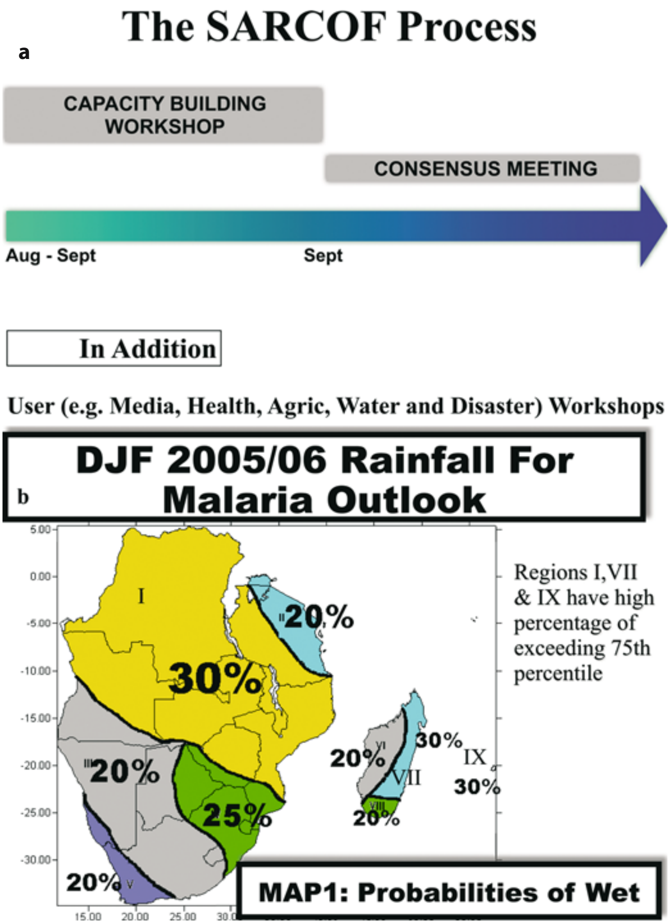


Fig. 17.9. (**a**) SARCOF process and (**b**) Malaria outlook product from SARCOF

strategies to combat the adverse effects of climate extremes on various socio-economic sectors such as agriculture, disaster management, health, water resources, media, etc.

Workshops for climate practitioners and other targeted users are held back to back with SARCOFs (Figs. 17.9a and b). Climate experts from all NMHSs of the SADC countries attend the SARCOFs. The overall objective of the workshops is to build the capacity of the SADC NMHSs in preparing and issuing seasonal forecasts in their respective countries.

The Forums also look at lessons learned from previous SARCOFs. In particular, the usability of forecasts and their verification are areas that generate interest from participants (Figs. 17.10a and b). The DMC is responsible for organizing the annual SARCOF subject to availability of funds.

The investments in capacity building and climate application activities are yielding some return. Particularly after the SARCOF processes there are greater possi-

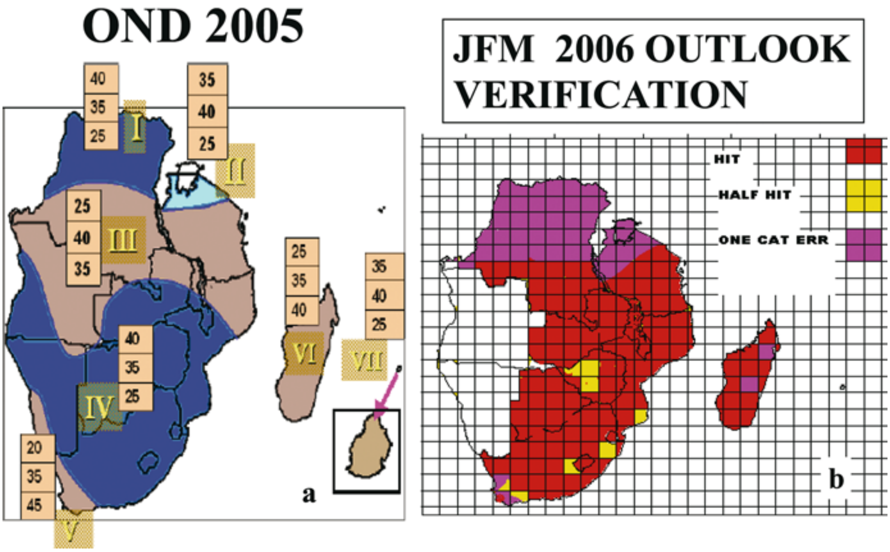


Fig 17.10 a, b. **a** Seasonal forecast product and **b** and forecast verification product samples

bilities for the application of climate information to minimize impacts of hydrometeorological disasters and to enhance potentialities to maximize production. However, the funding constraints sometimes lead to half measures being taken because there will not be adequate resources to fully implement the potential programmes to fruition. Some of the benefits are realizable long-term. Reaching affected people is itself a major challenge in the assessment of the usefulness of application of climate information by many stakeholders. SADC Member States await the outcome from the SARCOF process through their NMHSs in order to make appropriate plans.

17.11 Conclusions

Extremes in climate variability are major and recurrent problems for southern Africa. The ability of the majority to cope with such disasters is compromised by the fact that the population is predominantly rural, and is directly or indirectly dependent on rainfed agriculture. In addition, many of these people continue to live below the poverty datum line, lacking resources, access to necessary modern facilities, information and economic advantages. As such their capacity to absorb, deflect or manage potential or actual disasters is reduced. These disasters often exacerbate land degradation. Environment with its ecosystems is sensitive to climate change, especially those ecosystems which have been heavily exploited. Thus, in order to help mitigate future vulnerability, it is essential to ensure that local, regional and global policies be promoted for sustainable use of the environment free of man-made land degradation. Southern Africa is a region highly prone to a variety of hazards including drought, floods, cyclones, pest infestation, epidemics and environmental hazards, including landmines. Regional structures such as SADC have begun to prioritize disaster management by identifying human and financial resources to strengthen information sharing and for rational natural resource management. The DMC plays a key role in areas such as disaster management, land management, energy, health and other sectors. Many users, including policy makers, highly value the services and products provided by the centre. A great deal has been achieved by the DMC in informing end-users of impending droughts, floods or other climate patterns that impact negatively on agricultural production, the environment and other socio-economic sectors within the region.

References

Barry RG, Chorley RJ (1998) Atmosphere, Weather & Climate. Routeledge

DMC (Drought Monitoring Centre) (1991-2006) Southern Africa Ten Day Drought Watch Bulletin [Available from the DMC, Harare, Zimbabwe]

DMS (Department of Meteorological Services) (1981) Climate Handbook of Zimbabwe.

Deser C, Wallace JM (1987) El Niño events and their relation to the Southern Oscillation:1925-1986. J Geophy Res 92:14189-14196

Garanganga BJ (1996) Austral winter anomalous circulation patterns 1983-1993 and southern African rainfall in summer. Paper submitted for the International Conference on Tropical Climatology Meteorology and Hydrology Brussels, Belgium.

Griffiths JF (ed) (1994) Handbook of Agricultural Meteorology. Oxford University Press, Oxford, UK

Matarira CH, Unganai SL (1994) A rainfall prediction model for southern Africa based on Southern Oscillation phenomena. Technical Handbook SADC – REWU Harare, Zimbabwe.

Ropelewski CF, Halpert MS (1987) Global and regional scale precipitation patterns associated with the El Niño/Southern Oscillation. Mon Wea Rev 115:1606-1626

Ropelewski CF, Halpert MS (1989) Precipitation patterns associated with high index phase of the Southern Oscillation. J Clim 2:268-284

Riehl H (1979) Climate and Weather in the Tropics. Academic Press, Oxford, UK.

SADC(1995) SADC Statistics, Facts and Figures 1995. SADC Secretariat, Gaborone, Botswana.

SADC/IUCN/SARDC (1994) State of the Environment in Southern Africa, Southern African Development Community (SADC), IUCN-The World Conservation Union and Southern African Research and Documentation Centre (SARDC), Maseru/Harare, Zimbabwe.

Tyson PD (1986) Climate Change and Variability in Southern Africa,
Oxford University Press, Cape Town.

Wallace JM, Hobbs PV (1977) Atmospheric Science, An Introductory Survey. Academic Press, Oxford, UK

CHAPTER 18

Carbon Sequestration and Land Degradation

Alan J. Franzluebbers and Paul C. Doraiswamy

Abstract. Storing carbon (C) in soil as organic matter is not only a viable strategy to sequester CO_2 from the atmosphere, but is vital for improving the quality of soil. This presentation describes (1) C sequestration concepts and rationale, (2) relevant management approaches to avoid land degradation and foster C sequestration, and (3) a summary of research quantifying soil C sequestration. The three primary greenhouse gases (CO_2, CH_4, and N_2O) derived from agriculture have increased dramatically during the past century. Conservation management practices can be employed to sequester C in soil, counter land degradation, and contribute to economic livelihoods on farms. Trees can accumulate C in perennial biomass of above-ground and below-ground growth, as well as in the deposition of soil organic matter. Minimal disturbance of the soil surface with conservation tillage is critical in avoiding soil organic C loss from erosion and microbial decomposition. Animal manures contain 40-60% C, and therefore, application to land promotes soil organic C sequestration and provides readily-available, recycled nutrients to crops. Green manures can be used to build soil fertility, often with leguminous plant species having symbiotic root associations with nitrogen-fixing bacteria. Grasslands have great potential to sequester soil organic C when managed properly, but can also be degraded due to overgrazing, careless management, and drought leading to accelerated soil erosion and undesirable species composition. Opportunities exist to capture and retain greater quantity of C from crop and grazing systems when the two systems are integrated. Fertilization is needed to achieve production goals, but when applied excessively it can lead to environmental pollution, especially when considering the energy and C cost of manufacture and transport. Agricultural conservation management strategies to sequester CO_2 from the atmosphere into soil organic matter will also likely restore degraded land and/or avoid further land degradation.

18.1 Introduction

Land degradation is an insidious process that threatens the sustainability of agriculture, not only in the arid and semi-arid regions, but also in the sub-humid and humid regions, as a result of the loss of agro-ecosystem capacity to meet its full potential. Resulting from complex, and little understood, interactions among periodic weather stresses, extreme climatic events, and management decisions, land degradation is a serious global concern in a world searching for sustainable development to meet the needs of a rapidly increasing human population, to reverse the negative impacts of our choices on the environment in which we live, and to fairly distribute the world's resources in a socially justifiable manner.

Atmospheric concentration of radiatively active trace gases [also called greenhouse gases (GHGs)] has been increasing dramatically during the past several centuries (IPCC 2001). Several of the important GHGs in the atmosphere are derived, at least partially, from agricultural activities. Three of the most important GHGs related to agricultural activities are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). On a global scale, the relative contribution of each of these GHGs to global warming potential is depicted in Figure 18.1. Carbon dioxide accounts for almost 75% of the global warming potential of GHGs. The source of this CO_2 is dominantly from fossil fuel combustion. Since 1750, the concentration of CO_2 has increased 31%, the concentration of CH_4 has increased 151%, and the concentration of N_2O has increased 17% (Fig. 18.2). In the USA, the contribution of agriculture to GHG emission has been estimated to be only 7% of the country's total GHG emission (USDA 2004).

Global concern for the rising atmospheric concentration of GHGs is also increasing, because of the important implications of these gases on global warming. Potentially dramatic consequences of even relatively minor climate change could cause devastating weather-related occurrences, such as increased frequency and duration of droughts, more widespread and severe flooding events, greater frequency and intensity of tornadoes and cyclones, and melting of polar ice caps that could threaten abundant human civilizations along coastal continental areas. Understanding the linkages between agricultural land-use activities and GHG dynamics should help society to strengthen its resolve to avoid these potentially devastating impacts and design effective mitigation strategies to bolster ecosystem functioning and overcome human-induced land degradation.

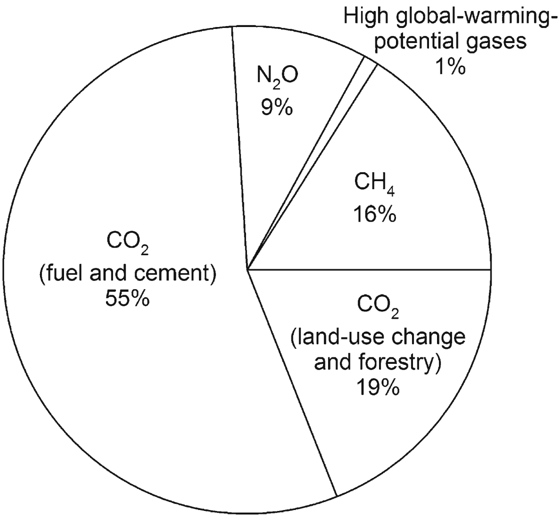


Fig. 18.1. Relative distribution of greenhouse gas emission by gas type on a global basis in 2000 (EPA 2006)

Rising concentration of atmospheric CO_2 has been largely attributed to expanding use of fossil fuels as an energy source. Reducing net GHG emission is possible by:

- Reducing fossil fuel combustion and becoming more energy efficient
- Relying more on low-C energy sources, such as
  - Capturing solar energy
  - Generating wind power
  - Harvesting biofuels
- Sequestering C

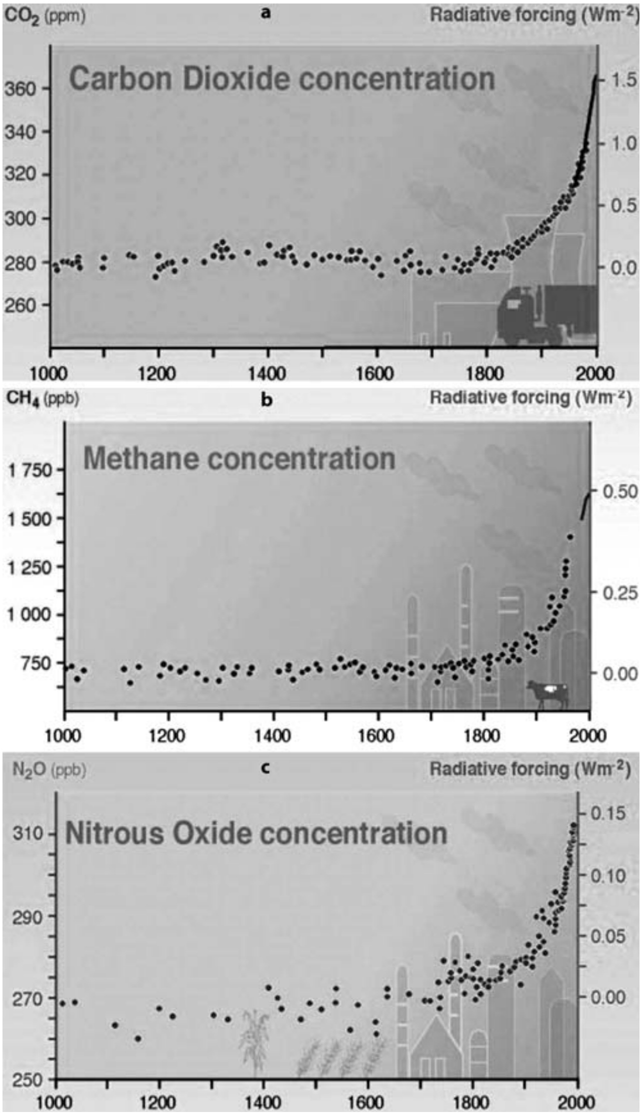


Fig. 18.2. Historical record of CO_2, CH_4, and N_2O in the atmosphere (IPCC 2001)

This paper focuses on the last option of sequestering C to reduce GHG emission. Carbon sequestration can be defined as the long-term storage of C so that the accumulation of CO_2 in the atmosphere can be reduced or slowed. Carbon sequestration can occur globally in one of several compartments:

- Terrestrial biosphere
- Underground in geologic formations
- Oceans

This paper focuses on the terrestrial biosphere, which is directly manipulated by agriculture through changes in vegetation and soil disturbance.

Carbon sequestration in the terrestrial biosphere can be accomplished by:

- Increasing the net fixation of atmospheric CO_2 by terrestrial vegetation with emphasis on enhancing physiology and rate of photosynthesis of vascular plants.
- Retaining C in plant materials and enhancing the transformation of C to soil organic matter.
- Reducing the emission of CO_2 from soils caused by heterotrophic oxidation of soil organic C.
- Increasing the capacity of deserts and degraded lands to sequester C.

Storing C in soil as organic matter is not only a viable strategy to sequester C from the atmosphere, but is also essential in improving the quality of soil. Soil organic matter plays a vital role in:

- Soil fertility, by slowly supplying nitrogen and many other essential elements and molecules to plants through mineralization/immobilization turnover.
- Water cycling, by contributing to soil aggregation and water-holding capacity.
- Soil biodiversity, by providing the C and energy sources needed for soil biological community development.
- Environmental detoxification, by supplying chemical bonds, physical support, and biological activity.
- Biogeochemical cycling, by storing and delivering many globally important elements interacting through the atmosphere, hydrosphere, lithosphere, and biosphere.

18.2 Management Approaches

The terrestrial C cycle can be simply divided into the two primary processes of photosynthetic uptake of CO_2 from the atmosphere (i.e., C input) and respiration of CO_2 from living organisms back to the atmosphere (i.e., C output). On a global scale under steady-state conditions, rates of C input and output have often been considered balanced (Schlesinger 1997). Terrestrial C sequestration efforts, therefore, must recognize the inherent balance between these processes.

Maximizing C input to the terrestrial biosphere from the atmosphere is possible in agricultural systems through a variety of management options, including:

- Plant selection, whereby large differences in photosynthetic capacity occur among species, cultivars, and varieties. Perennial plant species often have ad-

vantages over annual crops at capturing C, because of a longer growing season and more extensive root distribution (Liebig et al. 2005). However, selection of appropriate annual crops in rotation sequence can maximize growth potential under certain environments. A continuing effort has focused on cultivating high-biomass producing energy crops to maximize photosynthetic capture of CO_2 (Baral and Guha 2004).
- Tillage management, whereby the type and frequency of tillage is used to promote the most prolific plant production possible. Tillage is often used to improve the physical condition of soil so that crops can achieve maximum growth potential, but it is also a tool that disturbs soil and promotes oxidation of soil organic matter (Franzluebbers 2004).
- Fertilization management, whereby the source, rate, timing, and placement of fertilizer is used to optimize plant production potential. Sufficiently balanced and adequate nutrient supply are essential management considerations to maximize genetic potential of plants (Lal and Bruce 1999), but the high energy cost of mining and manufacturing inorganic sources of nutrients must be recognized as a source of GHG emission (Schlesinger 2000).
- Integrated management, whereby pests can be adequately controlled and environmental and socio-economic consequences of agricultural activities can be balanced with agronomic production considerations (Makumba et al. 2007).

Minimizing C loss from soil to the atmosphere has also been a major focus of agricultural research on C sequestration. Management options to minimize C loss from soil include:
- Reducing soil disturbance by less intensive tillage and erosion control (Lal et al. 1998).
- More fully utilizing available soil water, which not only promotes optimum plant growth, but also reduces the oxidative capacity of soil microorganisms to decompose soil organic matter and crop residues (Lal 2004).
- Maintaining surface residue cover to increase plant water use and production. Surface residue cover also fosters greater fungal abundance in the soil microbial community, which promotes greater stabilization of soil aggregates and resistance of soil organic C to decomposition (Nichols and Wright 2004).

In agriculture, there are many management practices that can be employed to sequester C and counter land degradation. The following sections describe some key management practices to combat land degradation. How these management practices might also contribute to soil C sequestration will be highlighted.

18.2.1 Tree Plantings

Trees can accumulate C in perennial biomass of above-ground and below-ground growth, as well as in the deposition of soil organic matter. The intentional mixing of trees or other woody perennials with agricultural crops, pastures, and/or livestock is defined as agroforestry. Agroforestry exploits the ecological and economic interactions of the different components to attain greater sustainability (Nair 1993). This section focuses on agroforestry-related changes in C accumulation rather than on natural or planted forests.

Issues of importance in agroforestry systems are:
- Climate
- Selecting adapted species
- Soil conditions
- Plant density
- Intended use
- Spatial arrangement of trees and other land uses.

The types of agroforestry practices include complex agroforestry systems, boundary plantings, hedgerow intercropping, and improved fallow (Albrecht and Kandji 2003). Carbon sequestration potential of tropical agroforestry systems has been estimated.

From plantation survey data in Australia (400-600 mm zone), mean C accumulation rate of 3.8 Mg ha^{-1} yr^{-1} occurred in the woody biomass from a variety of tree species (Fig. 18.3). In the central Philippines, C sequestration in the above-ground biomass of *Leucaena leucocephala* during 6 years of growth was estimated at 10.7 Mg C ha^{-1} yr^{-1} (Lasco and Suson 1999).

Carbon accumulation in the soil is the major sink for hedgerow intercropping systems used to produce biomass for improving soil fertility. In Nigeria, *L. leucocephala* and *Gliricidia sepium* intercropping systems sequestered 0.20 Mg C ha^{-1} yr^{-1} in the topsoil compared with sole cropping (Kang et al 1999). From two exper-

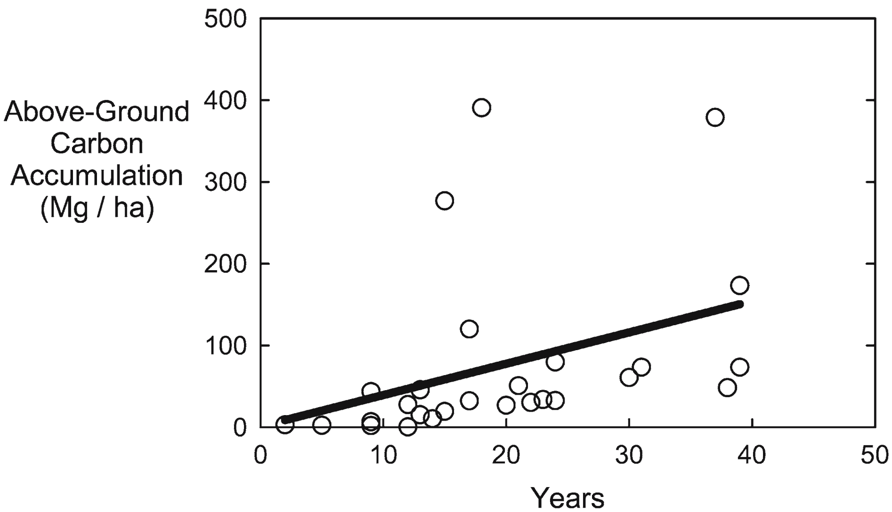


Fig. 18.3. Survey of above-ground C accumulation from a diversity of trees in Victoria, Australia (400-700 mm rainfall) as affected by stand age (Hassall and Associates Pty Ltd 1998)

iments in Malawi (6 to 9-year studies), a *G. sepium* intercropping system sequestered soil organic C at a rate of 1.2 Mg ha^{-1} yr^{-1} in the surface soil (0-20 cm), but at a rate of 6.2 to 11.7 Mg ha^{-1} yr^{-1} when calculated to a depth of 0-200 cm (Makumba et al. 2007). Deep rooting of the trees was considered a key feature of this difference in estimates. Using Century and RothC models in Sudan and Nigeria, soil organic C accumulation with tree plantings was estimated at 0.10 ± 0.05 Mg ha^{-1} yr^{-1} (Farage et al. 2007).

18.2.2 Conservation-Tillage Cropping

Minimal disturbance of the soil surface is critical in avoiding soil organic matter loss from erosion and microbial decomposition. Successful conservation-tillage cropping systems have been developed and evaluated throughout the world. As part of a system for conservation agriculture, conservation-tillage cropping can improve plant production, reduce environmental pollution, and store a greater quantity of soil organic C (http://www.fao.org/ag/ca/index.html).

Climatic conditions can influence the amount of soil organic C expected to be sequestered with adoption of conservation tillage. With more extreme dry and/or wet conditions, soil organic C sequestration tended to be highest in milder and warm-wet climatic regions of North America (Fig. 18.4). Mean soil organic C sequestration in North America is estimated at 0.33 Mg C ha^{-1} yr^{-1}. In the warm-moist climatic region of the southeastern USA, adding a cover crop to a conservation-tillage system can nearly double the rate of soil organic C sequestration due to addi-

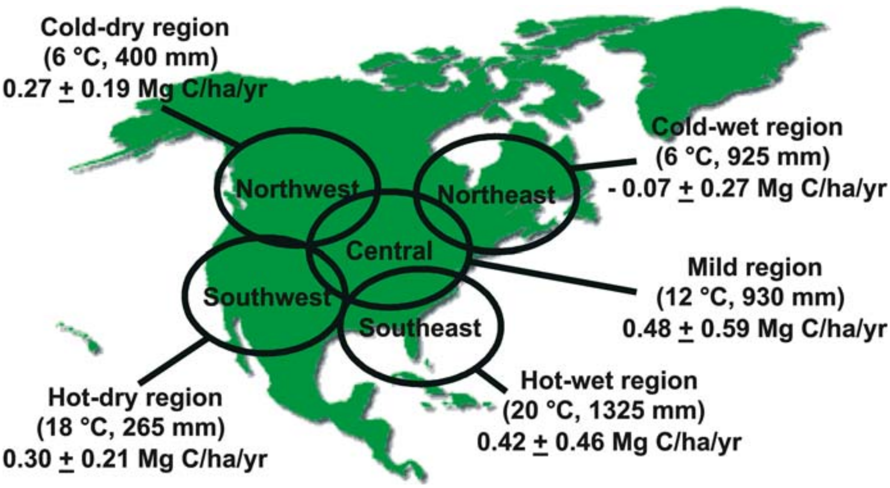


Fig. 18.4. Summary of mean ± standard deviation of soil organic C seques-tration by no tillage in different regions of North America (Franzluebbers and Follett 2005)

Table 18.1. Predicted change in soil erosion and organic C sequestration by EPIC-Century modeling during a 25-year period in Mali (Doraiswamy et al. 2007). Traditional cropping and mean crop yield from 1985-2000 included maize (1.5 Mg ha^{-1}), cotton (1.2 Mg ha^{-1}), and millet and sorghum (1.0 Mg ha^{-1})

Management	Erosion (Mg ha^{-1} yr^{-1})	Change in organic C (Mg C ha^{-1} yr^{-1})
Conventional tillage (CT)	16.5	−0.023
CT with increased fertilizer	15.0	−0.006
Ridge tillage (RT)	6.6	0.001
RT with increased fertilizer	5.9	0.027
RT with fertilizer and residues	3.5	0.086

Fertilizer inputs averaged 24 kg N ha^{-1} and 7 kg P ha^{-1} with the low level and 39 kg N ha^{-1} and 9 kg P ha^{-1} with increased fertilizer level

tional plant biomass input and better crop growth due to surface residues (Franzluebbers 2005).

Maintaining adequate surface residue cover with conservation-tillage cropping systems has also been shown to be very important for efficiently utilizing rainfall and producing adequate crop yield. From the 12th year of an irrigated wheat–maize rotation in the volcanic highlands of central Mexico, the rate of water infiltration was 18 cm h^{-1} when crop residue was removed and 90 cm h^{-1} when crop residue was retained on the soil surface with no tillage management (Govaerts et al. 2007). The change in water delivery to the soil resulted in rather dramatic changes in crop yield during the last 7 years of the study, in which maize and wheat yields were 40% greater when crop residue was retained as compared to removal of crop residues.

Using a remote sensing–crop modeling approach in Mali, Doraiswamy et al. (2007) observed that modification of traditional cropping systems to better control erosion with ridge tillage could shift agricultural production in the region from a net emitter of CO_2 to a net sink for CO_2. Combining ridge tillage with other improvements in crop management could reduce soil erosion to 20-40% of that predicted in traditional cropping systems with conventional tillage (Table 18.1).

18.2.3 Animal Manure Application

Since animal manure contains 40-60% C, its application to land should promote soil organic C sequestration. In a review of studies conducted in the southeastern USA, poultry litter application to crop and pasture lands led to significant change in soil organic C only when evaluations were conducted for more than 2 years (Table 18.2). Conversion of C in poultry litter to soil organic C was 17 $\pm$ 15% among these studies. Although soil organic C has been shown to increase with animal ma-

Table 18.2. Summary of how poultry litter application to crop and grazing land affected soil organic C in 8 published studies in the southeastern USA (Franzluebbers 2005)

Response	Soil organic C (Mg ha^{-1})	
	Without manure	With manure
2-year studies (n=6)	19.8 ± 8.9	19.6 ± 8.4
11 ± 8-year studies (n=8)	30.6 ± 11.4	36.8 ± 10.6
SOC sequestration for all (Mg ha^{-1} yr^{-1})	0.26 ± 2.15	
SOC sequestration for >2-year studies	0.72 ± 0.67	

nure application, very few whole-system data have been collected. Manure application may simply transfer C from one land to another, while investing energy in transport and handling operations. A full C accounting approach is needed to adequately assess manure application as a viable C sequestration strategy.

Other long-term studies on farmyard (FYM) application to soil have clearly shown its benefit to soil fertility, yield enhancement, and soil organic C storage. In an 18-year field experiment in Kenya (23 °C, 970 mm), soil organic C increased by 0.17 ± 0.07 Mg C ha^{-1} yr^{-1} with FYM (10 Mg ha^{-1} yr^{-1}) compared to without FYM (Kapkiyai et al. 1999). Of the C applied in FYM, 9 ± 3% was retained in soil as organic C. Crop yield with FYM (5.3 Mg ha^{-1}) was 61% greater with FYM than without FYM.

In a 45-year field experiment in Nigeria (28 °C, 1070 mm), soil organic C increased by 0.21 ± 0.01 Mg C ha^{-1} yr^{-1} with FYM (5 Mg ha^{-1} yr^{-1}) compared to without FYM (Agbenin and Goladi 1997). In this naturally P-deficient soil, total soil P increased by 12 ± 12 kg ha^{-1} yr^{-1} with FYM.

In a 30-year field experiment at Ranchi, India (23 °C, 1450 mm), soil organic C was greater with FYM (3.9 g kg^{-1}) than without FYM (3.3 g kg^{-1}) (Manna et al. 2007). Total soil N was also 17% greater with FYM than without FYM application. However, soybean and wheat yields were generally not affected by FYM application.

In a 30-year field experiment at Hawalbagh, India (1035 mm), soil organic C increased by 0.56 ± 0.02 Mg C ha^{-1} yr^{-1} with FYM (10 Mg ha^{-1} yr^{-1}) compared to without FYM (Kundu et al. 2007). Above-ground crop biomass production with FYM (6.4 Mg ha^{-1}) was 2.4 times greater than without FYM application.

In a 22-year field experiment in Italy (14 °C, 760 mm), soil organic C increased by 0.20 Mg C ha^{-1} yr^{-1} with FYM (7.5 Mg ha^{-1} yr^{-1}) compared to without FYM (Govi et al. 1992). Soil humification index increased to 60% with FYM compared to 51% without FYM.

In a 20-year study of pearl millet–wheat cropping in India (26 °C, 440 mm), soil organic C increased with increasing FYM application rate (Fig. 18.5). However as a percentage of C applied in FYM, increasing FYM application rate led to less efficient retention of C in soil (Gupta et al. 1992).

Reviewing the climatic influence of animal manure application on soil organic C storage, temperature regime appears to have a greater impact than precipitation

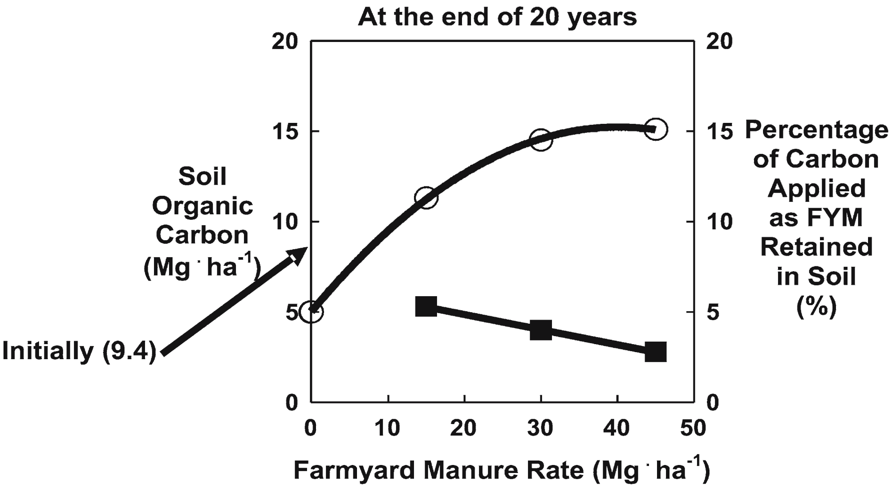


Fig. 18.5. Soil organic C as a function of farmyard manure application rate during 20 years in India (Gupta et al. 1992)

regime. Retention of C in soil was 23 ± 15% of C applied from animal manure in temperate or frigid regions, but was only 7 ± 5% in thermic regions. Moist regions retained 8 ± 4% of C applied with animal manure, while dry regions retained 11 ± 14%. These data are consistent with environmental controls on soil microbial activity and suggest that future research will require increasing acknowledgement of the linkage between climate and potential C sequestration.

18.2.4 Green-Manure Cropping Systems

Green manures are used to build soil fertility, often with plant species having the capacity to fix nitrogen from the atmosphere through root associations with nitrogen fixing bacteria. The C contained in green manure biomass following its termination can be subsequently stored in soil organic matter.

On an abandoned brick-making site in southeastern China (16.5 °C, 1600 mm), planting of ryegrass as an understory crop under China fir for 7 years resulted in soil organic C sequestration of 0.36 ± 0.40 Mg C ha^{-1} yr^{-1} (Zhang and Fang 2006). With soybean as a green manure for 8 years in Columbia (27 °C, 2240 mm), maize yield with green manure (4.2 Mg ha^{-1}) was 20% greater than without green manure (Basamba et al. 2006). Soil organic C did not change during the 8 years of green manuring, probably because of rapid decomposition caused by abundant precipitation, warm temperature, and nutritious residue quality.

At the end of 12 years of *Sesbania* green manuring in India (24 °C, 715 mm), soil organic C sequestration was 0.09 ± 0.03 Mg C ha^{-1} yr^{-1} (Singh et al. 2007). At the end of 13 years of wheat/soybean–maize cropping with and without vetch as a green-manure cover crop in southern Brazil (21 °C, 1740 mm), soil organic C sequestration was −0.30 ± 0.15 Mg C ha^{-1} yr^{-1} under conventional tillage and 0.66 ± 0.26 Mg C ha^{-1} yr^{-1} under zero tillage (Sisti et al. 2004). These data suggest that climatic conditions, green manure nutrient quality, and placement in the soil are all important considerations in affecting soil organic C change with green manuring.

18.2.5 Improved Grassland Management

Degradation of permanent grasslands can occur from accelerated soil erosion, compaction, drought, and salinization. Strategies to sequester soil organic C in grasslands must, by necessity, improve the quality of grasslands. Strategies for restoration should include:

- Enhancing soil cover
- Improving soil structure to minimize water runoff and soil erosion

Achieving a balance between agricultural harvest and environmental protection is needed (i.e., stocking density should be optimized). On an oak-grassland in central Texas USA (18 °C, 440 mm), water infiltration was highly related to percent ground cover. However, cattle stocking density played an even larger role in controlling water infiltration with time (Fig. 18.6).

Establishment of bermudagrass pasture following long-term cropping in Georgia USA (16 °C, 1250 mm) resulted in significant soil organic C accumulation during the first 8 years of management (Fig. 18.7). How forage was managed had a large impact on the rate of soil organic C accumulation during the first 5 years, e.g. soil organic C sequestration rate was 0.30 Mg C ha^{-1} yr^{-1} when forage was removed as hay, 0.65 Mg C ha^{-1} yr^{-1} when forage remained unharvested, and 1.40 Mg C ha^{-1} yr^{-1} when forage was grazed moderately to moderately heavy by cattle during the summer (Franzluebbers et al. 2001).

18.2.6 Cropland-Grazingland Rotation

Opportunities exist to capture a greater quantity of C from crop and grazing systems when the two systems are integrated, because:

- Ligno-cellulosic plant materials can be utilized by ruminant animals
- Manure is deposited directly on the land
- Weeds can be managed with management rather than chemicals

Especially when combined with conservation-tillage cropping, significant potential exists to avoid loss of soil organic C that can accumulate during a perennial pasture phase (Fig. 18.8). In Uruguay, soil erosion averaged 19 Mg ha^{-1} under conventional-tillage continuous cropping, 7 Mg ha^{-1} under conventional-tillage crop–pasture rotation, 3 Mg ha^{-1} under no-tillage continuous cropping, and <2 Mg ha^{-1} under under no-tillage crop–pasture rotation (Garcia-Prechac et al. 2004). Soil or-

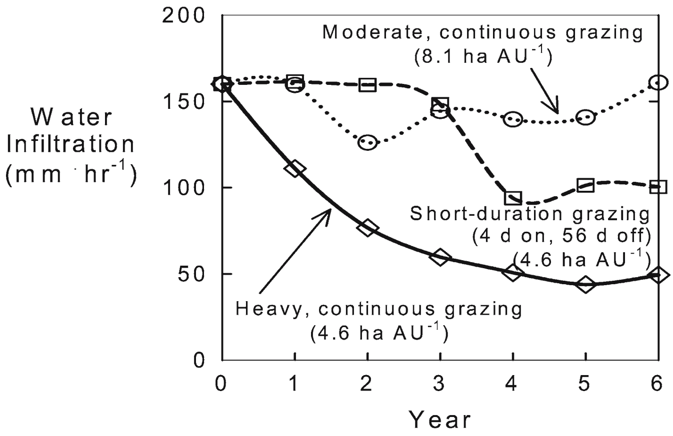


Fig. 18.6. Water infiltration as affected by long-term grazing management in an oak-grassland from Texas (Thurow et al. 1988)

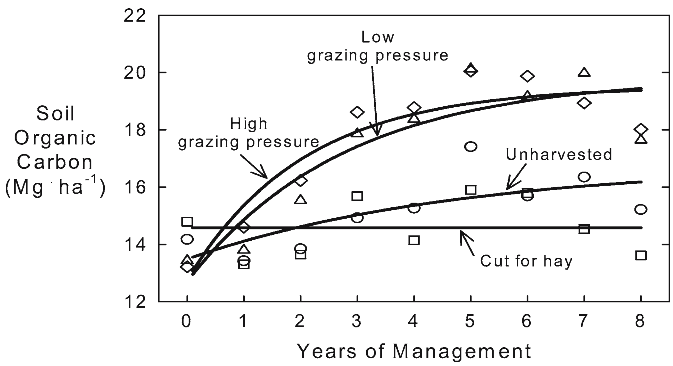


Fig. 18.7. Soil organic C as affected by 8 years of bermudagrass manage-ment in Georgia USA (Franzluebbers et al. 2001)

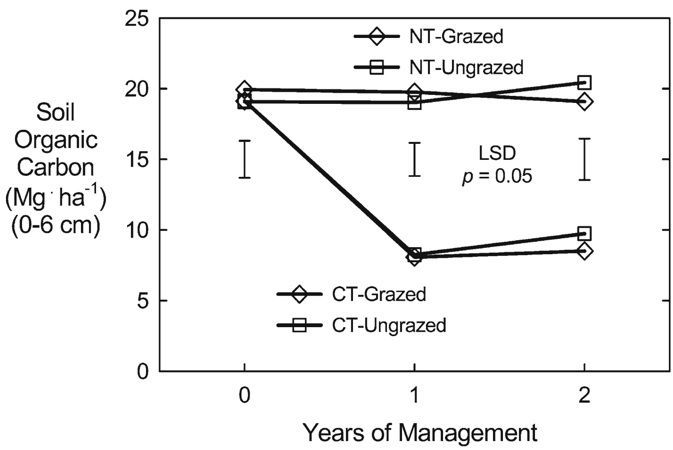


Fig. 18.8. Organic C in the surface 6 cm of soil during the first 2 years of cropping following long-term perennial pasture in Georgia (Franzluebbers unpublished data)

ganic C with crop–pasture rotation was also greater than with continuous cropping in both tillage systems. In the long-term, crop yield was enhanced with crop–pasture rotation than with continuous cropping, especially with no tillage (Garcia-Prechac et al. 2004).

In Argentina, rotations with ≤7 years of conventional-tillage cropping alternated with ≥3 years of perennial pasture were able to maintain soil organic C and other important soil properties within acceptable limits to avoid degradation (Studdert et al. 1997). Diaz-Zorita et al. (2002) found that cattle grazing in crop–pasture rotations compacted surface soil only under conventional tillage, but not under no tillage. The ability of soil to resist compaction under no tillage was attributed to greater structural stability.

In warm-moist climatic regions of the world, sufficient opportunities exist to integrate crops and livestock to achieve greater agricultural sustainability through enhanced nutrient cycling, better pest control, and diversification of agricultural enterprises (Katsvairo et al. 2006, Franzluebbers 2007).

18.2.7 Optimal Fertilization

Fertilization of crops is often needed to overcome deficiencies in nutrients supplied by soils, especially in soils exhausted by years of (a) soil erosion, (b) intensive disturbance with tillage, and (c) continuous harvest of products that remove large quantities of nutrients. On the other hand, excessive fertilization can occur when maximum agronomic prescriptions exist without regard for economic and environmental consequences. Today, the C cost of fertilization has become increasingly scrutinized (Schlesinger 1999; Izaurralde et al. 2000).

In a review of data available from the warm-moist climatic region of the southeastern USA, there was a positive response of soil organic C with the application of N fertilizer (Fig. 18.9). The mean N fertilizer rate to achieve maximum soil organ-

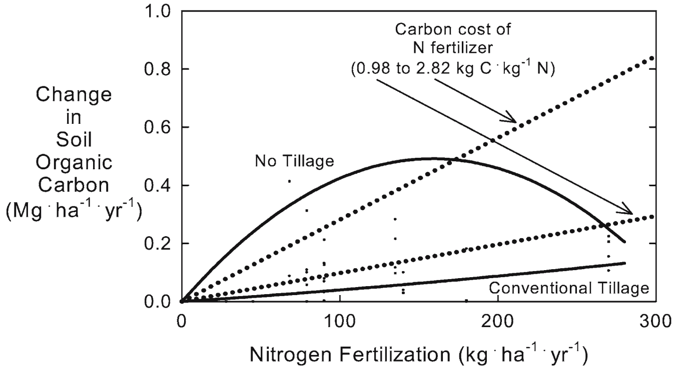


Fig. 18.9. Mean change in soil organic C as affected by N fertilizer rate in the southeastern USA (Franzluebbers 2005). Dotted lines represent the lower and upper limits of C cost of N fertilizer manufacture, distribution, and application

ic C sequestration was 171 kg N ha^{-1} yr^{-1}, within the range of values often reported to maximize plant yield. However, when considering the C cost of N fertilizer (i.e. C costs of manufacture, distribution, and application), the optimum N fertilizer rate was 107-120 kg N ha^{-1} yr^{-1} based on C costs of 0.98 to 1.23 kg C kg^{-1} N fertilizer (Izaurralde et al. 1998, West and Marland 2002). Also accounting for the global warming potential of assumed N_2O emission associated with N fertilizer application (1.586 kg C kg^{-1} N fertilizer; IPCC 1997), optimum N fertilization to maximize C offset would then be reduced to 24-37 kg N ha^{-1} yr^{-1} to achieve soil organic C sequestration of 0.07-0.11 Mg C ha^{-1} yr^{-1} (Franzluebbers 2005).

18.3 Summary and Conclusions

- Greenhouse gas concentrations in the atmosphere are increasing and the threat of global change requires our attention.
- A diversity of agricultural management practices can be employed to sequester a greater quantity of C in plants and soils. However, further research efforts are needed to:
  - Synthesize currently available data
  - Fill the gaps in our knowledge with additional, targeted research efforts
- Strategies to sequester soil C will also likely restore degraded land and avoid further degradation.

References

Agbenin JO, Goladi JT (1997) Carbon, nitrogen and phosphorus dynamics under continuous cultivation as influenced by farmyard manure and inorganic fertilizers in the savanna of northern Nigeria. Agric Ecosyst Environ 63:17-24

Albrecht A, Kandji ST (2003) Carbon sequestration in tropical agroforestry systems. Agric Ecosyst Environ 99:15-27.

Baral A, Guha GS (2004) Trees for carbon sequestration or fossil fuel substitution: The issue of cost vs. carbon benefit. Biomass Bioenerg 27:41-55

Basamba TA, Barrios E, Amézquita E, Rao IM, Singh BR (2006) Tillage effects on maize yield in a Colombian savanna oxisol: Soil organic matter and P fractions. Soil Tillage Res 91:131-142

EPA (2006) Methane to markets partnership fact sheet brochure. Available at: http://www.epa.gov/climatechange/emissions/globalghg.html

Diaz-Zorita M, Duarte GA, Grove JH (2002) A review of no-till systems and soil management for sustainable crop production in the subhumid and semiarid Pampas of Argentina. Soil Tillage Res 65:1-18

Doraiswamy PC, McCarty GW, Hunt ER Jr, Yost RS, Doumbia M, Franzluebbers AJ (2007) Modeling soil carbon sequestration in agricultural lands of Mali. Agric Syst 94:63-74

Farage PK, Ardö J, Olsson L, Rienzi EA, Ball AS, Pretty JN (2007) The potential for soil carbon sequestration in three tropical dryland farming systems of Africa and Latin America: A modelling approach. Soil Tillage Res 94:457-472

Franzluebbers AJ (2004) Tillage and residue management effects on soil organic matter. In: Magdoff F, Weil RR (eds) Soil organic matter in sustainable agriculture. CRC Press, Boca Raton FL, pp 227-268
Franzluebbers AJ (2005) Soil organic carbon sequestration and agricultural greenhouse gas emissions in the southeastern USA. Soil Tillage Res 83:120-147
Franzluebbers AJ (2007) Integrated crop-livestock systems in the southeastern USA. Agron J 99:361-372
Franzluebbers AJ, Follett RF (2005) Greenhouse gas contributions and mitigation potential in agricultural regions of North America: Introduction. Soil Tillage Res 83:1-8
Franzluebbers AJ, Stuedemann JA, Wilkinson SR (2001) Bermudagrass management in the Southern Piedmont USA: I. Soil and surface residue carbon and sulfur. Soil Sci Soc Am J 65:834-841
Garcia-Prechac F, Ernst O, Siri-Prieto G, Terra J (2004) Integrating no-till into crop-pasture rotations in Uruguay. Soil Tillage Res 77:1-13
Govaerts B, Fuentes M, Mezzalama M, Nicol JM, Deckers J, Etchevers JD, Figueroa-Sandoval B, Sayre KD (2007) Infiltration, soil moisture, root rot and nematode populations after 12 years of different tillage, residue and crop rotation managements. Soil Tillage Res 94:209-219
Govi M, Francioso O, Ciavatta C, Sequi P (1992) Influence of long-term residue and fertilizer applications on soil humic substances: A case study by electrofocusing. Soil Sci 154:8-13
Gupta AP, Narwal RP, Antil RS, Dev S (1992) Sustaining soil fertility with organic-C, N, P, and K by using farmyard manure and fertilizer-N in a semiarid zone: A long-term study. Arid Soil Res Rehabil 6:243-251
Hassall & Associates Pty Ltd (1998) Carbon sequestration in low rainfall areas: The measurement of plantations of trees in Victoria. Environment Australia, Canberra
IPCC (2001) Climate change 2001: The scientific basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change [Houghton JT, Ding Y, Griggs DJ, Noguer M, van der Linden PJ, Dai X, Maskell K, Johnson CA (eds)]. Cambridge University Press, Cambridge UK
Izaurralde RC, McGill WB, Bryden A, Graham S, Ward M, Dickey P (1998) Scientific challenges in developing a plan to predict and verify carbon storage in Canadian Prairie soils. In: Lal R et al. (ed) Management of carbon sequestration in soil. CRC Press, Boca Raton FL, pp. 433-446
Izaurralde RC, McGill WB, Rosenberg NJ (2000) Carbon cost of applying nitrogen fertilizer. Science 288:809
Kang BT, Caveness FE, Tian G, Kolawole GO (1999) Long-term alley cropping with four species on an Alfisol in southwest Nigeria – Effect on crop performance, soil chemical properties and nematode population. Nutr Cycl Agroecosyst 54:145-155
Kapkiyai JJ, Karanja NK, Qureshi JN, Smithson PC, Woomer PL (1999) Soil organic matter and nutrient dynamics in a Kenyan nitisol under long-term fertilizer and organic input management. Soil Biol Biochem 31:1773-1782
Katsvairo TW, Wright DL, Marois JJ, Hartzog DL, Rich JR, Wiatrak PJ (2006) Sod-livestock integration into the peanut-cotton rotation: A systems farming approach. Agron J 98:1156-1171
Kundu S, Bhattacharyy R, Prakasha V, Ghosh BN, Gupta HS (2007) Carbon sequestration and relationship between carbon addition and storage under rainfed soybean–wheat rotation in a sandy loam soil of the Indian Himalayas. Soil Tillage Res 92:87-95
Lal R (2004) Soil carbon sequestration to mitigate climate change. Geoderma 123:1-22
Lal R, Bruce JP (1999) The potential of world cropland soils to sequester C and mitigate the greenhouse effect. Environ Sci Policy 2:177-185
Lal R, Kimble JM, Follett RF, Cole CV (1998) The potential of U.S. cropland to sequester carbon and mitigate the greenhouse effect. Ann Arbor Press, Chelsea MI

Lasco RD, Suson PD (1999) A *Leucaena leucocephala*-based indigenous fallow system in central Philippines: The Naalad system. Int Tree Crops J 10:161-174.
Liebig MA, Johnson HA, Hanson JD, Frank AB (2005) Soil carbon under switchgrass stands and cultivated cropland. Biomass Bioenerg 28:347-354
Makumba W, Akinnifesi FK, Janssen B, Oenema O (2007) Long-term impact of a gliricidia-maize intercropping system on carbon sequestration in southern Malawi. Agric Ecosyst Environ 118:237-243
Manna MC, Swarup A, Wanjari RH, Mishra B, Shahi DK (2007) Long-term fertilization, manure and liming effects on soil organic matter and crop yields. Soil Tillage Res 94:397-409
Nair PKR (1993) An introduction to agroforestry. Kluwer Academic Publishers, Dordrecht, The Netherlands, 499 pp.
Nichols KA, Wright SF (2004) Contributions of fungi to soil organic matter in agroecosystems. In: Magdoff F, Weil RR (eds) Soil organic matter in sustainable agriculture. CRC Press, Boca Raton FL, pp 179-198
Schlesinger WH (1997) Biogeochemistry: An analysis of global change. Academic Press, London
Schlesinger WH (1999) Carbon and agriculture: Carbon sequestration in soils. Science 284:2095
Schlesinger WH (2000) Carbon sequestration in soils: Some cautions amidst optimism. Agric Ecosyst Environ 82:121-127
Singh G, Jalota SK, Singh Y (2007) Manuring and residue management effects on physical properties of a soil under the rice–wheat system in Punjab, India. Soil Tillage Res 94:229-238
Sisti CPJ, dos Santos HP, Kohhann R, Alves BJR, Urquiaga S, Boddey RM (2004) Change in carbon and nitrogen stocks in soil under 13 years of conventional or zero tillage in southern Brazil. Soil Tillage Res 76:39-58
Studdert GA, Echeverria HE, Casanovas EM (1997) Crop-pasture rotation for sustaining the quality and productivity of a Typic Argiudoll. Soil Sci Soc Am J 61:1466-1472
Thurow TL, Blackburn WH, Taylor CA Jr (1988) Infiltration and interrill erosion responses to selected livestock grazing strategies, Edwards Plateau, Texas. J Range Manage 41:296-302
USDA (2004) U.S. agriculture and forestry greenhouse gas inventory: 1990-2001. Global Change Program Office, Office of the Chief Economist, U.S. Department of Agriculture. Technical Bulletin No. 1907. 164 pp.
West TO, Marland G (2002) A synthesis of carbon sequestration, carbon emissions, and net carbon flux in agriculture: Comparing tillage practices in the United States. Agric Ecosyst Environ 91:217-232
Zhang M-K, Fang L-P (2007) Effect of tillage, fertilizer and green manure cropping on soil quality at an abandoned brick making site. Soil Tillage Res 93:87-93

CHAPTER 19

Sustainable Land Management Through Soil Organic Carbon Management and Sequestration – The GEFSOC Modelling System

E. Milne, M.F. Sessay, M. Easter, K. Paustian, and K. Killian

Abstract. Soil organic carbon (SOC) is vital for ecosystem and agro-ecosystem function. Any sustainable land management strategy should, therefore, include a consideration of long-term effects on SOC. In the future, we have the opportunity to adopt land management strategies that lead to greater C storage in the soil. However, to do so, we need consistent estimates of SOC stocks and changes under varying land use and climate change scenarios. A Global Environment Facility (GEF) project developed a generically applicable system (the GEFSOC Modelling System) for making such estimates. The system links two dynamic SOC models, designed for site scale applications (Century and RothC) and an empirical method, to spatial databases, giving spatially explicit results that allow geographic areas of change in SOC stocks to be identified. The system was developed using data from four contrasting eco-regions (The Brazilian Amazon, Jordan, Kenya and the Indian part of the Indo-Gangetic Plains). These areas were chosen, as they are located in regions previously underrepresented by soil C models. The system was then used to estimates SOC stocks and changes between 1990 and 2030 under likely land use change scenarios in each of the four regions. Losses in SOC of between 5 and 16 % were projected for each of the four areas over a 30-year period (2000–2030), driven by a range of factors including deforestation, overgrazing and conversion of grazing land to agriculture. Implications for sustainable land management and future land use policy are discussed for The Brazilian Amazon, Jordan, Kenya and the Indian Indo-Gangetic Plains.

19.1 Introduction

Soil organic carbon (SOC) is vital for ecosystem and agro-ecosystem and function is a major determinant of soil fertility and soil physical properties such as aggregate stability and water holding capacity. The loss of SOC is almost always synonymous with a loss of productivity and an increased risk of land degradation. Any sustainable land management strategy should, therefore, include a consideration of long-term effects on SOC. The management of SOC is also important because of its role in the global carbon cycle and therefore, the part it plays in the mitigation or exacerbation of atmospheric levels of greenhouse gases (GHGs).

SOC is highly sensitive to changes in land use and management, with changes from native ecosystems such as forest or grassland to agricultural systems almost always resulting in a loss of SOC. Similarly, climate change has the potential to alter SOC as changes in temperature, precipitation and carbon dioxide (CO_2) concentrations could affect net primary production (NPP), C inputs to soil and soil C decomposition rates (Falloon et al. 2007). To complicate issues, climate change is likely to act as a driver for land use change, thus further altering terrestrial C fluxes. We have the opportunity in the future to devise and adopt land use and land management strategies that lead to greater C storage in the soil, thereby improving soil fertility, minimising loss of C from soils to the atmosphere and potentially mitigating the effects of greenhouse gases (GHGs). The importance of taking this opportunity is recognised by 3 of the United Nations Environmental conventions, the UN Convention to Combat Desertification (UNCCD), the UN Framework Convention on Climate Change (UNFCCC) and the UN Convention on Biodiversity (UNCBD). However, before we can take this opportunity, we need consistent estimates of SOC stocks and future SOC stock changes under varying land use and climate scenarios.

Between 2002 and 2005, The Global Environment Facility (GEF) co-financed a project entitled 'Assessment of soil organic carbon stocks and change at national scale'. The aim of this project was to improve national assessment methodologies relating to land use options and UNFCC requirements and to support core activities of the GEF and the Intergovernmental Panel on Climate Change (IPCC) by developing and demonstrating a generic tool that quantifies the impact of land use/management and climate change scenarios on carbon sequestration in soils at the national and regional scale.

The project developed The Global Environment Facility Soil Organic Carbon (GEFSOC) modelling system.

19.2 Project Rationale and Approach

The GEF identified a need to determine how proposed large scale projects involving changes in land use and land management are likely to impact SOC in the future. This would help them to identify those projects with potential benefits in terms of C sequestration or potential dangers in terms of land degradation risk. Likewise, land use planners and policy makers working at the national and subnational scale benefit from knowing how proposed large scale land management plans may affect SOC stocks in the future. In the case of non-Annexe I countries, this can also help in the identification of projects that may be suitable for Clean Development Mechanism (CDM) funding. The GEFSOC project therefore designed a system that works at large scales namely the sub-national or national scale.

Several studies have considered SOC stocks at the plot scale (Paustian et al. 1992, 1997; Smith et al. 1997; Schlesinger and Lichter 2001). Such studies use site specific data sets to make inferences about SOC stocks and changes in relatively homogeneous conditions. Results are also site specific, limiting their wider applicability. The IPCC developed a computational method for estimating SOC stock

[1] This paper represents the view of the authors and not necessarily that of UNEP.

changes that can be used at the national and sub national scale. An updated version of the method is described in the IPCC Good Practice Guidance (GPG) for Land Use, Land Use Change and Forestry (IPCC 2004). The method computes projected net stock changes of C over a given period of time (the default period is 20 years), in a one step process. The method can use default information on climate, soil type and land use/management (tillage and productivity) held by the IPCC (a Tier 1 approach) or, if available, country specific data (a Tier 2 approach). One main drawback is that it considers the change in one step (e.g. one stock for year 1 and another for year 20), assuming a linear rate of change over the period in question.

Another drawback is that much of the data available for deriving the empirical factors in the IPCC default approach are derived from studies in North America and Europe (typically more studies are available for temperate versus tropical areas and mesic versus arid areas), which may result in bias (IPCC 2004). Consequently there are few studies applying the IPCC method to large areas in non-temperate countries. One exception is a study by Grace et al. (2004), that used a modification of the IPCC method to estimate SOC stock changes in five contrasting eco-regions including The Indo-Gantic Plains and Uraguay. This produced a robust starting point, from which stock change estimates could be made. It also allowed an analysis of the uncertainties associated with stock change estimates. The study used the stock change between years 1 and 20 to calculate an average annual C stock change rate. However such an approach does not account for possible annual fluctuations or the dynamic processes underlying SOC stock change.

A modelling approach allows estimates to be made in a manner that accounts for the underlying dynamic processes leading to SOC change. Ecosystem models, designed for site scale applications can be linked to spatial databases, giving spatially explicit results that allow geographic areas of change in SOC stocks to be identified. There are several advantages to this approach. SOC can be divided into several conceptual pools for modelling purposes, with turnover times ranging from days to centuries (Jenkinson 1990). Stock changes over relatively short timescales can, therefore, be influenced by events (such as land use change), that have occurred throughout a site's history. SOC models allow land use and land management histories to be taken into account when projecting future SOC stocks. Another advantage of a modeling approach is that it allows identification of geographic areas with potential for C release or potential for C sequestration. This can be useful for land use planners and policy makers when considering a range of different possible scenarios (Falloon et al.1998).

Over the past ten years, researchers at the Natural Resource Ecology Laboratory (NREL), USA have developed software with this approach and used it to estimate SOC stock changes at the sub-national and national scale for areas of the USA (Paustian et al. 1997). A similar approach has been used at the national scale in Europe (Falloon et al. 1998) and at the watershed scale for areas of Mexico and Cuba (Ponce Hernandez 2004). However, a need remained for a national and regional scale spatially explicit dynamic system that is generically applicable and can be applied to as wide a range of soil types, climates and land uses as possible. The GEFSOC Modelling System was developed to meet this need.

19.3 Development of the GEFSOC Modelling System

In order to make the GEFSOC system generically applicable, data from four contrasting eco-regions (The Brazilian Amazon, Jordan, Kenya and the Indian Indo-Gangetic Plains) were used. These areas were chosen for several reasons: First, the areas are currently under represented by soil organic matter models; Second, they all had relatively good availability of soils data; Third, research groups with expertise in SOC dynamics were already established in these countries. The GEFSOC Modelling system links two of the most widely used SOC models Roth-C (Coleman and Jenkinson 1996) and Century (Parton et al. 1988) and the IPCC computational method (Penman et al. 2003) to spatial databases via a GIS. RothC is a soil carbon model that accounts for the effects of soil type, temperature, moisture content and plant cover on the turnover of organic C in soils. It uses a monthly time-step to calculate total organic C and microbial biomass. SOC is split into 4 active compartments and a small amount of inert organic matter. Century is a general ecosystem model which simulates the dynamics of C, N, P and S in different plant/soil systems. Unlike Roth-C it has plant productivity, water movement, and nitrogen leaching sub-models. Both models were originally developed using temperate data sets.

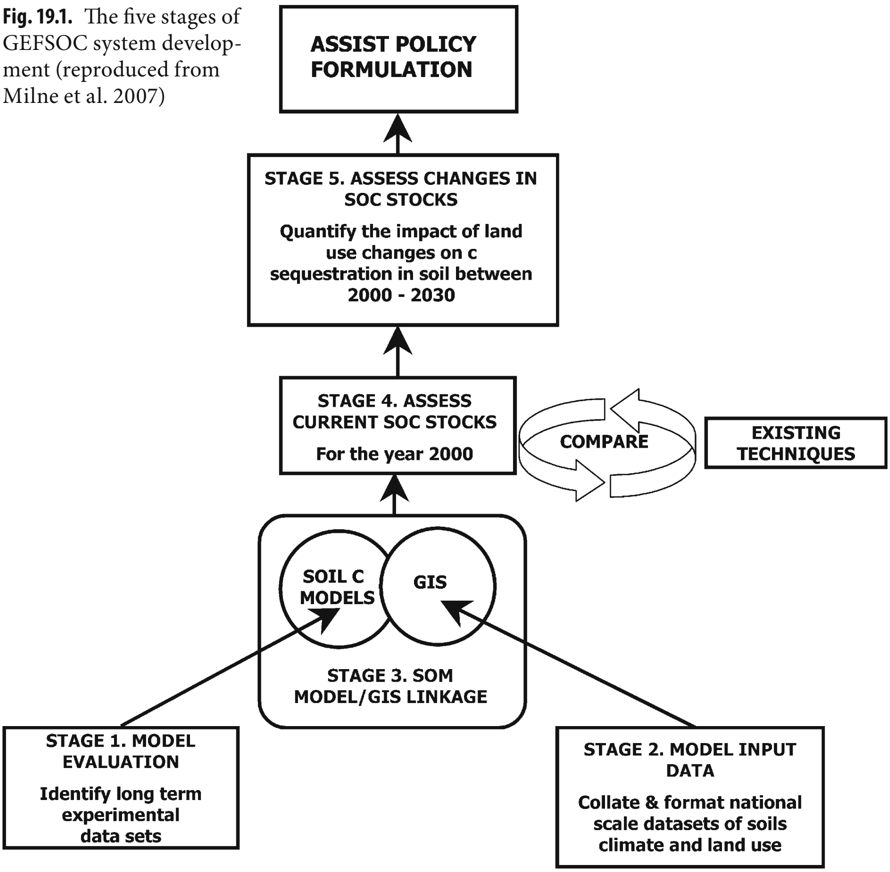
The GEFSOC System was developed in stages (Fig. 19.1). The first stage was the evaluation of the performance of the two SOC models in soil/climate and land use conditions found in the 4 case study countries. In order to do this, long-term data sets, which had repeatedly measured SOC, were needed. These were taken from long term experiments where possible and from chronosequences where this was not possible (for example in the case of the Brazilian Amazon). The models were then run and their ability to simulate these data sets assessed (Bhattacharya et al. 2007a; Cerri et al. 2007a; Kamoni et al. 2007). Modifications were then made to the models, including the addition of new and improved crop forestry and pasture files to the Century plant productivity sub-model (Easter et al. 2007).

At the same time, case study scientists collated and formatted spatially explicit national and sub-national data sets of soil, climate and land use (Stage 2). All soils data were put into SOTER (soil and terrain database) format (van Engelen 1999). In some cases, attributes needed to run the models were missing (for example bulk density). A consistent method for filling these attribute gaps, using a combination of newly collated data, expert opinion and taxotransfer rules, was developed by Batjes et al. (2007). Application of this method resulted in a complete soils database for each case study area, with all the necessary attributes needed to run the two models. Land use data included historical, current and projected future land use. These were used to build land management sequence diagrams for predetermined geographic units (for example in the case of the Brazilian Amazon for Municipios or counties). Historical and current land use was based primarily on in-country government statistics. Future land use was estimated using FAO projections of changes in cropping area and crop production (FAO 2002). This was supplemented with knowledge of future government plans and expert opinion.

Stage 3 was the development of the GEFSOC system itself which consisted of 2 primary elements, a set of program modules to run RothC, Century and the IPCC method and a graphical user interface (GUI) (Easter et al. 2007). The approach was based on research work carried out at the NREL, Colorado State University over the past 10 years. The GUI allows the user to input detailed land management information such as crop type, planting/harvest time, grazing events, fertiliser inputs etc. for all possible land uses in the area to be considered.

Stages 4 and 5 were to run the system to give estimated SOC stocks and stock changes for each case study area between the years 1990 and 2030. For stage 4, the year 2000 was used as the 'current' year, dictated by the availability of land use data. The GEFSOC system can generate output data at points in time determined by the user. The models operate on a monthly time-step and therefore produce large amounts of data. To help produce meaningful output, the user determines output years on the last page of the GUI. The system then gives SOC stocks for these years. In addition, the system carries out a regression using all data between the output years to give estimated SOC change rates. The model runs for the GEFSOC Project therefore produced SOC stocks for the years 1990, 2000 and 2030 and change rates between these years for the Brazilian Amazon, Jordan, Kenya and the Indian

Fig. 19.1. The five stages of GEFSOC system development (reproduced from Milne et al. 2007)



Indo-Gangetic Plains. As a means of determining how well our system was working, SOC stocks produced by the GEFSOC system for a base line year (1990) were evaluated against independent results obtained using 'existing' techniques, for example mapping based approaches (Batjes et al. 2007; Bhattacharya et al. 2007b; Al-Adamat et al. 2007; Cerri et al. 2007b; Kamoni et al. 2007b).

19.4 Estimated SOC Stocks and Stock Changes Between 1990 and 2030 and Implications for Sustainable Land Management

Table 19.1 shows estimated SOC stocks for the year 2000 (the 'current' stock) made using The GEFSOC System. RothC and Century make estimates for the first 20 cm of soil and the IPCC method for the first 30 cm. RothC estimates for the Indian IGP were unrealistically high and are therefore omitted. Evaluation of RothC

Table 19.1. Soil organic carbon stocks and stock change estimates for the years 2000 and 2030 made using the GEFSOC Modelling System. Source: Milne et al. (2007b)

Area	GEFSOC Modelling System outputs SOC stocks Tg C		
	Year 2000		
	RothC (0-20 cm)	Century (0-20 cm)	IPCC (0-30 cm)
Amazon Brazil	27,003	32,603	26,951
Jordan	102	66	242
Kenya	1,522	1,415	2,009
IGP, India	–	1,324	1,381
	Year 2030		
Amazon Brazil	25,004	30,431	23,391
Jordan	100	57	249
Kenya	1,308	1,311	1,975
IGP, India	–	1,265	1,381
	Estimated SOC stock change 2000 – 2030, Tg C		
Amazon Brazil	–1999	–2,172	–3,560
Jordan	–2	–9	7
Kenya	–214	–104	–34
IGP, India	–	–59	0

model runs for this area is being carried out. In general, estimates made using the GEFSOC System were in the same range as those made using more traditional map based approaches (Batjes et al. 2007).

19.4.1 The Brazilian Amazon

The Brazilian Amazon has a hot humid climate, experiencing precipitation of up to 3,000 mm yr^{-1} in some places. However, due to the vast area covered by the region (> 5 million km^2) local climate varies throughout. Two soil orders (Oxisols and Alfisols) cover approximately 75% of the area (Cerri et al. 2007). The Brazilian Amazon is dominated by comparatively recent land use change, namely the conversion of tropical forest to pasture or crop land. Approximately 80% of the area is still under native vegetation but the area also has the highest rate of deforestation in the world. An estimated 2.38 million ha were deforested throughout the Brazilian Amazon in 2002-2003 (Simon and Garagorry 2005).

The GEFSOC project used a land use change scenario for the Brazilian Amazon, for 2000-2030 that was based on deforestation rates over the past 20 years, some 60 years of agricultural census data and FAO predictions of agricultural expansion in the area. This 'business as usual' scenario, assumed a deforestation rate of 20,000 km^2 yr^{-1} with deforestation continuing to be most intensive in the southern and eastern sections of the basin. The increasing importance of soybean production as a driver of deforestation was taken into account in the scenario, with an estimated 70% of newly deforested land being cleared for soybean production by 2030 (Cerri et al. 2007b).

GEFSOC System SOC estimates for the Brazilian Amazon in the year 2000 ranged from approximately 27,000 to 32,000 Tg depending on the method used (Cerri et al. 2007b). The highest stocks were associated with native forest and well managed pasture. Between 1990 and 2030, under a scenario of continued land use conversion, Cerri et al. (2007b) estimate an overall loss of 4,200 Tg C from soils. Most of this would be associated with the loss of native forest although some losses would also result from the degradation of rangeland. Under the same scenario, small gains in SOC stocks (from 217 Tg in 1990 to 620 Tg in 2030) are projected as secondary vegetation becomes established on abandoned areas. Slow gains are also projected for well-managed pasture during the same period, however this is a long way from offsetting overall losses from soil and becomes insignificant when the large losses of C from above ground vegetation are considered (approximately 8,000 Tg, Cerri et al. 2007b).

Given the estimated losses of SOC associated with a business as usual scenario, the most obvious recommendation for future sustainable land management in the Brazilian Amazon is the cessation, or at least reduction of deforestation. Unfortunately this is unlikely to happen in the near future given current agricultural subsidies (Fearnside 2001) and the phenomenal rate of agricultural expansion that is currently occurring in the region (Sanches et al. 2005). The SOC stock changes estimated by the GEFSOC project show the long-term advantages of good pasture management. Several studies have shown that under good management, pasture can reach or even surpass SOC levels found under native forest (Cerri et al.1991; Moraes et al.1995; Neill et al.1997). Another recommendation to increase SOC stocks, should therefore, be enforcement of measures to reduce overgrazing such as minimising stocking rates and using appropriate pasture species on the 50 % plus of degraded pasture land in the Brazilian Amazon.

19.4.2
The Indian Indo-Gangetic Plains

The predominantly flat alluvial plains of the Indian IGP become increasingly humid as you travel from west to east, with precipitation ranging from 300 – 1600 mm yr^{-1} (Bhattacharya et al. 2007b). In contrast to the Brazilian Amazon, the Indian Indo-Gangetic Plains have a long history of cultivation going back hundreds of years. The area is, therefore, likely to be subject to changes in land management in the future, rather than drastic change in land use. Over the past 40 years, the Indian IGP has been dominated by a rice wheat rotation. Current land use information for the Indian IGP, gathered for the GEFSOC project shows 50 % under a rice/wheat rotation, 45 % under some form of double or triple cropping system, 1% under fallow rice, with the remainder under other systems including a small amount of natural forest (Bhattacharya et al. 2007b). The future land use change scenario used in the project assumes a diversification of cropping systems in the area in response to the fact that India is currently over producing both rice and wheat. Therefore, triple cropping systems are assumed to expand at the expense of double cropping and fallow systems.

For the year 2000, GEFSOC system estimates of total SOC stocks for the Indian IGP were approximately 1300 Tg (Bhattacharya et al. 2007b). Over 99% of the Indian IGP is cultivated with 49% under a rice wheat system. All of the multi crop systems involving rice had C stocks of approximately 30 Mg ha^{-1}. The triple crop systems had lower stocks than the double crop systems, probably due to lower crop residue returns associated with vegetable production. There are small SOC losses between 1990 and 2000 associated with conversion of pasture and forest to cropland. However, overall there is a gain in SOC during 1990–2000, associated with an increase in productivity. Between 2000 and 2030, this increase is lost and levels fell back to 1990 SOC levels. This is due mainly to the increase in triple cropping systems at the expense of rice/fallow and double cropping systems.

Output from the GEFSOC project has shown that a move to triple cropping systems involving a wider range of crops in the Indian IGP could lead to a decrease in SOC (Bhattacharya et al. 2007b). However, the levels of SOC in the double cropping rice wheat system are associated with higher productivity and an assumption of higher returns to the soil. Under continued rice/wheat, SOC increases are projected to reach equilibrium by the year 2020 in clay soils and to have already reached equilibrium by 2000 in sandy soils. Several studies have shown declining yields of rice and wheat in the IGP in recent years (Kataki et al. 2001; Pingali and Shah 2001) and sustainability of the system has been questioned (Duxbury 2001). Diversification of crops grown in the Indian IGP has the potential to reduce irrigation in the area, especially if less rice is grown. Less irrigation could reduce land degradation problems by curbing salinisation. At present, the GEFSOC Modelling System does not account for salinisation and feedback on SOC stocks, however, the system developers are hoping to address this in the future. Diversification of crops therefore appears to be a reasonable strategy in terms of sustainability, although it should be done with a mixture of double and triple cropping systems. The model runs also showed the SOC benefit of systems involving fallow. A rotation of different systems in the Indian IGP, with some involving fallow could take advantage of this benefit without reducing yields too drastically.

19.4.3 Jordan

Jordan covers a relatively small area (89,206 km^2) and has an extremely arid climate with 80% of the country being classed as desert and receiving precipitation of < 200 mm yr^{-1} (Al-Adamat et al. 2007). In recent years, sustainable land management has become a national priority as land and water resources struggle to keep up with population increase. As expected, SOC stocks in Jordan were low, reflecting the arid climate. Stocks for the year 2000 were 102 Tg and 66 Tg according to RothC and Century (Al-Adamat et al. 2007). Despite the difference between the two estimates, stock distribution between land classes was similar, with rangeland accounting for about 70%, cropland about 20% and other land uses the remaining 10%. The projected land use change scenario for Jordan saw continued overgrazing in the Badia region leading to the degradation of good rangeland. This drives SOC stock decline from the year 2000–2030 at a rate of 0.46% yr^{-1} according to the Century model. Some small increases in SOC stocks are predicted in the Jordan Valley between 2015 and 2030 due to vegetable production being replaced by banana and citrus (Al-Adamat et al. 2007). However this assumes sufficient water will continue to be available between 2015 and 2030.

Declining SOC stocks in the Jordan Badia region will have serious consequences, potentially leading to irreversible land degradation and desertification. Measures to reduce overgrazing and allow rangeland regeneration should therefore be a priority for Jordanian policy makers if existing SOC stocks are to be safeguarded. Excessive overgrazing began in the Jordanian Badia during the 1990s. Subsidies led to a massive increase in the number of sheep and goats in the region, having a detrimental effect on traditional nomadic grazing practices. National initiatives to address overgrazing problems are in place, such as rangeland management agreements with Bedouin and research into drought tolerant species (Personal communication, Badia Research and Development Centre, Safawi, Jordan). However, the problem is complex involving socioeconomic and cultural as well as environmental factors.

Land degradation in the Badia has a knock-on effect on land use in the rest of the country. The Jordanian Ministry of Agriculture cites rural to urban migration as a key problem in Jordan (MoA 2003). A growing urban population will have increased water demands, creating more competition for water resources with other sectors such as agriculture. This has implications for the SOC stocks in the heavily irrigated Jordan Valley. Experts from Jordan have argued that the production of many of the crops grown in the Jordan Valley makes no sense in economic terms or in terms of water use (Al-Weshah 2000). In general, the same products can be imported at a lower price. However, political instability in the wider region has dictated a policy of self sufficiency and unless circumstances change, Jordan is likely to continue growing heavily irrigated crops in the Jordan Valley.

19.4.4 Kenya

Of the four case studies considered, Kenya has the most complex land use (Kamoni et al. 2007). This is a reflection of the variety of climatic zones in the country that range from humid to very arid. Like Jordan, Kenya is dominated by grazing land with approximately 40% of the country being used for grazing. GEFSOC national SOC stock estimates for Kenya were approximately 1450 Tg for the year 2000. The largest C stocks were associated with grazing land as this occupies the largest area of the country. Native forest had the highest C stocks on a per ha basis (approximately 80 M ha^{-1}). Following forest, commercial agriculture and plantations had the highest per area SOC stocks reflecting higher inputs and production. Grazing lands tend to occur in the driest areas of the country where agricultural opportunities are limited. For both Jordan and Kenya, IPCC estimates made using the GEFSOC system were higher than estimates made using the two modelling methods. This was due to default land classifications being used and highlights one of the limitations of the IPCC method Tier 1 aaproach. The land use change scenario between the year 2000 and 2030 for Kenya assumed continued conversion of natural savannah to subsistence agriculture. Using this scenario, the GEFSOC system estimated a national decline in SOC stocks of approximately 100 Tg over the 30-year period.

The findings of the GEFSOC project suggest that in order to maintain SOC stocks in Kenya in the next 30 years, efforts should focus on the sustainable use of existing grazing lands and a reduction in the rate of conversion of savannah and grazing lands to subsistence agriculture. Loss of SOC would lead to an increased risk of soil erosion, a lowering of soil fertility and a lowering of the soils capacity to store water. This last point is especially important as Kenya receives rainfall in two distinct rainy seasons and water storage capacity can therefore prolong the growing season. Encouraging sustainable use of grazing lands and reducing conversion to subsistence agriculture is made difficult by Kenya's complicated land tenure system. In recent years, a sub-division of land has lead to a complex multitude of land owners and a degradation of resources. The situation is compounded by the fact that only 18% of Kenya is deemed to be high to medium potential agricultural land (Kamoni et al. 2007) and that 57% of Kenyans live below the poverty line (NEMA 2003). In such circumstances, the appropriate management of SOC is vital to ensure the sustained productivity of land in the future.

19.5 Conclusions

The GEFSOC Modelling System provides the opportunity for developing countries to use an advanced (Tier 3) inventory method, incorporating the two most widely used soil C simulation models available (Century and RothC), to improve their estimates of land use related C emissions and/or sequestration. The GEFSOC system also provides estimates using the default Tier 1 approach (the IPCC method), within the same software package. SOC stock change estimates produced for the four case areas in this project all showed a general decline in SOC if current land use trends continue. These estimates can help in the formulation of national GHG inventories and in the identification of SOC enhancing land management activities in specific soil/climate combinations in each case study area. The GEFSOC System is available to anyone wishing to use it for research, educational or planning purposes from http://www.nrel.colostate.edu/projects/gefsoc-uk/.

Acknowledgements

The project "Assessment of Soil Organic Carbon Stocks and Change at National Scale" was co-financed by the GEF (GFL-2740-02-4381), implemented by UNEP, and coordinated by the University of Reading, UK. Model development was lead by The Natural Resource Ecology Laboratory, USA. The project was carried out by a consortium of partners from Austria, Brazil, France, India, Jordan, Kenya, the Netherlands, the United Kingdom and the USA with supplemental funding from a wide range of sponsors (see http://www.nrel.colostate.edu/projects/gefsoc-uk/ for details).

References

Al-Adamat R, Rawajfih Z, Easter M, Paustian K, Coleman K, Milne E, Falloon P, Powlson DS (2007) Projected soil organic carbon stocks and changes in Jordan between 2000 and 2030. In: Milne E, Powlson DS, Cerri C (Eds.) Soil carbon stocks at regional scales. Agric Ecosyst Environ 122(1) 34-45.

Al-Weshah RA (2000) Optimal use of irrigation water in the Jordan Valley: A case study. Water Resour Manag 14:327-338

Batjes NH, Al-Adamat R, Bhattacharyya T, Bernoux M, Cerri CEP, Gicheru P, Kamoni P, Milne E, Pal DK, Rawajfih Z (2007) Preparation of consistent soil data sets for modelling purposes: secondary SOTER data for four case study areas.In: Milne E, Powlson DS, Cerri C (Eds.), Soil carbon stocks at regional scales. Agric Ecosyst Environ 122(1) 26-34.

Bhattacharyya T, Pal DK, Easter M, Williams S, Paustian K, Milne E, Chandran P, Ray SK, Mandal C, Coleman K, Falloon P, Powlson DS, Gajbhiye KS (2007a) Evaluating the Century model using long-term fertiliser trials in the Indo-Gangetic Plains, India. In: Milne E, Powlson DS, Cerri CEP (Eds.), Soil carbon stocks at regional scales. Agric Ecosyst Environ 122(1) 73-83.

Bhattacharyya T, Pal DK, Gajbhiye KS, Chandran P, Ray SK, Mandal C, Easter M, Paustian K, Williams S, Killian K, Coleman K, Falloon P, Powlson P, Batjes NH, Milne E (2007b)

Predicted soil organic carbon stocks and changes in the Indo-Gangetic Plains, India during 1980 to 2030. In: Milne E, Powlson DS, Cerri C (Eds.) Soil carbon stocks at regional scales. Agric Ecosyst Environ 122(1) 84-94.

Cerri CC, Volkoff B, Andreux F (1991) Nature and behaviour of organic matter in soils under natural forest and, after deforestation, burning and cultivation, near Manaus. Forest Ecol Manag 38:247-257.

Cerri CEP, Easter M, Paustian K, Killian K, Coleman K, Bernoux M, Falloon P, Powlson DS, Batjes NH, Milne E, Cerri CC (2007a) Simulating SOC changes in 11 land use change chronosequences from the Brazilian Amazon with RothC and Century models. In: Milne E, Powlson DS, Cerri CEP (Eds.), Soil carbon stocks at regional scales. Agric Ecosyst Environ 122(1) 46-57.

Cerri CEP, Easter M, Paustian K, Killian K, Coleman K, Bernoux M, Falloon P, Powlson DS, Milne E, Cerri C (2007b) Projected soil organic carbon stocks and changes in the Brazilian Amazon between 2000 and 2030. In: Milne E, Powlson DS, Cerri C (Eds.) Soil carbon stocks at regional scales. Agric Ecosyst Environ 122(1) 58-72.

Coleman K, Jenkinson DS (1996) RothC-26.3 –A model for the turnover of carbon in soil. In: Powlson DS, Smith P, Smith JU (eds.) Evaluation of Soil Organic Matter Models. NATO ASI Series, Vol. 138.

Duxbury JM (2001) Long – term yield trends in the rice – wheat cropping system: results from experiments and Northwest India. In: Kataki PK (Ed.) The rice-wheat cropping systems of South Asia: trends, constraints, productivity and policy. Special Issue J Crop Prod 3:27–52

Easter M, Paustian K, Killian K, Feng T, Williams S, Milne E, Al-Adamat R, Bhattacharyya T, Cerri CEP, Kamoni P, Coleman K, Powlson DS, Falloon P (2007) The GEFSOC soil carbon modelling system: a tool for conducting regional-scale soil carbon inventories and assessing the impacts of land use change on soil carbon. In: Milne E, Powlson DS, Cerri C (Eds.) Soil carbon stocks at regional scales. Agric Ecosyst Environ 122(1) 13-25.

FAO (2002) World agriculture: towards 2015/2030. Food and Agriculture Organization of the United Nations, Rome, Italy

Falloon PD, Smith P, Smith JU, Szabó J, Coleman K, Marshall S (1998) Regional estimates of carbon sequestration potential; linking the Rothamsted carbon model to GIS databases. Biol Fert Soils 27:236-241

Falloon P, Jones CD, Cerri CE, Al-Adamat R, Kamoni P, Bhattacharya T, Easter M, Paustian K, Killian K, Coleman K, Powlson D, Milne E (2007) Climate change and its impact on soil and vegetation carbon storage in Kenya, Jordan, India and Brazil. In: Milne E, Powlson DS, Cerri CEP (Eds.) Soil carbon stocks at regional scales. Agric Ecosyst Environ (*In press*).

Fearnside PM (2001) Soybean cultivation as a threat to the environment in Brazil. Environ Conserv 28:23-38

Grace PR, Antle J, Aggarwal PK, Andren O, Ogle S, Conant R, Longmire J, Ashkalov K, Baethgen W, Valdivia R, Paustian K, Davidson J (2004) Assessment of the costs and enhanced global potential of carbon sequestration in soil, International Energy Agency, IEA/CON/03/95, Cheltenham, UK.

IPCC (2004) Good Practice Guidance for land Use, Land-Use Change and Forestry. Penman J, Gytarsky M, Hiraishi T, Krug T, Kruger D, Pipatti R, Buendia L, Miwa K, Ngara T, Tanabe K, Wagner F (Eds.). Intergovernmental Panel on Climate Change/IGES, Hayama, Japan.

Jenkinson DS (1990) The turnover of organic carbon and nitrogen in soil. Philos T R Soc B 329:361-368

Kamoni PT, Gicheru PT, Wokabi SM, Easter M, Milne E, Coleman K, Falloon P, Paustian K, Killian K, Kihanda FM (2007a) Evaluation of two soil carbon models using two Kenyan long term experimental datasets. In: Milne E, Powlson DS, Cerri CEP (Eds.) Soil carbon stocks at regional scales. Agric Ecosyst Environ 122(1) 95-104.

Kamoni PT, Gicheru PT, Wokabi SM, Easter M, Milne E, Coleman K, Falloon P, Paustian K (2007b) Predicted soil organic carbon stocks and changes in Kenya between 1990 and

2030. In: Milne E, Powlson DS, Cerri CEP (Eds.) Soil carbon stocks at regional scales. Agric Ecosyst Environ 122(1) 105-113.

Kataki PK, Hobbs P, Adhikary B (2001) The rice-wheat cropping systems of South Asia: trends, constraints and productivity – a prologue. In: Kataki PK (Ed.) The rice-wheat cropping systems of South Asia: trends, constraints, productivity and policy. Special Issue J Crop Prod 3:1-26

Milne E, Al-Adamat R, Batjes NH, Bernoux M, Bhattacharyya T, Cerri CC, Cerri CEP, Coleman K, Easter M, Falloon P, Feller C, Gicheru P, Kamoni P, Killian K, Pal DK, Paustian K, Powlson D, Rawajfih Z, Sessay M, Williams S, Wokabi S (2007a) National and sub national assessments of soil organic carbon stocks and changes: the GEFSOC modelling system. In: Milne E, Powlson DS, Cerri CEP (Eds.) Soil carbon stocks at regional scales. Agric Ecosyst Environ 122(1) 3-12.

Milne E, Paustian K, Easter M, Sessay M, Al-Adamat R, Batjes NH, Bernoux M, Bhattacharyya T, Cerri CC, Cerri CEP, Coleman K, Falloon P, Feller C, Gicheru P, Kamoni P, Killian K, Pal DK, Powlson D, Williams S, Rawajfih Z (2007b) An increased under standing of soil organic carbon stocks and changes in non-temperate areas: national and global implications. In: Milne E, Powlson DS, Cerri CEP (Eds.) Soil carbon stocks at regional scales. Agric Ecosyst Environ 122(1) 125-136.

MoA (2003) The National strategy for agricultural development, 2000 – 2010. The Jordanian Ministry of Agriculture, Amman, Jordan.
(available from: www.moa.gov.jo.html/strat/strategic_eng/AS-111-BG.htm)

Moraes JL, Cerri CC, Melillo JM, Kicklighter D, Neill C, Skole DL, Steudler PA (1995) Soil carbon stocks of the Brazilian Amazon basin. Soil Sci Soc Am J 59:244 – 247

Neill C, Melillo J, Steudler PA, Cerri CC, Moreas JFL, Piccolo MC, Brito M (1997) Soil carbon and nitrogen stocks following forest clearing for pasture in south western Brazilian Amazon Ecol Appl 7:1216-1225

Parton WJ, Stewart JWB, Cole CV (1988) Dynamics of C, N, P and S in grassland soils: a model. Biogeochemistry 5:109-131.

Paustian K, Levine E, Post WM, Ryzhova IM (1997) The use of models to integrate information and understanding of soil C at the regional scale. Geoderma 79:227-260.

Paustian K, Parton WJ, Persson J (1992) Modelling soil organic matter in organic amended and nitrogen fertilised long term plots. Soil Sci Soc Am J 56: 476-488

Penman J, Gytarsky M, Hiraishi T, Krug T, Kruger D, Pipatti R, Buendia L, Miwa K, Ngara T, Tanabe K, Wagner F (eds) (2003) Good Practice Guidance for Land Use, Land-Use Change and Forestry. IPCC National Greenhouse Gas Inventories Programme, Technical Support Unit, C/o Institute for Global Environmental Strategies, 2108 -11, Kamiyamaguchi, Hayama, Kanagawa, Japan, http://www.ipcc-nggip.iges.or.jp/

Pingali PL, Shah M (2001) Policy re-direction for sustainable resource use: the rice – wheat cropping systems of the Indo-Gangetic Plains. In: Kataki PK (Ed.) The rice-wheat cropping systems of South Asia: trends, constraints, productivity and policy. Special Issue J Crop Prod 3:103-118

Ponce-Hernandez R (2004) Assessing carbon stocks and modelling win-win scenarios of carbon sequestration through land use change. FAO Report, ISBN 92-5-105158-5, Rome, Italy

Sanches AC, Michellon E, Roessing AC (2005) Os limites de expansão da soja. Rev Econ 9:1-21

Schlesinger WH, Lichter J (2001) Limited carbon storage in soil and litter of experimental forest plots under increased atmospheric CO2. Nature 411:466-469

Simon MF, Garagorry FL (2005) The expansion of agriculture in the Brazilian Amazon. Environ Conserv 32:203-212.

Smith P, Powlson DS, Smith JU, Elliot TE (Eds.) (1997) Evaluation and comparison of soil organic matter models using long-term datasets. Special Issue of Geoderma 81:1-255

van Engelen VWP (1999) SOTER: The World Soils and Terrain Database. In: Sumner ME (Ed.) Handbook of Soil Science. CRC Press, Boca Raton, pp. H19-28.

Seasonal Variation of Carbon Dioxide, Rainfall, NDVI and it's Association to Land Degradation in Tanzania

Juliana J. Adosi

Abstract. In recent years there has been global concern over extreme weather events like droughts and floods which are linked to climate change. This concern has arisen from both observed and modeling studies that have indicated a possible climate change. Carbon dioxide which is principally linked to climate change, is a green house gas that has been blamed to be the driving force. However extreme weather events have been observed to cause land degradation in different parts of the globe. While studies on global scale show a significant increase in CO_2 resulting in global warming and hence climate change, few regional studies have been carried out to demonstrate changes at the regional level. In this study trends and variability of CO_2, rainfall and NDVI over Tanzania were investigated to find out their association with land degradation.

Results reveal that CO_2 exhibits a bimodal distribution, with a maximum in March and December, while minimum values are observed in January and May. This pattern can be associated with the annual cycle of vegetation cover. During maximum CO_2 season, the land is bare and thus subjected to land degradation. NDVI showed a maximum in May and January/December for areas with bimodal rainfall and March/April for areas with unimodal rainfall. NDVI showed a minimum in March and October for bimodal areas and September/October for unimodal areas. A decreasing trend in NDVI is evident in most stations in different seasons over the country. This is a signal for land degradation and should be arrested. Rainfall, a very important factor in environmental sustainability, has proved to be decreasing in different seasons over the country. As it decreases it leaves the land dry, hinders vegetation and other hydro related factors. Decreased rainfall results in dry soil, decreased vegetation and hence land degradation. Excessive rainfall also contributes to land degradation by washing away loose and exposed soil in some parts of the country by floods. There is a need to arrest this situation for better land use.

20.1 Introduction

Over the recent decades many parts of the world have experienced a high frequency of extreme weather events such as floods and droughts. These extreme anomalies in weather systems has been linked with climate change. The main indicator of climate change has been the rise in global temperature which has principally been linked with increase of carbon dioxide in the atmosphere. Carbon dioxide (CO_2), being a green house gas, plays a major role in the energy balance of the earth's atmosphere. It transmits short wave radiation while absorbing out going long wave radiation. Instrumental records indicate an increase of 0.3-0.6 °C in global mean surface temperature over the last 100 years (IPCC 1992; 1995; 2001). A study on the space and time characteristics of minimum and maximum temperatures over Tropical East Africa indicated a positive trend (King'uyu 1994; King'uyu et al. 2000). Scenarios of climate change (Hyera and Matari 1996) and trends and variability of surface temperature over Tanzania (Adosi 2002) also showed similar patterns.

Rise in global temperature may cause the melting of glaciers and polar ice caps which will lead to sea level rise. This may submerge islands and lowlands resulting in displacements that may interfere with clean water resources and food shortage. Health problems like increases in malaria cases also arise because of warm climate, which favors breeding places for vectors. Excessive rainfall may favor breeding places for hostile insects like Nairobi fly as is evident by their increase during the 1997/98 El Niño rains. Outbreaks of other related waterborne diseases like cholera and diarrhoea may reach such a level that the medical personnel may not be able to cope with. Climate change may impact on the ecosystem by the extinction of the present plant and animal species and emergence of new hostile species. There may be changes in the weather patterns such as a shift in the rainfall seasons resulting in extreme weather events like floods and droughts which will cause land degradation. Exposed mountain peaks due to the melting of the ice caps will make them susceptible to land degradation through wind and rainfall erosion.

While there have been studies on the trend in CO_2, NDVI and rainfall, few studies have addressed their seasonal variations and association with land degradation.

20.2 Objective

The main objective of the study is to examine the seasonal variation of CO_2, rainfall, NDVI and their association with land degradation in Tanzania.

For this purpose, the following patterns were studied:
- Annual and seasonal variations of CO_2
- Time series and seasonal variations of NDVI and rainfall
- The association between the above and land degradation

Distribution of stations in Tanzania for Rainfall and NDVI is shown in Figure 20.1.

Apart from having two significant rainfall systems, some parts of the country close to the lakes are influenced by the great lakes i.e. Lake Victoria, Tanganyika and Nyasa. The northern part of the country experiences bimodal type of rainfall distribution with Kigoma, Tabora, Dodoma and Morogorro being in the transition zone. The southern part of the country has unimodal type of rainfall distribution i.e. Songea, Mbeya, Iringa and Mtwara.

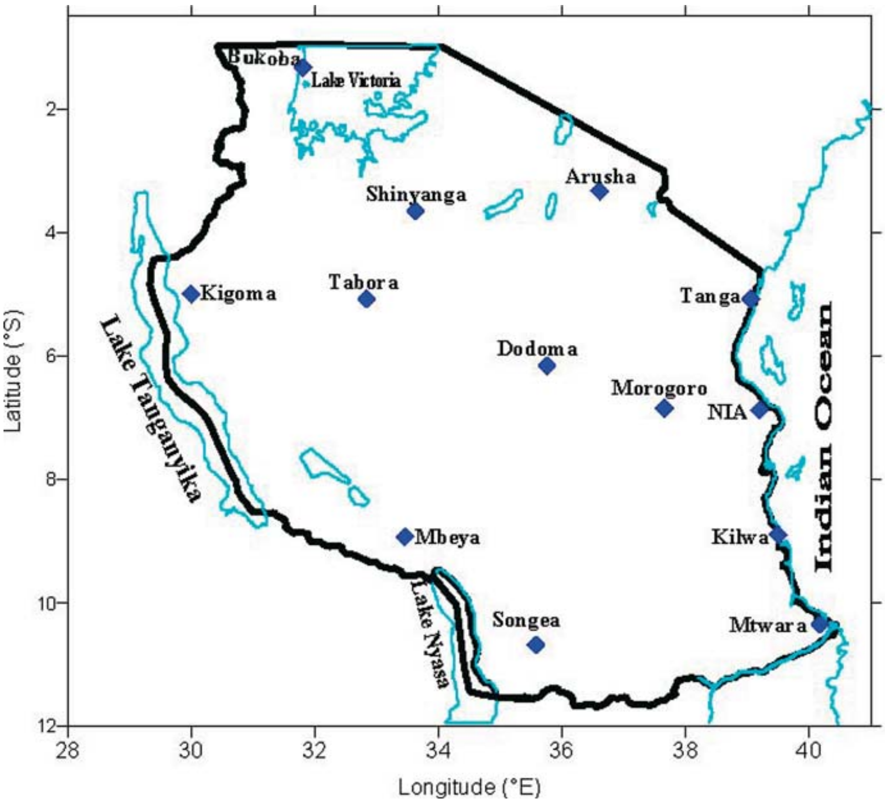


Fig. 20.1. Distribution of stations in Tanzania for Rainfall and NDVI

20.2 Data and Methodology

Mean monthly data of CO_2 for Mahe (Seychelles) which is the CO_2 baseline station, NDVI from DMC Harare, and rainfall from Tanzania Meteorological Agency were used in this study. The data were subjected to standard statistical methods of time series analysis, which included trend and spectral analysis. The study was carried out on monthly, seasonal and annual time scales.

20.3 Results and Discussion

20.3.1 Monthly NDVI (1982-2005)

As shown in Figure 20.2, the NDVI shows high values in May / December when the land has maximum foliage cover after the long/short rains in areas with bimodal rainfall distribution i.e. Musoma, Bukoba, Arusha, Tanga and Dar es Salaam. In areas with unimodal rainfall distribution i.e. Kigoma, Tabora, Dodoma, Morogoro, Songea, the high values in NDVI were observed in March/April which is the period of maximum foliage cover.

Due to variations in rainfall, seasonal analysis of NDVI in the country shows that the vegetation index decreases and increases in some stations. A significant decrease has been noted in Tabora SON with an R^2 of 0.6446 (Fig. 20.3). Arusha and Dodoma show a negative trend in all seasons (Table 20.1). This signifies a decrease in rainfall or deforestation and grazing is dominant in these regions. With a reduction of vegetation, the consumption of CO_2 is reduced which leads to accumulation of CO_2 in the atmosphere.

20.3.2 Tabora Rainfall

Rainfall time series at Tabotra (Fig. 20.4) show that rainfall is increasing in some parts of the country while NDVI is decreasing in Shinyanga, Morogoro, Mbeya, Tabora, which may be due to:

- Deforestation
- Overgrazing
- Forest fires and deliberate fires for clearing farms
- Only Songea has positive trend in NDVI and rainfall in MAM and JJA.
- Tanga and Kigoma have a decrease in rainfall but an increase in NDVI in December to February, March-May and June-August (Tables 20.1 and 20.2), as this area has thick forests which are fed by water from underground sources.

20.3.3 Deforestation, forest fire, over grazing, floods and droughts in Tanzania

Most of the farmers in the country use fire to clear their farms after cutting down the trees and other ecological structures (Figure 20.5). Some parts of the country are prone to drought e.g. central part of the country (Dodoma) and overgrazing (Figure 20.6) which makes the land susceptible to land degradation. This leaves the land exposed and the loose soil is blown by wind (Figure 20.7a). With heavy rains, the remaining soil is washed away thus forming gullies (Figure 20.7b) and hence land degradation.

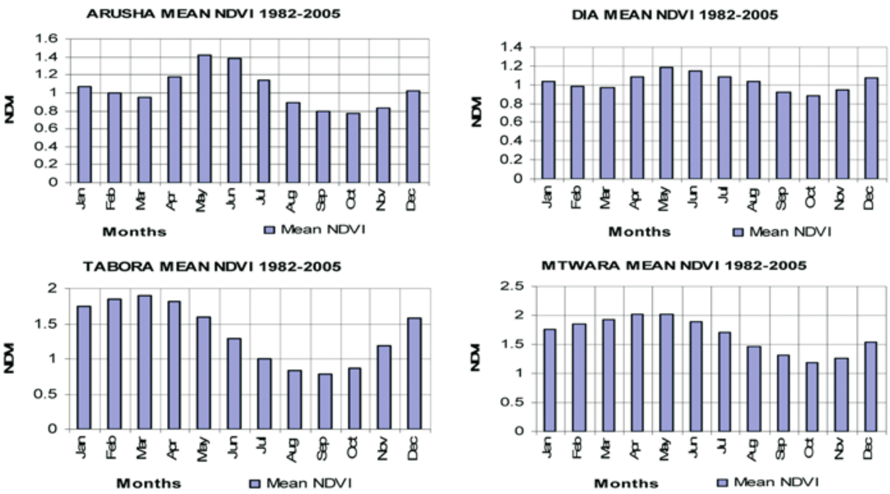


Fig. 20.2. Seasonal patterns in mean NDVI at selected locations in Tan-zania

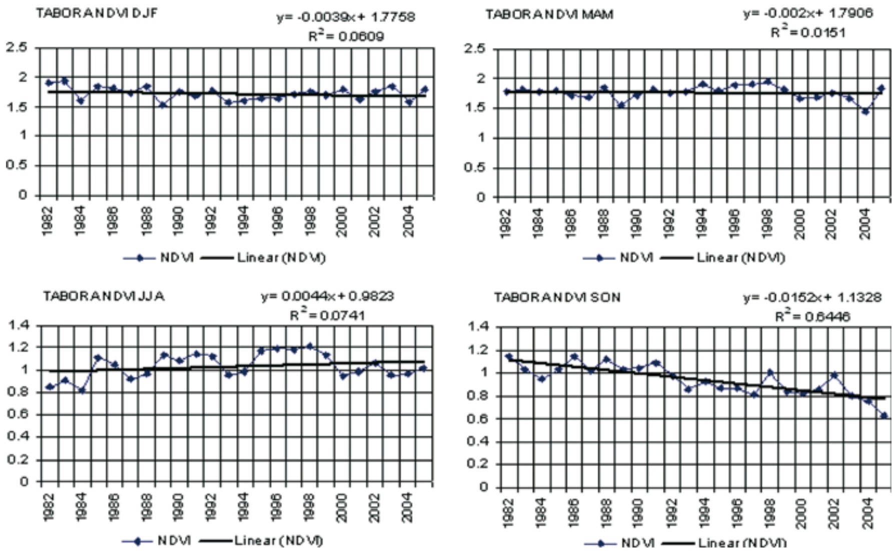


Fig. 20.3. Trends in NDVI at Tabora during different seasons (DJF: December, January, February; MAM: March, April, May; JJA: June, July, August; SON: September, October, November)

Table 20.1 Trends in NDVI at selected stations

Station	DJF	MAM	JJA	SON	SON R^2
Bukoba	–	+	–	–	0.089
Shinyanga	–	–	+	–	0.365
Arusha	–	–	–	–	0.038
Kigoma	+	+	+	–	0.243
Tanga	+	+	+	–	0.034
Tabora	–	–	+	–	0.645
Dodoma	–	–	–	–	0.015
Morogoro	–	–	+	+	0.013
Dia	–	+	+	–	0.009
Mbeya	–	–	+	–	0.018
Kilwa	–	+	+	+	0.019
Songea	–	+	+	–	0.063
Mtwara	–	+	+	–	0.006

DJF: December, January, February; MAM: March, April, May; JJA: June, July, August; SON. September, October, November

Table 20.2 Rainfall trends at selected stations

Station	DJF	MAM	JJA	SON
Bukoba	–	–	–	–
Shinyanga	+	+	+	–
Arusha	+	–	–	–
Kigoma	–	–	–	–
Tanga	–	–	–	–
Tabora	+	+	+	–
Dodoma	+	–	–	–
Morogoro	+	+	–	–
Dia	+	–	–	–
Mbeya	+	+	+	–
Kilwa	–	+	+	+
Songea	–	+	+	–
Mtwara	–	–	–	+

DJF: December, January, February; MAM: March, April, May, JJA: June, July, August; SON. September, October, November

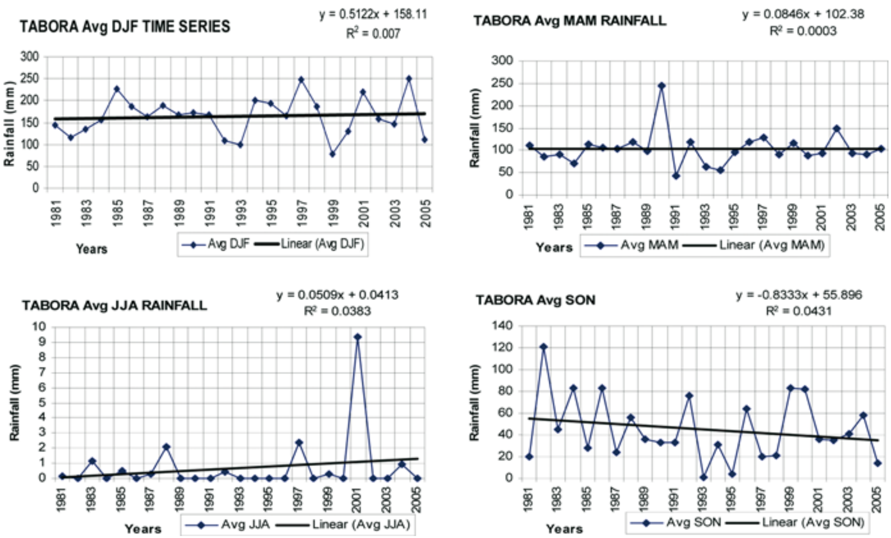


Fig. 20.4. Seasonal rainfall time series at Tabora (1981 to 2005). DJF: December, January, February; MAM: March, April, May, JJA: June, July, August; SON. September, October, November

Fig. 20.5 a, b. **a** Farm clearing through fires in Morogoro, **b** Drought in Arusha in 2005

Fig. 20.6. Overgrazing in Arusha

Fig. 20.7.a,b **a**Exposure of deforested land to erosion, **b** Gully formation through erosion

20.3.4 Floods and Droughts

Droughts make the soil dry and loose (Figure 20.8b), while floods wash away loose soil and other ecological features (Figure 20.8a) making them susceptible to degradation. Areas affected by droughts, floods, deforestation and overgrazing have little or no vegetation growing. Vegetation uses CO_2 in photosynthesis, hence a reduction in vegetation will result in increased CO_2 in the atmosphere. This is evident at global level as well as regional level as shown by the trends of CO_2 from a station close to East Africa. This will result in increased global warming and increased extreme weather events and finally increased land degradation.

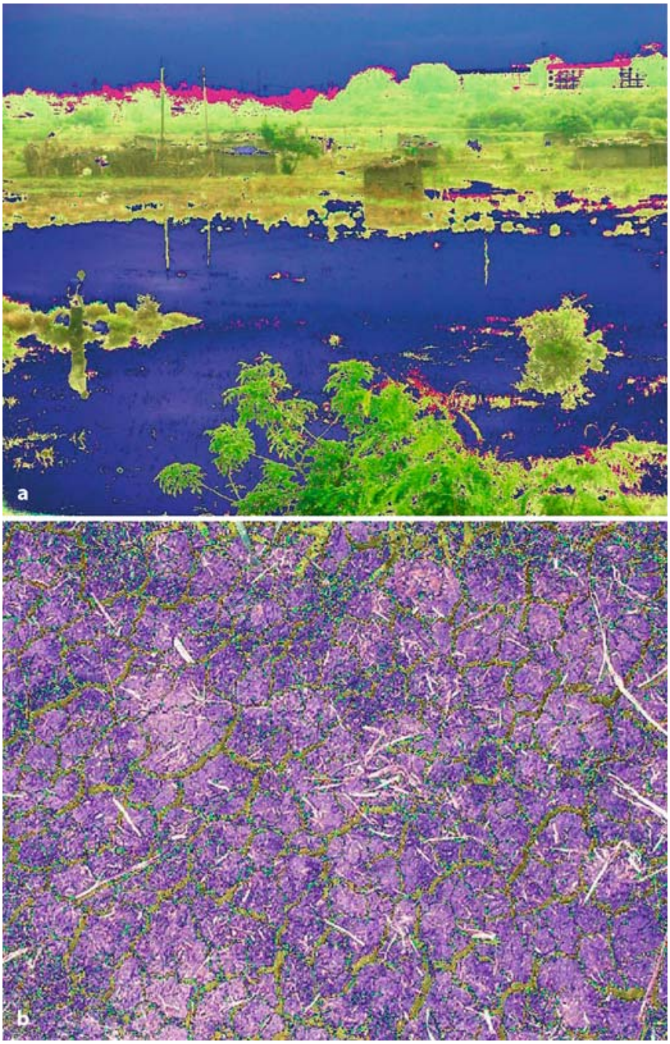


Fig. 20.8 a, b. **a** Floods and **b** droughts in Dar Es Salaam

20.3.4 Carbon dioxide

From Figure 20.9a, it can be seen that CO_2 exhibits a seasonal variability. A bimodal distribution is evident with a minimum in January and May. This pattern may be associated with a seasonal variation in the vegetation cover. Around the tropical region, where the CO_2 observatory station is located, there are two main rainfall seasons: March to May and November to December. However March to May is the main season. The largest vegetation cover occurs in May, which corresponds to the minimum level of CO_{2}, as during this time of the year the photosynthetic levels

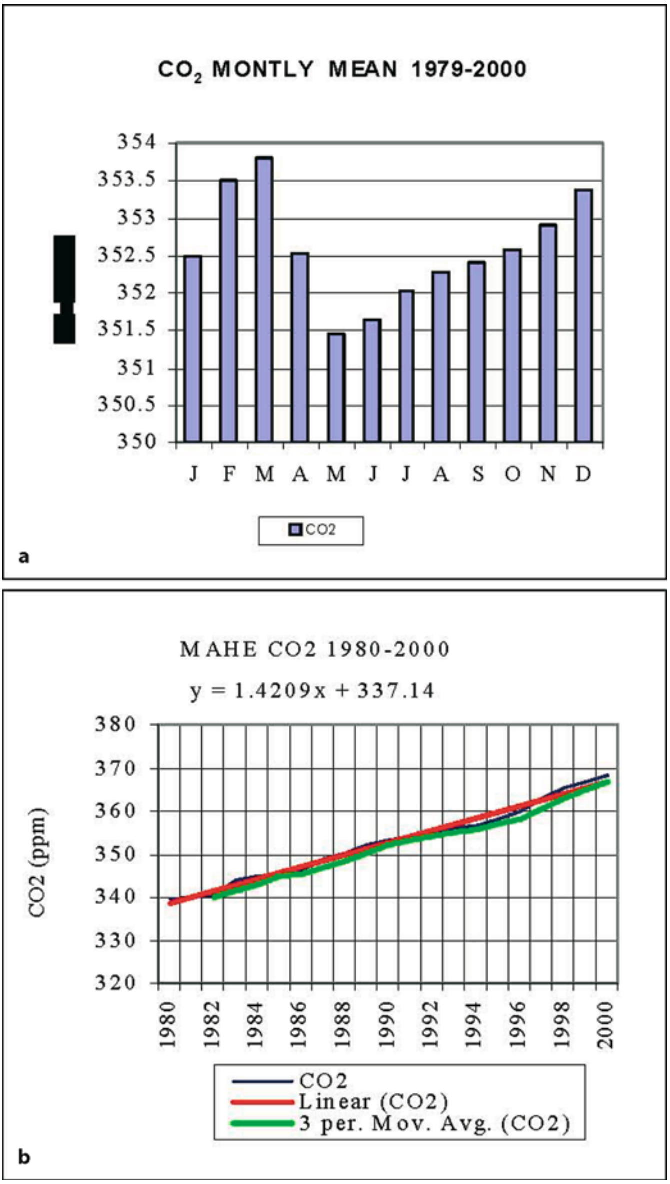


Fig. 20.9 a, b. **a** Seasonal variations in mean monthly CO_2 levels. **b** Increase in CO_2 concentrations at Mahe, Seychelles

are high. The secondary minimum of CO_2 in January corresponds to the revival of vegetation cover after the short rains of November to December.

A trend analysis was performed for both annual and seasonal CO_2 concentrations. The annual mean indicated an increase of 1.42 ppm per annum (Figure 20.9b). On seasonal basis, the analysis showed that the northern hemisphere au-

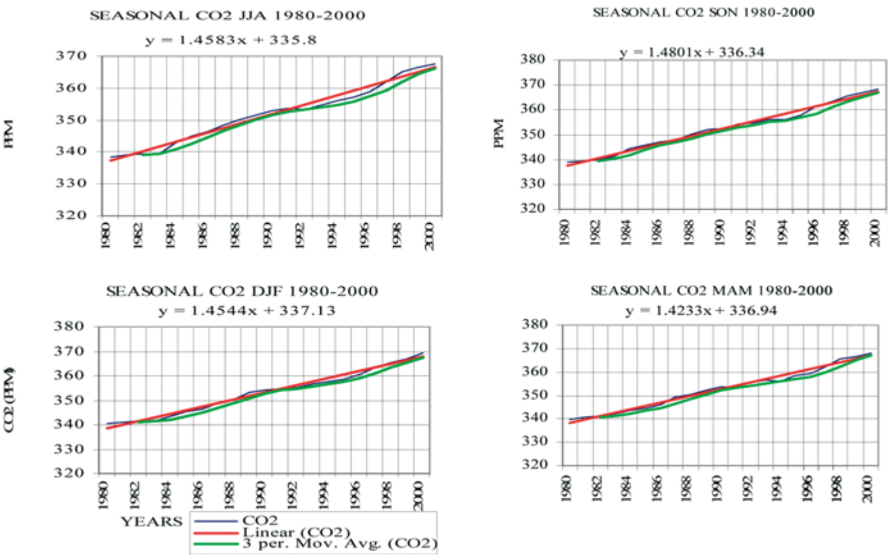


Fig. 20.10. Seasonal trends in CO_2

tumn (September-November) has the largest trend of 1.48ppm (Figure 20.10b) while spring (March-May) has the lowest trend (figure 20.10d).

20.3.5
Glacier and thick forests of Kilimanjaro

Decreased rainfall as well as vegetation has been observed over different parts of the country in different seasons. There are good natural watershed forests, which have in recent years been in danger due to forest fires. Mount Kilimanjaro has natural forests which are attacked by fire regularly, the latest severe attack being in 1996 when thousands of hectares were burned. Gullies are observed over several places as one ascends over the slopes. Some trees are trying to recover by producing off shoots to protect the land, but with little effect. This vast burned area shows a serious reduction in vegetation as well as increased redundant CO_2.

The following observations can be made in this regard:

- Due to global warming and continuous dry spells that have prevailed for some years and the serious disturbance to the watershed environment, mount Kilimanjaro glaciers have experienced a retreat. Observations show a horizontal loss of 0.45 m yr^{-1} while side loss is 1.0 m yr^{-1}.
- Precipitation changes have most probably initiated and maintained glacier retreat on Kilimanjaro. This can be due to atmospheric conditions which are much drier than during the previous period when glaciers experienced expansion.

- It is assumed that coupling effect between the dry atmosphere and the glacier is the major retreating factor resulting in very strong sublimation.
- Mass loss at the glaciers is also due to increased incoming solar radiation because of decrease in cloudiness and interaction with precipitation frequency and amount.
- Global warming, though at lower scale because of little heat flux at 500 hPa, is also contributing to the retreat of the glacier.
- Geothermal heating has also been observed to be contributing to the retreat of the glacier. The crater part of the summit has completely lost the glacier and vents seem to be existing in some parts of the glacier which puff hot gases like sulphur leading to glacier melting.
- Since the mountain has a dormant volcano, which probably will erupt again, regular tremors and severe gas puffing have been observed. When Kilimanjaro was visited in January 2006, there was a lot of sulphur puffing and a nearby mount Oldonyo Lengai on the southern shore of Lake Natron in Arusha erupted on 24 March 2006.

Kilimanjaro glaciers have been experiencing a depletion with clear difference between 1993 which had a well covered cap and 2000 with a ragged cap (Cullen et al. 2006).
Crater part that used to be covered is now exposed, with glacier at the ream of the summit and few patches (Fig. 20.11).

Land that used to be covered by glaciers for millions of years is now exposed and is vulnerable to degradation by erosion (Fig. 20.12).

Very strong winds prevail at the top of Mt. Kilimanjaro which at times blows away loose volcanic soil that has been exposed by the melting of the glacier. Rainfall erodes the soil forming gullies (Fig. 20.13) and this type of land degradation is difficult to control because the summit has an average temperature of -7°C which is not conducive to plant growth that could conserve the watershed by allowing moisture penetration to the summit. Erosion accompanied by melting of ice is dangerous especially on the slopes because it may result to sliding of boulders and endanger structures and life on the way.

20.3.6
Mount Oldonyo Lengai (3450m) eruption March 2006

This volcano, the only sodium carbonate volcano in the world, has frequent eruptions with the recent severe eruptions in 1983 and 2006 with several others in 1954, 1955, 1958, 1960, 1967 and 1994. An attempt is being made to relate the Lengai eruption with Kilimanjaro in the sense that they are close and probably Kilimanjaro mountain as well as Mount Meru, have very strong base that a weak volcano cannot penetrate easily and found Lengai to be the exit. This means that the pressure that will erupt mount Kilimanjaro, which is dormant, will have a very severe impact on Lengai.

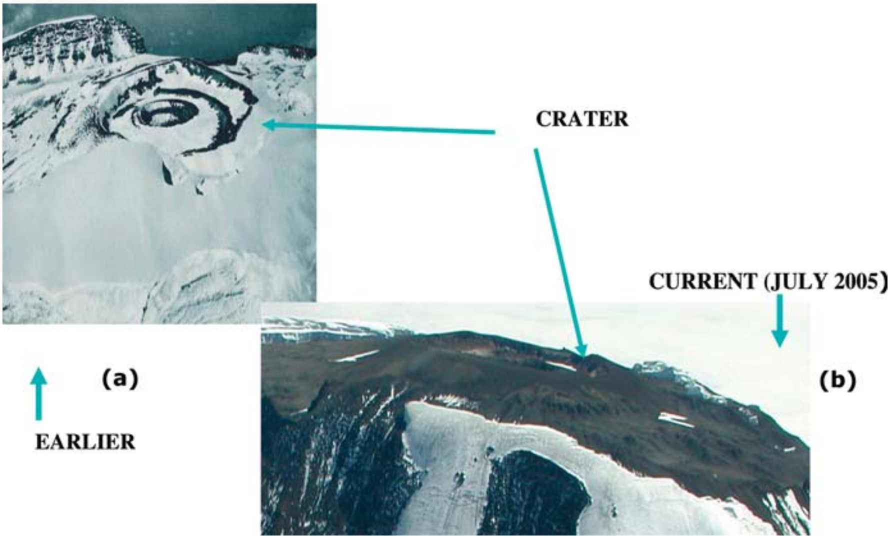


Fig. 20.11. Kilimanjaro crater aerial view

Fig. 20.12. Land degradation at 500hPa Kilimanjaro (5895m) NIF

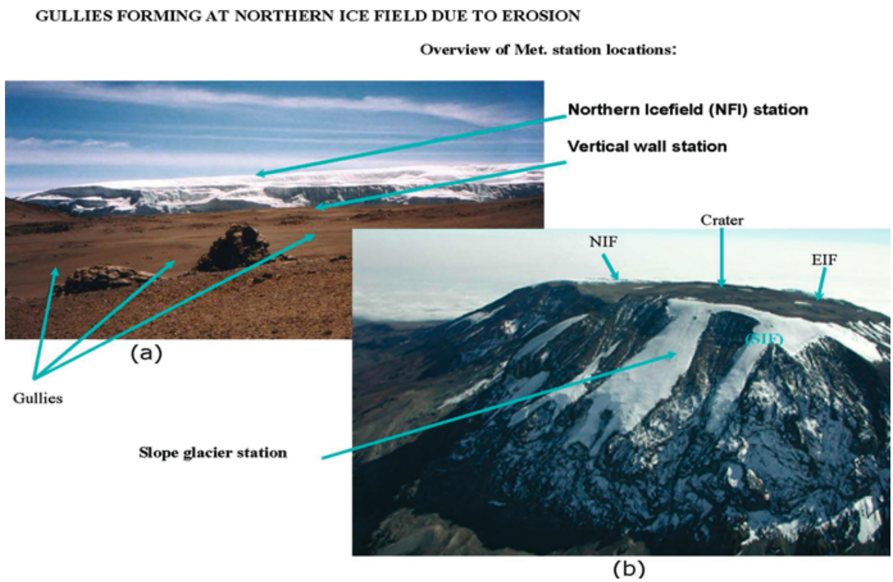


Fig. 20.13. Gullies due to erosion at the summit of Kilimanjaro

- The Lengai eruption in 2006 plume (Figure 20.14a) and lava flow streams are shown in Figure 20.14b. A circular crater in Figure 20.14c, with lava flow towards the east, west and south can be clearly seen. From this, the summit is free of growth with its cone shaped soil vulnerable to degradation. As the lava sweeps down the mountain it burns structures on the way hence making the soil vulnerable to degradation.

20.4 Conclusions

This study has shown that:

- An increase of CO_2 will cause an increase in temperature and increased land degradation due to increase in frequency and intensity of severe weather and extreme climatic events (floods & droughts).
- Increased land degradation will lead to reduced retention of soil moisture and increased soil erosion, and hence desert encroachment.

20.5 Recommendations

- To reduce land degradation planting of trees, where possible, is recommended because trees will use CO_2 in photosynthesis and thus reduce its accumulation

Fig. 20.14. a–c. Lengai plume March 2006 **b** Lengai Lava flow March 2006 **c** Lengai Crater January 2007 and lava flow March/April 2006

in the atmosphere. This will reduce extreme weather events and hence reduce land degradation.

- To make the tree planting effective, new and affordable energy sources should be sought to reduce distraction of forests.
- Agriculture is also contributing to land degradation and to combat this problem, proper land use plans need to be instituted.
- A meteorological station be installed at the summit of Kilimanjaro to monitor weather elements responsible for its depletion with rainfall stations and temperature loggers on few slopes.

20.6 Acknowledgement

Thanks are due to Dr Lennie Thompson, University of Ohio, USA, leader of the ice core drilling expedition in 2000. All subsequent measurements and glacier-climate studies have been done by Universities Innsbruck and Massachusetts (Prof. Kaser, Dr. Hardy, Dr. Cullen, Dr. Mölg). participants of the expedition, for facilitating the expedition of the author; University of Massachusetts USA and Innsbruck Austria for funding, Blessing Siwela, DMC Harare for providing NDVI data; TANAPA, KINAPA for giving permission to climb the mountain; COSTEC for issuing the license to conduct the research; Keys Hotel Staff, for providing accommodation; Errick Massawe, Guides for facilitating the climb; Dr Mohamed Mhita, Director General TMA for allowing the author to join the glacier retreat group, Dr Emanuel Mpeta and Dr Tharsis Hyera, TMA Tanzania former participants in the expedition; and D. Kashasha and all TMA staff for their contribution to the success of the trips.

References

Adosi JJ (2002) Trends and Variability of Surface Temperature Over Tanzania. Tanzania Meteorological Agency, Dar Es Salaam, Tanzania. Mimeo.

Adosi JJ (2002) Seasonal and Interannual Variation of Carbon Dioxide over Tanzania. Tanzania Meteorological Agency, Dar Es Salaam, Tanzania. Mimeo.

Cullen NJ, Mölg T, Kaser G, Hussein K, Steffen K, Hardy DR (2006) Kilimanjaro glaciers: recent areal extent from satellite data and new interpretation of observed 20th century retreat rates. Geophys Res Let 33:LI6502, doi:10.1029/2006GL027084

Mölg T, Hardy DR (2004) Ablation and Associated Energy Balance of a Horizontal Glacier Surface on Kilimanjaro. J Geophys Res 109, D16104, doi;10.1029 / 2003 JD 004338

Hyera T, Matari E (1996) The development of climate change scenarios in Tanzania. In: The assessment of vulnerability and adaptation to climate change impacts in Tanzania. Associates of CEEST (Centre for Energy Environment Scientific Technolgy) from the Directorate of Meteorology.

Kaser G, Hardy DR, Mölg T, Bradley RS, Hyera T (2004) Modern glacier retreat on Kilimanjaro as evidence of climate change: Observations and Facts. Int J Climatol 24: 329 –339.

IPCC (1992) Climate Change 1992, The Supplementary Report to the IPCC Scientific Assessment. Houghton JT, Callander BA, Varney SK (eds). World Meteorological Organization and United Nations Environment Programme, Geneva, Switzerland and Nairobi, Kenya. Cambridge University Press. pp. 200.

IPCC (1996) Climate Change 1995: The Science of Climate Change, In: Houghton JT, Meira Filho LG, Callander BA, Harris N, Kattenberg A, Maskell K (eds), Cambridge University Press, Cambridge, UK. pp. 570

IPCC (2001) Climate Change 2001: The Scientific Basis, In: Houghton JH, Ding Y, Griggs DJ, Noguer M, van der Linder PJ, Dai X, Maskell K, Johnson CA (eds.) Cambridge University, UK. pp. 881

King'uyu (1994) The Space Time Characteristics of Minimum and Maximum Temperature Values Over Tropical East Africa Region, M. Sc. Thesis, University of Nairobi, Nairobi, Kenya

King'uyu SM, Ogallo LA, Anyamba EK (2000) Recent Trends of Minimum and Maximum Surface Temperatures over Eastern Africa. J Clim 13:2876-2886

Molg, T., Hardy, D.R. and Kaser, G (2003) Solar-radiation-maintained glacier recession on Kilimanjaro drawn from combined ice-radiation geometry modeling. J Geophys Res 108 :10.1029/2003JD003546.

Land Degradation Control in Northern Africa

Ismail H. M. El Bagouri

Abstract. North Africa sub-region represents the entire range of aridity index. The major issues of concern in the sub-region are rainfall variability, recurrent droughts, and possible impacts of climate change. Aridity is manifested by scarcity of water resources and arable lands which represent 26.4% of the total land area with extremely varied distribution among the countries of the sub-region. Presently cultivated areas occupy 45 million ha, mostly rainfed, with 8 million ha of irrigated lands. Rangelands occupy about 13% and forest / woodland represent 8% of the total land area of the sub-region. All land use categories are subject to land degradation processes, through more than three decades, due to several pressures including; rapid population growth, climatic stresses, human mismanagement practices, and inappropriate agricultural policies. Land degradation processes are varied and diversified under the conditions of rain-fed, irrigated, range and forestlands. Land degradation processes are conducive to serious productivity losses, reduction in return from capital investment, lower income of rural households, spread of poverty and increased rural to urban migration.

Through the last decade all countries ratified UNCCD and formulated NAPs. Most governments adopted reform agricultural policies. Measures were taken to curtail losses due to inefficient use of water resources in irrigated lands, activating water harvesting practices, enhancing the use of groundwater resources, and supplementary irrigation under rainfed conditions. Activities were enhanced to establish protective belts of trees and shrubs and formulate and implement projects for better management of rangeland and forestland. Setting up of coordination committees, enhancing the role of women and NGOs, and encouraging research activities were also addressed to varied extent. However, the execution of the aforementioned activities does not replace the dire need for adoption of a holistic approach to combat land degradation including formulation of integrated strategies for short, medium and long-terms based on priorities. The adherence to ecosystem integrated approach is a must, in addition to activation of synergies among the major three environmental conventions, i.e., UNCCD, CBD and UNFCCC.

An integrated strategy should be planned to accomplish tasks of prime significance including; the elaboration of thematic databases, adoption of sub-regional indicators, activating unified networking for all six countries to facilitate the exchange of knowledge, experience, and lessons learned in establishing Drought Early Warning Systems. Elaboration and coordination of activities to establish genebanks for indigenous plant species adapted to the harsh environment, and facilitation of the use of agro-biodiversity to combat desertification is important. National and sub-regional preparedness to mitigate the adverse impacts of drought

should be promoted. Rational guidelines should be formulated for the use of vast but non-renewable groundwater resources, available in huge aquifers with varied water qualities. Focus must be placed on demand driven and coordinated research activities in multiple institutions throughout the sub-region. Concerted efforts are needed to curtail conflicts and local wars which present formidable constraints to development and enhance degradation. Implementing meaningful sub-regional projects and coordinating international funding and transfer of needed technologies, capacity building and collecting indigenous knowledge in a sub-region of very similar conditions are equally important.

21.1 Introduction

The north African sub-region is one of the major five sub-regions of the continent of Africa. It includes six countries; Egypt, Sudan, Libya, Tunisia, Algeria and Morocco with vast total area of 8.49 million km^2 and includes varied topographic features of extended plateaus, depressions, dry valleys, and relatively limited highlands and mountainous areas. The sub-region is endowed with lengthy strategic coastal lines extending over 9,500 km, over looking the southern coastal lines of the Mediterranean Sea, in addition to costal lines extending along the Red Sea to the east, and the Atlantic Ocean to the west of the sub-region.

At the turn of the 21st century total population of the six countries exceeded 180 million people. The population of the sub-region almost doubled through the past 30 years with varied rates of increase per country, but with an overall average of 2% per annum (World Bank 2001). Continued population increase, in addition to increased consumption of food and agricultural commodities, led to continued increased demands for agricultural products and placing serious pressures on the use of land and water resources. Enhanced use of agricultural chemicals, fertilizers and other inputs are common features (FAOSTAT 2001).

21.2 Land use

Table 21.1 shows the major land use categories in the sub-region.

Natural rangelands represent the largest land use category occupying about 26.8% of the total land area. Arable lands represent 11.4% of the total land area while forest land represents 5.7%, mostly in elevated areas in the sub-region. The data in Table 21.1 show the wide disparity of areas occupied by the main three land use categories among the countries of the sub-region.

Rangelands are abundant in Sudan, Morocco and Algeria, while the least areas are projected by Egypt and Tunisia. Rangelands extend over areas of marginal rainfall (100-300 mm yr^{-1}) and soils of limited fertility. The natural plant cover of the rangelands is under pressures of overgrazing and variable rainfall conditions.

Arable lands (lands suitable for cultivation) are scarce compared to the total land area, which is typical of arid lands. Areas already cultivated represent about

Table 21.1 Major categories of land use in northern Africa ('000 ha)

Country	Cultivated	Rangelands	Forest Land
Algeria	7,876	34,362	3,861
Egypt	3,209	1,500	34
Libya	2,366	12,712	400
Tunisia	3,945	2,700	555
Morocco	9,545	21,000	1,725
Sudan	17,082	39,480	43,613

30% of the arable land with most of the non-cultivated arable areas located in Sudan and Morocco. Rainfed cultivated lands are prevailing in the total croplands in the sub-region, which are estimated at 45.23 m ha (WRI 2004). Irrigated lands are estimated at 12.2% of the arable land (with the exception of Egypt where irrigated lands represent more than 95%). Irrigated land in the sub-region, despite its low percentage, produces about 70% of the agricultural commodities (FAOSTAT 1998).

Forestland represents the least land use category and unfortunately the area occupied by forests is continually declining due to varied factors, as will be described in a following section.

The previous review of land –use categories shows that over 55% of the total land area of Northern Africa sub-regions is barren lands.

21.3 Climatic Features

21.3.1 General features

The Northern African sub-region represents the full range of aridity index prevailing over different physiographic areas. The northern coastal areas have southern Mediterranean climate while inlands are characterized by arid and hyper-arid climatic conditions along the southern direction. In general, 65% of the total area of the sub-region has hyper arid conditions, 25% arid, 8% semi-arid and only 2% of the area has dry sub-humid climatic conditions (UNEP 2002). Northern coastal areas are distinguished by moderate Mediterranean climatic conditions with higher rainfall reaching a maximum of 1500 mm and high relative humidity, especially during the rainy season. Rainfall (as well as relative humidity) decreases rapidly towards inland along the southern direction, reaching a minimum rainfall of few mm yr^{-1} (with the exception of the elevated areas). Heat stress increases as well along the southern direction.

21.3.2 Rainfall variability

Water resources in the sub-region are comprised of rainfall, surface water and groundwater and represent 90%, 8.1% and 1.9% respectively of the available water resources in the sub-region (AOAD 2000). These figures clearly show that marginal rainfall represents the major water resource in the Northern sub-region of Africa. Such valuable resource, however, is characterized throughout the sub-region by rapid changes in spatial distribution, seasonal variations, inter-annual variability, varied intensities, and length of growing season. Such wide variability in the sub-region are exemplified by the data from coastal areas in Egypt (Figs. 21.1 and 21.2 and Table 21.2, El-Bagouri 2000)

These factors strongly affect the efficiency of rainwater received and the surface runoff in streams and wadies, in addition to the recharge of the groundwater aquifers. National country reports clearly show that a major fraction of the rainwater received is lost through a combination of evaporation, evapotranspiration, seepage and runoff in uncultivated wadies or to lakes and marine coastal areas.

21.3.3 Droughts

Most Northern African countries experience recurrent drought spells of varied severity and length. Algeria, Tunisia and Libya experienced droughts in the late eighties till 1993. Morocco has experienced a drought in one year out of every three years over the past few decades (UNEP 2002). Northern Sudan experienced droughts in the seventies and the eighties along with the major drought events in the Sahel. Rainfall variability and drought spells have an adverse impact on land

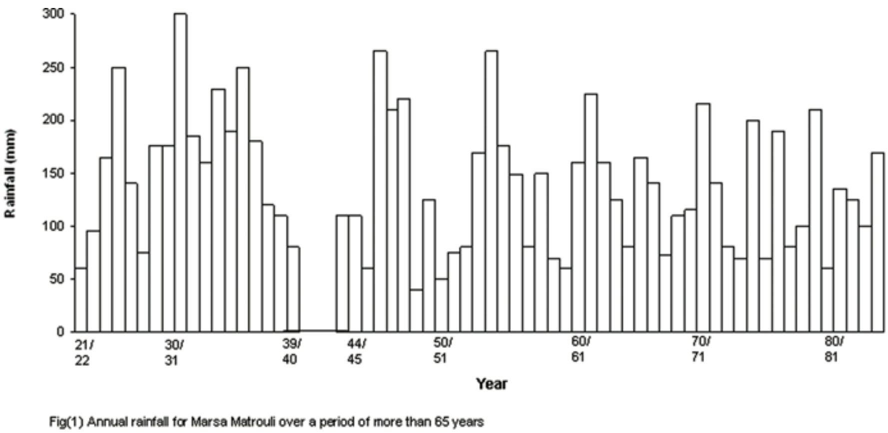
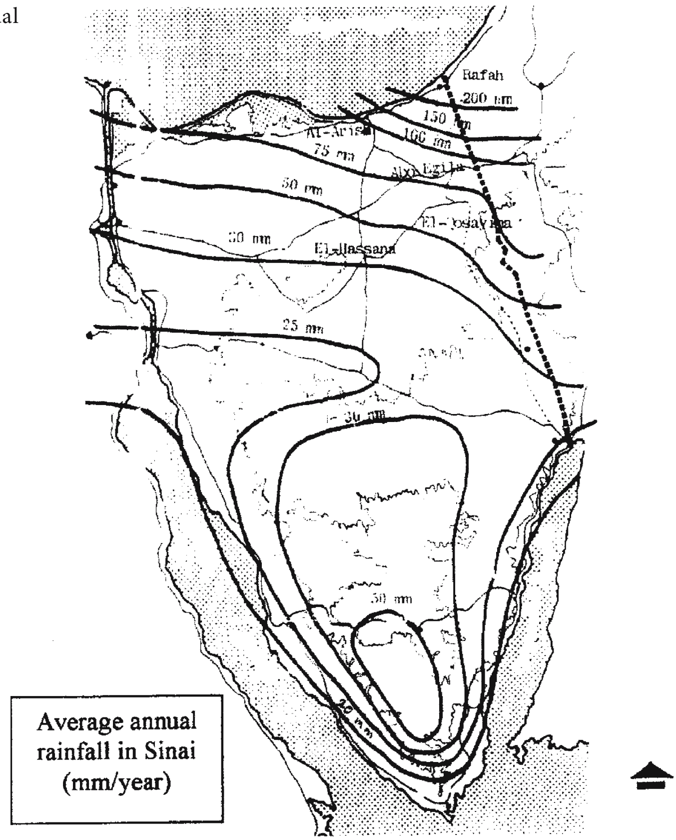


Fig. 21.1. Annual rainfall variation for Marsa Matrouh over a period of over 65 years (After El Bagouri 2000)

Table 21.2. Inter-annual Variability (IAV) in the Northwest Coast of Egypt (After El-Bagouri 2000)

Station	Number of Years of Observation	Annual average (mm)	IAV (mm)	Relative LAV (%)
Alexandria	50	199	57	28.6
El Dabaa	38	141	57	40.7
Marsa Matrouh	40	140	67	47.8
Sidi Barrani	35	144	57	39.6
El Salloum	38	105	72	68.6

Fig. 21.2. Average annual rainfall in Sinai (mm)



After El-Bagouri (2000)

productivity by enhancing erosion processes, degrading plant cover and through other desertification processes.

21.4 State of Water Resources

Present and future scarcity of water resources is a common feature throughout the sub-region with the exception of Sudan, followed by Morocco. Variability in rainfall, as well as variability in flow of major rivers like the Nile, conveyance and on farm losses of water resources, inadequate water harvesting and spreading techniques, as well as under exploitation of vast groundwater and non traditional water resources contribute to deficiencies and inefficiencies in the supply and utilization of water resources.

Due to continued population increase, per capita share of water resources is declining rapidly. It is expected that all countries of the sub-region –with the exception of Sudan- will experience water scarcity (less than 1000 m^3 $person^{-1}$ yr^{-1}) by the year 2025 (UNEP 2000).

The ever-increasing water demand in contrast to the slow increase in water supply is leading to unsustainable water use and competition for water resources among varied sectors. Such a trend also has serous impacts and strained relations among countries with shared water resources (Nile River is shared among nine nations including Egypt and Sudan).

21.5 Degradation processes in the sub-region

All land use categories in the sub-region are subject to several degradation processes as shown by country reports through the last four decades. Among the major pressures are rapid population growth, climatic stresses, human practices, inappropriate agricultural policies, certain land tenure systems and other factors. The following is a brief review of land degradation processes active in each of the major land use categories.

21.5.1 Rangelands

Rangelands extend over areas of marginal rainfall (100-300 mm yr^{-1}). The soils are of limited fertility, which are classified as marginal lands within fragile ecosystems.

By the middle of the 20th century, the rapidly mounting population pressures, increasing demands for food and feed commodities led to the introduction of cultivation to rangelands. The over-exploitation of the fragile natural ecosystem of rangelands caused the loss of the natural plant cover due to the low probability for the cultivated crops to reach maturity ie., once every three or four years due to the marginality of rainfall.

The increased demand for rangeland products led to overstocking of animals on the range beyond the proper carrying capacity which in turn caused serious overgrazing, the loss of plant cover, severe degradation of palatable species, loss of highly valued biodiversity and adapted species. Improper grazing and range management practices, as well as the introduction of inappropriate techniques like spreading of boreholes for watering the stock, caused serious adverse impacts on the sustainability of plant cover.

In all cases the loss of the natural plant cover of the rangelands led to the enhancement of erosional processes through wind and water, causing the loss of valuable top soil i.e., loss of resource base and rapid degradation of soil productivity (onsite). Meanwhile, eroded soil materials carried by water or airborne by wind cause severe adverse environmental impacts in the settling areas (offsite) including health hazards. Siltation of water reservoirs, sand encroachment on strategic installations, industrial areas, highways and infrastructure in urban areas imply huge economic losses, both onsite and offsite.

Land tenure system based on communal tribal bases prevailing in the rangelands has adverse impacts on range management practices, sustainable development, introduction of needed investments and enhancing social benefits.

21.5.2 Cultivated Areas

The physiographic features and terrain attributes in the sub-region are highly varied including plateaus, depressions, wadies, dry valleys with different elevations and slopes, which strongly affect the properties of the relevant soil resources especially with respect to soil texture and soil profile depth. Physiographic features have definite impacts on soil/moisture relations, water harvesting and surface water development and movement.

Rainfed areas are susceptible to prolonged drought spells, which adversely affect the soil development and its productivity. The adoption of improper farming systems and agronomic practices including center contouring tillage, fallow areas, inappropriate crop varieties and lack of soil conservation practices could lead to soil degradation. Low rate of appropriate application of water harvesting and water spreading techniques lead to serious flash floods under the conditions of intense rainstorms, which frequently take place in elevated areas despite the general scarcity of rainfall. Such flash floods lead to the loss of soil and water resources, in addition to the adverse environmental impacts.

Irrigated lands, which represent the highest production potential in the Arab Region, are subject to several processes of degradation including salinity, water logging, pollution, urban encroachment and over-exploitation. Soil salinity is reported as the most pronounced factor of degradation, affecting more than 35% of the total area of irrigated lands (FAOSTAT 1998). Salinity of the soil resource base is attributed to several factors including overuse of irrigation water leading to water logging, elevated water table, reduced soil potential and adverse effects on availability of plant nutrients. Soil salinity could also occur under improper use of brackish and saline irrigation water. Improper management practices such as inappropriate irrigation techniques, poor field distribution, and inappropriate irrigation scheduling could contribute to soil salinity.

Pollution of soil resources could originate from the overuse of chemical fertilizers especially nitrogen fertilizers applied to coarse textured soils, which invariably lead to excessive nitrate concentration in the growing plants and in the soil leachates, causing in many cases the pollution of groundwater resources. Soil pollution also results from the overuse of pesticides and herbicides, water pollutants originating from industrial and urban activities, application of untreated or insufficiently treated waste water and sewage sludge and the application of soil amendments containing, or forming, intermediate compounds of polluting nature (El Bagouri 1999).

Urban encroachment on valuable irrigated lands is practiced due to the pressures of rapid population increase to expand villages and towns.

Finally over-exploitation of irrigated lands without proper choice of cropping patterns and farming systems that would ensure progressive improvement of soil properties, productivity and sustainable development will lead to deterioration of soil productivity.

21.5.3 Forestland

Continued deforestation occurs in the sub-region for different reasons: conversion of forest land to cultivated lands, fires leading to destruction of thousands of ha every year (Algeria, Morocco), and cutting of trees and shrubs for fuel (representing, for example 70% of energy needs in Sudan). Mismanagement of forestlands leads to a decline in the goods and services provided by them, in addition to sand encroachment on productive lands, forest areas, rangelands and infrastructure.

21.6 Combating Land Degradation in the sub-region

21.6.1 Activities prior to UNCCD

Ever since the convening of the Nairobi Conference for Combating Desertification held in 1977, the countries of Northern African sub-region began to address the problems of land degradation over the next two decades, prior to the formulation of the UNCCD. Activities included surveys, studies, formulation of pilot programmes and execution of a limited number of projects. These activities were based on a sectoral approach, through governmental institutions in one or more of the main land use categories as projected by country national reports. The activities implemented were of limited duration and were discontinuous in nature. The impacts of such activities to halt land degradation met with very limited success.

Stakeholders at varied levels did not acknowledge significant changes in the continued rates of land degradation.

21.6.2 After the inception of UNCCD

After the inception of UNCCD in 1996, all six countries ratified the convention and formulated their National Action Programmes (NAPs). Through elaboration of the convention committees, meetings and guidelines, concerted efforts in the six countries took place to put the national activities on the right track. These efforts included a coordinated institutional setup, societies, defined roles for women and youth, adoption of a participatory approach, progressive awareness of the adverse impacts of desertification at varied levels, integration through development plans, execution of major projects with consultation and joint financing of regional UN organizations and established financial mechanisms, as well as, extensive discussions and meetings at the sub-regional, regional and international levels. Such activities were more pronounced and elaborate in some countries (Tunisia and Morocco) in comparison to the other countries. Activities executed resulted in positive impacts and diversified returns and generated both success and failure stories. Experiences were gained in both testing of technologies and in improved national capacity building.

21.6.3 Improved Measures for Combating Desertification

Some of the successful activities projected in the country reports could be quoted as follows, in the three main land use categories:

- Adoption of reform policies by most governments. Greater attention was given to indicators and benchmarks, and establishment of more climate stations for recording and analysis of the important climatic parameters.
- Formulation of legislations geared towards conservation of natural resources and environmental protection.
- Enhanced establishment of protective belts of trees and shrubs.
- Encouraging research activities to varied extents.
- Improved management of watersheds through establishment of water spreading, harvesting and storage facilities as well as the use of supplementary irrigation techniques to improve and develop rainfed agriculture.
- Curtailing losses of conveyance and on-farm use of irrigation water through appropriate measures.
- Increased use of groundwater resources and increased consideration of the use of nontraditional water resources under irrigated conditions.
- Implementing projects for better management of rangeland and forests, establishment of nurseries for replanting trees and shrubs of appropriate traits, and enhancing forage productivity.

21.7 Combating Land Degradation – the Way Forward

The execution of the aforementioned activities in the countries of the Northern African does not replace the significance of adoption of new and innovative approaches presented at the sessions of the Conference of Parties (COPs) of UNCCD with appropriate recommendations from the various UNCCD committees.

Combatting land degradation requires emphasis on the implementation of the following measures:

- Contrary to the sectoral systems, adoption of a more wholistic bottom-up approach geared towards progress.
- Promoting activities that exploit the synergies among the three major environmental conventions, i.e., UNCCD, CBD and UNFCCC is of high priority to prevent duplication of efforts, achieve efficiency of funding, coordinating the use of human resources and facilities, as well as facilitating capacity building and public awareness programs.
- Elaboration of thematic databases, and use of GIS to address gaps and achieve meaningful and unified networking in all six countries of the sub-region for efficient exchange of knowledge, experiences and lessons learned.
- Establish and activate ample considerations of potential climate change, investigate possible impacts and formulate plans for impacts on the lengthy coastal areas. This is assuming a high priority in view of the findings reported by the IPCC which point out the latest possible scenarios for sea level rise. These scenarios take on added significance in view of the lengthy coastal areas of the sub-region. Fig. 21.3 presents the predicted inundation areas in the northern areas of the Nile Delta in Egypt, in case of a sea level rise of 1m by 2050. This represents the least scenario which could lead to inundation of significant areas, loss of its productivity, salt water intrusion in the fresh water aquifer below the Nile Delta and migration of the populations of the inundated areas leading to varied socio-economic adverse impacts. Possible impacts of climate change on land resources in Egypt was reported by El Bagouri (2004).
- As drought spells are among the most significant factors of desertification in the sub-region, there is a significant need to join and participate in establishing Early Warning Systems (EWS) for drought and encourage pertinent investigations and research activities. In addition, arrangements of national and sub-regional preparedness measures including reserve feed and food seeds, stocking of vital crops, breeding of new and appropriate varieties, institutional setup, and proper allocation of funds are among the needed significant measures.
- In view of the significant impacts and interactions of climatic features and characteristics with land degradation processes in the sub-region, greater efforts should be geared towards enhancement of the meteorological data networks, their accessibility to relevant institution and their use for better implementation of NAPs in the respective countries of the sub-region.
- Due to the high aridity prevailing in the sub-region, the establishment of gene banks to conserve, propagate and use indigenous plant species adapted to drought, heat stress, salinity and other adverse conditions. The use of biotech-

Fig. 21.3. Predicted inundation of the Nile Delta (After UNDP 2000)

nologies and agro-biodiversity technologies should be among the demand-driven research activities.

- Formulate guidelines for the rational use and proper management of vast but mostly non-renewable groundwater resources, available in huge aquifers, with varied water qualities. Proper guidelines are badly needed to achieve the benefits and curtail the constraints and misconceptions pertinent to the use such important resources. One of the major and huge aquifers in the sub-region, the Nubian sandstone aquifer, with high quality water (Fig. 21.4), is shared by Libya, Egypt, Sudan through massive desert areas, and part of Northern Chad as well.

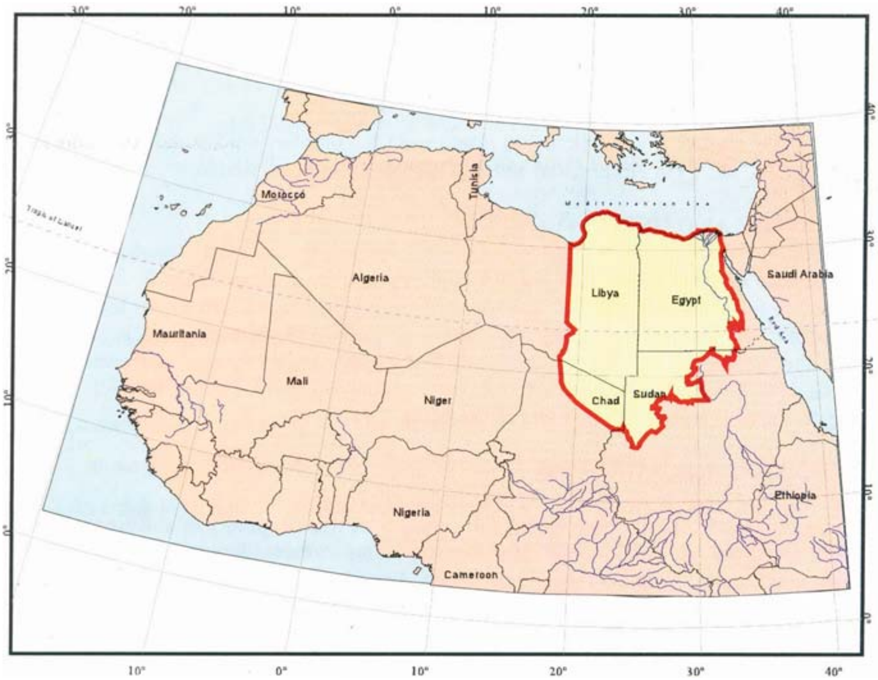


Fig. 21.4. Nubian Sandstone Aquifer System Programme (After CEDARE and IFAD 2000)

- Coordination among the varied institutions at the national level is needed including assignment of specific and coordinated role for each. This would lead to curtailing of duplication in activities, wastage of efforts, time and funds.
- Despite the large number of research institutions present in the sub-region, demand driven research is minimal at best, while exchange of knowledge, results and outcomes of investigation of research efforts needs to be widened and enhanced. Exchange of data, results and lessons learnt at the sub-regional and regional levels is very limited. Such important exchanges are achieved only through sub-regional and regional conferences, while networks are functioning at a minimum scale and in limited geographical areas.
- Compilation, documentation and processing of indigenous knowledge at the national and sub-regional levels is minimal at best. The use of such knowledge for proper planning and implementation of varied activities to combat desertification should be encouraged. Support of national, regional and international activities in these directions should be enhanced.
- Transfer of needed technologies and support of capacity building by national, regional and international authorities need to be coordinated and developed.
- Conflicts and wars within countries and among countries of the sub-region for resources present major factors for desertification, pose formidable constraints for rehabilitation and limit sustainable development.

References

AOAD (2000) Arab Organization for Agriculture Development Annual Reports. Khartoum. Sudan (In Arabic)

CAMRE / UNEP / ACSAD (2004) State of Desertification in the Arab Region. ACSAD, Damascus, Syria (In Arabic).

CEDARE and IFAD (2001) Regional Strategy for the Utilization of the Nubian Sandstone Aquifer System. CEDARE, Cairo, Egypt.

El Bagouri IH (1999) Sources of Pollution of Land Resources in the Arab Countries. Regional E-mail Conference "Pollution of Land Resources in the Arab Regin" CEDARE 3-12 May 1999, Cairo, Egypt.

El Bagouri IH (2000) Marginal Lands of the Arab World – Constraints and Potentials. Regional Workshop "Degradation and Rehabilitation of Marginal Lands in the Arab Region". CEDARE/ ICARDA, 2-4 July 2000, Cairo, Egypt.

El Bagouri IH (2004) Impacts of Climate Change on Land Resources in Egypt. 1st National Workshop on "Impacts of Climate Change on Natural Resources of Egypt". Academy for Scientific Research and Technology, 14 Sept. 2004, Ismailia, Egypt

FAOSTAT (1998) Statistics Databases. Food and Agriculture Organization of the United Nations, Rome, Italy

IPCC (2001) Climate Change 2001- Impacts, Adaptation and Vulnerability. Intergovernmental Panel on Climate Change, Cambridge University, Press, London.

UNEP (2002) Africa Environment Outlook, Past, Present and Future Perspectives. Earthprint Limited, UK. UNEP, Nairobi, Kenya.

World Bank (2001) Africa Development Indicators. The World Bank, Washington D.C.

WRI (2004) World Resources 2002-2004. Earth Trends Data. World Resources Institute Website.

Challenges and Trade-Offs in Environmental and Financial Approaches of the Afforestation of Degraded Lands

Viorel Blujdea

Abstract. Significant areas of unproductive and marginal lands create important economic and environmental imbalances at local, regional and national level, in many Eastern Europe countries. Despite available scientific and technological solutions for their enhancement, existing large degraded areas require major financing. Afforestation of degraded lands is acknowledged as an activity where environmental and financial synergies occur, as it generates a real carbon sequestration potential, besides other associated benefits at local, regional and global level. An opportunity to value carbon sequestration potential is represented by the flexible mechanism of the Kyoto Protocol, Joint Implementation and Clean Development Mechanism (JI/CDM). An afforestation project includes several steps, that should ensure the integration of the project outcomes with social and environmental priorities at local, regional and global level, in the short, medium and long term, such as: preparation, implementation (afforestation technology and plantation maintaining frame), plantation management (administration, planning, management); forest sustainability (local & regional integration); and project's carbon commercial aspects (baseline, carbon projections and validation, monitoring plan, reporting, transfer of carbon units). Carbon accumulation performance of the plantations influences potential revenues. Afforestation projects oriented toward carbon sequestration are exposed to multiple risks due to their long run, like vulnerability to illegal cutting, risks associated with unsustainable management practices or those related to climate change itself, biodiversity loss or social pressure.

22.1 Introduction

In a most common sense *synergy* is taken as "a mutually advantageous conjunction where the whole is greater than the sum of the parts" (www.wikipedia.org). In practice, there is an infinite series of possible arrangements that range from approaches to results, as based on innovative capacity of involved actors. Practical experience shows that a thorough *a priori* analysis is absolutely necessary to assess likely reciprocal positive, neutral or negative impact of each action over actual ecosystem components, as well as on their time evolution and interaction. Actually, synergy refers to innovative approaches and solutions that involve multiple partners, their long term commitment, specific financial contribution and sharing, and multiple environmental benefits, while the ultimate target is the contribution to sustainable development.

Afforestation is acknowledged as an activity where plenty of synergies occur, as it approaches local, regional and global issues and their associated interests. Benefits associated with the afforestation of degraded and marginal lands significantly contribute to improving the integrity of actions targeting the climate change mitigation, conserving and improving biodiversity and restoring the productivity of land. Such lands are found in a large proportion in Eastern Europe countries, under different intensities and types of degradation, out of which some important percentage of lands is abandoned (www.unccd.int/regional/centraleu/meetings/regional).

Abundance of lands available for afforestation may generate a significant positive effect as a global benefit in terms of CO_2 sink establishment.

22.2 Kyoto Protocol's JI/CDM Approach in Afforestation Activities

Degraded and marginal agricultural lands represent a real carbon sequestration potential, besides other several benefits generated by their reclamation through afforestation activities. Innovation regarding the afforestation under the Joint Implementation and Clean Development Mechanism (JI/CDM) is associated with the financial efficiency of the activity itself, according to the rate of carbon sequestrated in the ecosystem components (biomass, soil). Such a financing instrument should substantially stimulate the interest in land use improvement by afforestation of concerned lands. One of the environmental services provided by forest ecosystems, namely the sequestration of atmospheric CO_2, may be satisfactorily quantified, a feature that becomes the core issue in the joint implementation mechanism approaches (in comparison with the difficulties in accurate quantification of other environmental or societal services: soil and water protection, biodiversity conservation, landscape improvement, and protection of communities and crops). Apparent emphasis on carbon sequestration in JI/CDM afforestation projects does not exclude in any way "classical" scope of afforestation, but it additionally strengths targeting of multiple societal and environmental benefits.

Although the global effect on climate of the afforestation activities is still the subject of some debate (caused by age-related carbon sequestration rate, unpredictable late effects, associated uncertainties and large risks of hazards and leakage), it remains one of the most accessible, certain and easy-quantifiable forest activity associated with carbon sequestration.

22.2.1 Afforestation project cycle

A full project cycle includes several steps that should ensure total integration of the project outcomes with social and environmental priorities at local, regional and global level, on short, medium and long term. These steps include:

- preparation (construction of partnership; financial contributions; assessing incentives and compensation; availability, status and actual use of land; type of structure to be created, selection of species to be planted)
- implementation (afforestation technology and plantation maintaining frame)
- plantation management (forest administration, planning, management type)
- forest sustainability (local & regional integration)
- project's carbon commercial aspects (baseline, carbon projections and validation, monitoring plan, reporting, transfer of carbon units).

In a practical approach of JI afforestation project, it is important to review and understand the challenges for environmental and financial synergy and as to how to affect trade offs amongst, and create, least environmental and societal adverse effects on different horizons of time. Synergetic and trade off issues would come out easily from pairs (biodiversity *vs.* carbon bioaccumulation, land restoration *vs.* biodiversity alteration, sink reinforcing *vs.* degradation of lands, valued *vs.* not valued environmental services) and a multifactor balance brings more substance in such an approach.

22.2.2 Development of partnership

Crucial in JI afforestation projects is the fact that partners should have different targets in the project, as basis of their association and that there should be a proper balance of their complementary focus. Environmental and/or developmental needs should be balanced, in which the carbon issue plays a major role. Third party involvement is sometimes the key for ensuring the dialog and negotiations and bring on board the innovative issues.

Issues which are commonly raised over this process of negotiation and building up of partnership may be: uncertain land ownership; owner's indecision and long negotiations; weak, or lack of capacity of, forest administration; owner's restrictions or stipulations; and communication problems (technical, vocabulary nature). In case of a large number of owners, their will to associate together, their ability to entrust appropriate representatives, as well as the transparency of negotiations constitute the key factors in the success of the project, where identification of appropriate local "leaders" may play a major positive role, as well as promote a correct understanding of the project approach and the role of all partners.

22.2.3 Financial shares, incentives and compensations

Afforestation activities require significant input of effort in terms of labor, machinery and funds over a short period of time, while the generation of income is significantly delayed (early as secondary and later on as primary wood products). As degraded lands available for afforestation are generally associated with poverty affected area (where financial capacity is usually limited), the transfer of funds to these regions is crucial for achieving of afforestation activities. Public and/or private funding may contribute toward achieving of this goal. To join together several partners and their available funding there is a need for willingness and a capacity for negotiation amongst the partners. Always the afforestation beneficiary must be part of this process, just to ensure proper access to services created and commit his/her role in the project. Experience shows that public funds follow their own legal rules, but private partners may bring in innovative formulae in terms of financing, implementation or sharing of benefits.

Incentives to encourage the afforestation of poor lands range from free seedling offer and technical advice for planting to tax exemption on the land and grants for afforestation works. Incentive systems should be well analyzed and assessed within the economic environment so as to not distort other economical fields or socio-economical player's activities.

Afforestation of lands certainly reduces the areas available for other uses, such as: arable lands for perennial crops or pastures. In fact, an exhaustive impact assessment should warn and advice on negative impacts of land use changes and avoid any afforestation if this activity limits the benefits to the local population. In such cases, the compensation of the population would reduce the dissatisfaction generated by the afforestation of lands and allow time to become aware of the forest and restructure accordingly its own existence.

To address leakages, a relevant question is if the compensation measures, addressing local communities, which are taken to achieve the successful implementation of the afforestation projects are going to be quantified in terms of GHG emission/sequestration. An example of such a compensation measure could be the improvement of the quality of pastures or grazing land for communities, which may include small patches of trees as summer shelters for livestock. Accordingly, an increase of the carbon stock in the soil and biomass, as well as a likely increase of the livestock takes places, if appropriate planning and management apply. In case of a comprehensive green house gases national inventory, side effects of afforestation projects are fully and accurately accounted for.

Afforestation projects have usually a low yield, which may be increased if carbon offset is accounted for. "Afforestation of degraded lands project", developed between National Forests Administration of Romania and Prototype Carbon Fund/ World Bank between 2003-2017, (which includes 6,496 ha of degraded lands), yields a without-carbon Internal Rate of Return (IRR) of 2.04% equivalent to a Net Present Value (NPV) of -\$732 ha^{-1} at a 5% discount rate, and a with-carbon IRR of 3.86% equivalent to a NPV of -\$272 /ha. Estimated IRR values without carbon for pure black locust stands are 6.1%, 4.3% and 1.5% for site classes II, III and IV respectively. Site Class V, the lowest, does not yield an IRR as costs are greater than potential revenues. Still relatively low, the IRR values do not include the social and environmental benefits of the afforestation, which are usually of major significance in dry or drought affected areas (Brown et al. 2002; Abrudan et al. 2002).

Share of afforestation costs which may be covered from selling carbon could represent in amount a minimum of 20% of the total cost of afforestation work, a lot influenced by gap filling needs in case of low rate of survival. In the case of abandoned agricultural land or low degraded lands (which need less site preparation and maintenance work till canopy closure), the income from carbon sequestration may rise to 40-50% of the total project cost, but *nota bene* this amount is obtained over a period of 15 to 20 years (Blujdea 2003).

Usually, in KP's joint implementation approach there is a need for third party investment, a stable investor who is able to provide an amount of money for plantation establishment, which may be a serious constraint (Abrudan 2003). Alternative solution would be to get an upfront payment from carbon buyer. But in this case there are at least 2 more consequent problems which arise: upfront amount does not cover entirely the amount needed for the establishment of plantations and because of associated risks to afforestation projects (hazards, lower performance) the interest rate applied to upfront payment reduces the carbon revenues of the seller (up to 10%).

Incentives and financial mechanisms are key issues, especially in dry and drought affected areas, because of low incomes and spiraling costs from current activities (agriculture) (Geambasu 2002).

Additional environmental benefits like biodiversity should be reflected in the price of CO_2, as a "biodiversity incentive", even if there is no mechanism in place to accurately value such dimension. Still, buyer may have no interest in this feature as long as its carbon has no "shape" and it is up to national legislation of project's host country to manage biodiversity issues (Blujdea 2003).

22.2.4
Availability, status and actual use of land

Land for afforestation could exceed that for other uses following a regional/local improved planning or in most cases since it is degraded and is no longer suitable or economically efficient for other uses. Legal status and ownership are key things in the initiation of an afforestation project, a crucial issue when partners make their decision.

Land quality is a limiting factor for the afforestation technology, but it mostly could impact the growth of species to be planted (survival rate, stand characteristics, productivity and production). For a successful afforestation work, technology must be adapted to local situations, with focus on existing vegetation, both woody and herbaceous. A soft approach of land use change would allow conservation of carbon in vegetation or/and soils. On the contrary, a hard approach would generate increased emission from current ecosystem pools. Pastures store more carbon than arable soils, so different site preparations must be possibly approached, in order to reduce green house gases emissions (Houghton 2003).

Potential for damaging local diversity depends on how close the existing ecosystem is to natural status. In such situations, pastures, long term abandoned lands (whatever their use) and generally low intensive managed systems are susceptible to host significant biodiversity. In addition, in such cases, the stock and emission of carbon from existing structures is usually significant compared to arable lands.

Lower consumption of fuels and energetic effort in plantation maintenance is required for afforestation achieved on arable lands than on other lands (abandoned arable, pastures, etc). Issues that come out may have negative or positive impact on synergetic approach: land ownership and cadastral situation, land planning and legislation on land use, procedures on land use change, environmental impact assessment legal requests, consolidation of land (total area for afforestation, shape of the contour), capacity of negotiations of the different stakeholders or decision makers, institutional communication and the pressure and will of local populations to change from traditional to new life style. Also, land/soil status (chemical, physical and biological degradation), nature conservation interferences and type and structure of existing vegetation holds the key to understand and approach synergetic projects of afforestation.

22.2.5 Type of forest structure/plantation to be created

Multipurpose forests are generally the target in most cases of afforestation, having as main targets to "heal the poor lands", and further on to offer wood for consumption, protect communities against disasters and contribute to local social security by additional sources of income and alternative bioregenerable energy. Land use change is associated with emissions, which are higher as the current land use is less intensive.

Denomination of tree based structures is firstly driven by its designated spatial pattern (belts, forest like, patches) and purpose (halting erosion, windbreak), while other features remain secondary (management type, wildlife habitats, hydrological role, biodiversity sources, etc). Based on plantation of trees, whatever their purposes, there are several types of key structures to be created: forest, plantations/tree crops, agroforestry and pioneer/ transitory trees plantations. Establishment of any such structure generates different impacts on current ecosystems, in terms of biodiversity depletion and change of carbon stock/CO_2 emissions, as well as on other green house gas emissions (Table 22.1).

Minimizing the impact on biodiversity or carbon pools is associated with decisions on the technologies to be used for land preparation, plantation works or designing spatial pattern of plantations, removal or integration of existing vegetation in the new forest structure, selected species, connectivity and integration with existing forests, and cycle length and management type based on beneficiary needs. For some regions, increased frequency of intense or repeated droughts brings an additional factor in decision making process, namely climatic risks, what could be addressed properly based on specific coping local experience in different phases of the project (i.e autumn plantation, irrigation of plantations or versatile tree species).

22.2.6 Selection of species to be planted

Indigenous *vs.* exogenous species is the most challenging decision to be made in an afforestation project. This issue is more sensitive in case of private lands when owners have their own needs and have to operate under the restrictions of technical norms/regulations that promote ecological, not necessarily economical, solutions

Table 22.1. Likely impact of different types of forest plantations on biodiversity and carbon stocks and emissions

Main type of plantation structure	Impact on local biodiversity		Impact on carbon stocks & green house gases emissions	
	Positive	Negative	Positive	Negative
Local/ indigenous species	Self standing on medium / long term	Removal of current biodiversity	Permanent carbon stocks, trigger for biofuel and industrial wood	GHG emission from current structures
Exogenous species	Removal of current effort out of natural forests	Removal of current biodiversity Different degrees of genetic pollution (locally or distance) Soil repeated disturbance	Permanent carbon stocks Downstream fuel substitution	GHG emission from repeated soils disturbance Energy and carbon intensive technologies for (re)planting
Agroforestry	According local *vs.* exogenous species	Diminish natural areas	Allow implementation of neutral GHG emission land use models	Increased GHG emissions form pools and intensive associated activities
Fast growing crops (woody bio energy, pulp, etc)	Removal of current effort out of natural forests	Remove of local species Genetic pollution of local species	Replace classical fuels or supply wood industry	Repeated GHG emissions and additional energy input for activities

for species assortment. Advantages offered by exogenous species (like growth rate, wood quality or market demand) overcome the hidden and diffuse benefits generated by local species promotion (biodiversity conservation, site adapted). Such decisions are assisted by technical norms (normally legally approved), that provide advice on appropriate range of species, their share in composition and technology to be applied so that a high probability of a successful plantation under local circumstances can be assured. Actually, the type and degree of degradation, climatic conditions and management purposes determine the assortment of species to be used, usually from a limited number of options.

In case of carbon oriented business the interest for a high rate of annual carbon storage brings additional stakes in decision making on the selection of afforestation species. Generally speaking, from carbon sequestration point of view, the tree species may be categorized as: fast growing and high wood density; fast growing and

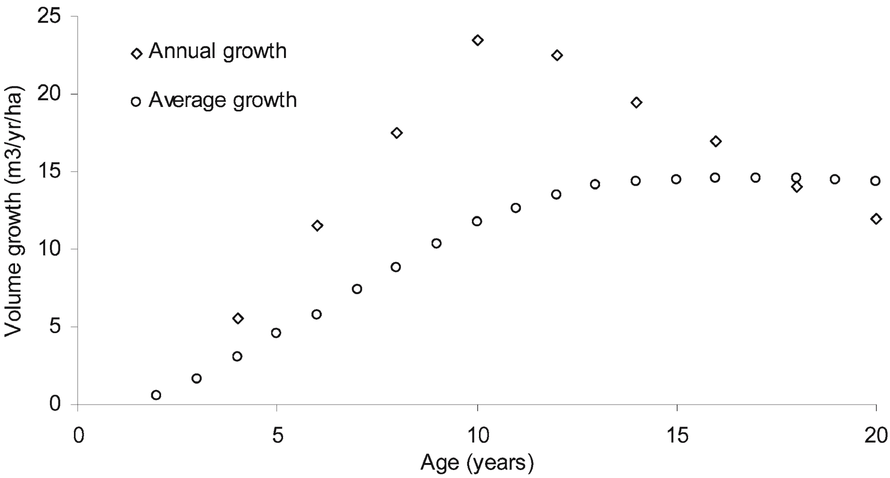


Fig. 22.1. Volume growth pattern in an exogenous poplar (*Populus hybride, I 214*)

low wood density; slow growing and low wood density. Classic forestry is "wood volume based" that allows cutting stands only after the age when rate of current annual growth in volume equals the average growth in volume (Figure 22.1).

Compared to this traditional approach, in the case of carbon sequestration interest, production cycle may be set shorter based on maximal value of annual current growth of the stand. Such decisions should involve a thorough analysis of subsequent benefits (wood, market need and supply for short cycles plantation products, i.e. pulp for fuel or cellulose, etc) and based on carbon or energy balance of whole production cycle of final wood products. In terms of green house gases emissions the effect of repeated irrigation and fertilization must be accounted for.

Different efficiencies in carbon sequestration of indigenous compared to exogenous tree species is shown in a particular case of afforestation of degraded lands in south west of Romania (Figure 22.2). Over 100 years analysis span, the total carbon accumulation in stands of exogenous tree is almost 6 times higher than in indigenous one (simulated with CO_2fix, v2.1; Nabuurs 2001; Masera 2003).

Under likely climate change, the key in afforestation is to approach species of trees that are versatile both in terms of different structures or management and the projected change in climate (droughts, shifts in vegetative seasons). Practically, tree species already tested in neighboring existing plantation may be used or species that allow both coppicing and old forests stands management (just to offer flexible option for management in case of climate change) (Blujdea 2002).

22.2.7
Afforestation technology and plantation maintaining frame

Land use change from current to forest plantation often requires high input of energy and intensive carbon emission. Usually, the afforestation technology refers

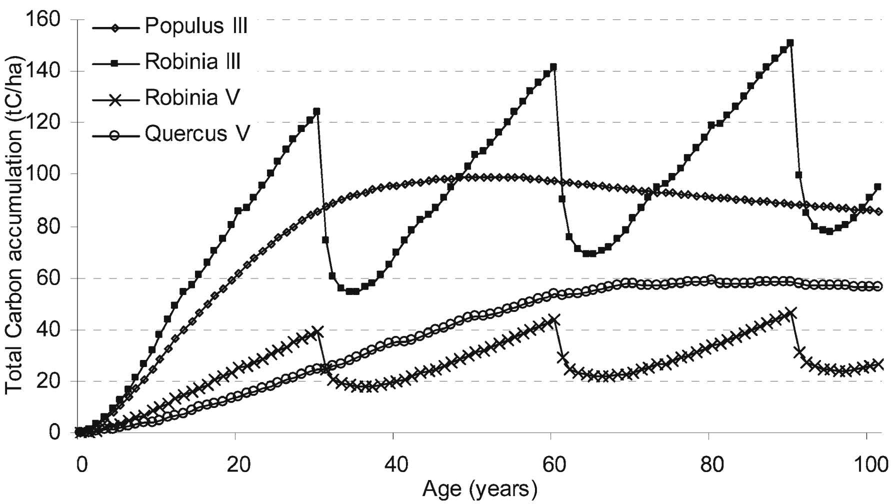


Fig. 22.2. Whole cycle carbon accumulation in different productivity stands of indigenous *(Quercus peduculiflora, Populus alba*) and exoge-nous (*Robinia pseudoacacia*) species

to a specific range of activities that would ensure successful establishment of the plantation. Currently, these technologies are energy and carbon intensive, with emissions both from machinery and ecosystem pools that additionally generate a heavy impact on existing biodiversity which is proportional to the intensity of management. Such intensity is actually caused by imposed activities set both by legal norms (standardized technologies) and the risk of unsuccessful plantations, especially in areas under drought. A full sequence of a standard afforestation technology comprises of site and soil preparation, seedling plantation, gap filling and maintenance/tending operations until the stage of canopy closure.

Plantation maintenance is intensive as well, not so much in terms of carbon emissions, as in terms of biodiversity reduction and replacement of species belonging to current structure to occasional associations in a transient structure. Stable flora of new forests may come in 2 to 3 decades, but its richness depends on seed sources. In cases of plantations established for ecological rehabilitation purposes, ground vegetation becomes closer to natural stands if there are available seed sources in the area (a management measure could be to transfer litter from natural forests to plantation to ensure the transfer of seeds and microflora). Forest ground vegetation has specific abilities to loosen upper soil layers and improve soil physical status, compared to other non forest species. Compared to arable lands, the forest plantation may host and ensure propagation of invasive species, both herbaceous and woody.

Specific management of plantations on sandy dunes, over the very early stages of development (First, and likely the second growing season of plantations) may have side effects on GHG balance of the soils due to fertilization and irrigation of associated crops (e.g. water melons) established between planted tree rows. The use of ammonium nitrate is followed by nitrous oxide release in the atmosphere, an effect that has to be quantified. Irrigation is not expected to create additional release of carbon from such soils due to low carbon content under continuous use for long period.

22.2.8
Forest administration and planning, management type

A key question is if the created forest is permanent or not. There are cases when community or owner enthusiasm of owning forests decreased in a short time and the young trees have been cut or plantations are heavily grazed. Forests administration, planning and management types are key issues under consideration when approaching an afforestation project. Over the forest cycle, the management objectives may change according evolution of ecological and societal needs, but the shift needs to be maintained within the framework of sustainable development. Management standards and human pressures (illegal cutting, grazing, accidental fires, deforestation, poverty) are issues that should be taken into consideration when planning an afforestation project.

Improvement of degraded lands by afforestation is associated with a trade off between the management purposes and the limited available site resources for forest establishment and growth. Traditionally, on heavy and medium eroded soils some exotic species are recommended, while low degraded soils are suitable for local indigenous species (specific to the natural type of forests in that area). Sustainability of forests in such areas is related to a certain management type adapted to the local environment, which actually contributes to the selection of the most suitable species (e.g. sprouting species are preferred to non-sprouting ones or those yielding other economic advantages than wood). In this respect some exotic species naturalized in Romania, like *Robinia pseudoacacia,* are the only viable solution for extreme types of sites (i.e. sandy dunes), where none of the local indigenous species has any chance to reach a minimum level of productivity or even to survive. In such situations, exogenous species present themselves as an optimal solution in providing convenient carbon sequestration compared to any local tree, and thus contributing significantly to the afforestation cost coverage, in addition to ecological and societal services.

22.2.9
Forest sustainability and regional/local integration

Behavior of local people against the forests created is crucial in ensuring their sustainability, and a range of question must be answered already when planning to establish a new forest: How does it integrate into local/regional land uses? Do people perceive the forest as wood supplier or acknowledge that the forests offer multiple benefits? Are they able to restructure their daily life and enjoy long term benefits of forests? Do they accept that forests have tight limits in offering goods (wood, etc) and services (protection, etc)? Is there adequate communication between planners and administrators? Are decisions in project steps taken with the participation of relevant local communities?

A high rate of internalization of benefits of the forests, in terms of a significant contribution to local economy and income patterns, is usually a strong driver to ensure long term sustainable management of the forests. Awareness of this issue versus a poor understanding of man-forest relation, is an issue to ponder on. As a general rule, the poorer the area, the higher the risk for forests sustainability, to which local interests (i.e. corruption and groups interests), real ownership of forest or capacity of owners to organize themselves, and implementation of transparent and equitable benefits sharing mechanisms should be added.

22.2.10 Project's carbon commercial aspects

Financing of carbon sequestration may act as an incentive for triggering afforestation programs or projects. Based on negotiations under UNFCCC and Kyoto Protocol, Annex I countries may use activities under Art 3.3 of the Kyoto Protocol to prove their emission reduction, namely ARD (afforestation, reforestation and deforestation) and may select optional activities under Art. 3.4, like revegetation (all definitions according FCCC/CP /13/Add1), for the same purpose. These arrangements open stronger discussions on the relations between financing of mentioned activities and emission reduction targets.

22.2.10.1 Project baseline – carbon approach

In a project approach, the key is to develop sound carbon accounting system, which means to establish a carbon reference stock against which the project generated accumulation may be assessed as accurately as practically possible. Accumulation of carbon in biomass may be satisfactorily estimated and verified, but in case of soils (especially for soil organic matter component) associated costs are high since credible statistical sampling in the form of large number of samples is required, caused by the large variability of SOM. Soil issue is generally complicated as it is necessary to address both scientific issues (in terms of replicable techniques, laboratory, statistical framework and quality assurance) and practical approaches (field sampling, appropriate equipment, achievable targets, etc.). Consequently, a decision needs to be made as to whether soil carbon is to be considered in the transaction deal or not. A full environmental integrity approach would be to prove that the soil is not a source, at least in the long term. This maybe true in case of afforestation of arable marginal land where soil organic matter is low, but in case of other less intensive current use (pastures, hayfields etc.), increased emissions associated with land use change are likely to occur and hence a concern for calculations of real net absorption from atmosphere.

In case the soil is taken into account the actual carbon stock in the soils of the area to be afforested should be determined just before the afforestation work starts, to ensure that short term emissions associated with land use change are offset by medium and long term sequestration.

A certain baseline survey implies the stratification of the land to be afforested in homogenous strata from the point of view of carbon in the soil, largely variable with the soil type and land uses. Recent history of lands in terms of tillage carried out is also important, and the same type of soil preparation over a long period creates a certain carbon balance with the atmosphere. In this respect, soils under agricultural crops may be considered to have a steady carbon balance with the atmosphere and tillage of soils as part of the site preparation for the afforestation is not associated with an increase of carbon release from soils. In the case of pasture lands, an increase of carbon release from soils is expected during the site/soil preparation work and consequent soil maintenance operations, for a short span (Liski 2002; Smith 2005).

22.2.10.2
Projection and validation of carbon accumulation

Patterns of biomass and carbon accumulation, respectively, largely depend on tree species, site conditions, as well as on afforestation schedule, considering that early plantations will produce earlier carbon accumulation and that there could be global and local environmental associated effects. Several projections regarding carbon accumulation in the project may be considered and accordingly several options would be available for the project negotiation culminating in one option for the final purchase agreement among the partners. When simulating carbon accumulation in tree plantation, entry data are generally provided based on yield tables used in forestry, which include wood volume which is late age oriented and can induce large uncertainties in early stages of projections. Presumed and simulated plantation productivity and production are validated as much as possible in the early stage of project (by assessing existing other plantation) or by field measurement (Figs. 22.3 and 22.4).

According to the recent developments regarding the afforestation activities based on scientific achievements, there is a statistical evidence of carbon sequestration in the biomass (foliage, stems and branches, roots) and soil (litter and organic matter in the soils) over short time periods.

Projections should represent "*bona fide*" estimates of the accumulation of carbon in the afforested area, as each approach must be based on certain requested input data and computation pattern, but it involves often much expert judgment or field measurements in similar plantations/stands in the neighborhood, if available. Consequently large uncertainties are associated with simulation of carbon accumulation in afforested areas, which is actually a continuous challenge for the scientists. One available option is to choose the minimum projection accumulation in the project, which allows both partners to be pretty sure about the achievability of the carbon target of the project. This would also allow the seller to get the market price at the moment of delivering the extra carbon sequestered in case of better performance of the project, if initial purchase contract did not state otherwise.

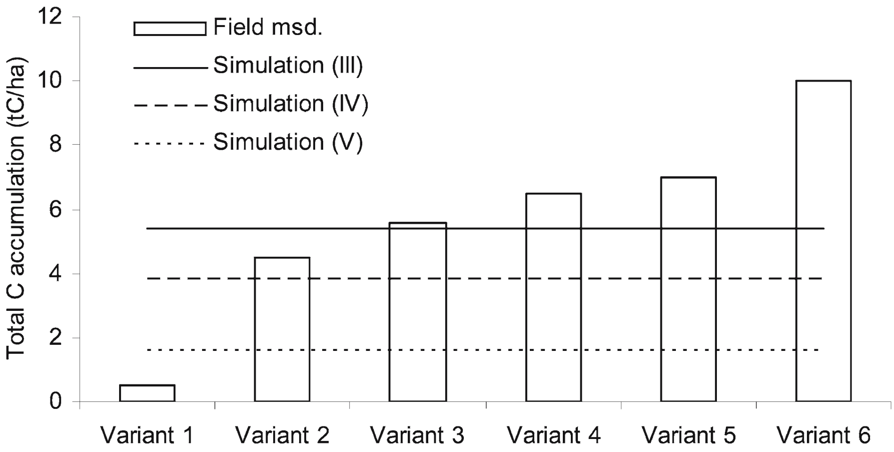


Fig. 22.3. Early accumulation of carbon in total biomass compared to simulated (*Robinia pseudo-acacia, 3 years old plantations*)

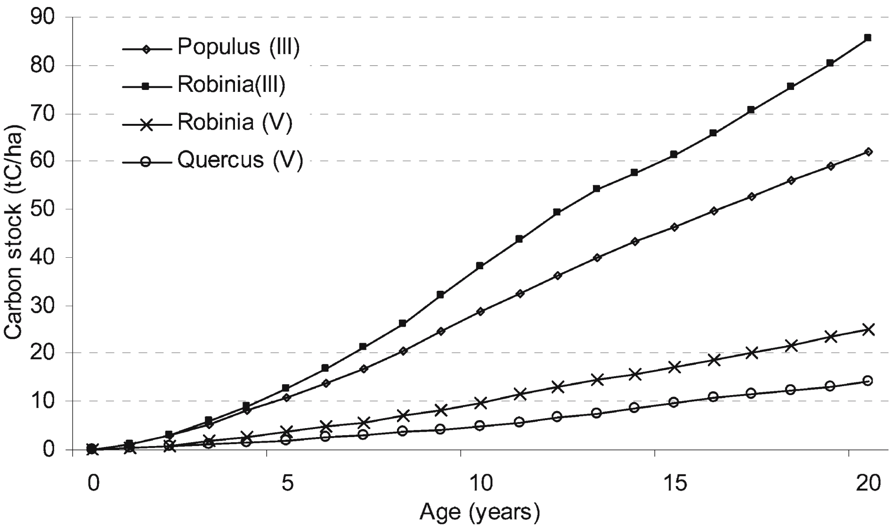


Fig. 22.4. Total carbon sequestration in 20 year-old plantations of different species (pure stands, first rotation) (generated by CO2fix, v2.1; Nabuurs 2001; Masera 2003, based on Romanian forest yield tables)

In the case of a Romanian afforestation project, the field measurements done in adjacent plantations to the project area showed a higher amount of carbon than predicted with CO_2Fix ver 2.1 (Nabuurs, 2001; Masera, 2003), mainly due to specific ecosystem processes (low rate of decomposition of necromasis) and higher growth rate of the stand than the initially projected one. Field estimation of accumulated carbon requests an appropriate approach for ecosystem components (stems, branches, foliage, DOM, SOM) both in terms of the method and the statistical framework adopted. Maximum yield approach as a basis for a carbon purchase agreement could be risky as based on project performance, except in the case where additional guarantees as "hot air" compensation for non-performance projects could backup the transaction amount initially planned and agreed.

22.2.10.3 Carbon estimation

Vegetation establishment on poor lands is associated, in many cases, with low productivity of the established forests due to the site conditions, and this creates difficulties in predicting and quantifying the carbon accumulation. Commercial afforestation projects are assessed by monitoring and reporting.

Annual reporting may refer mainly to an overview of the implementation stage: annual afforestation pace, composition of plantation, survival rate, records on fuels and fertilizers used.

Once the project implementation starts, every 5-7 years the amount of carbon sequestered has to be accurately estimated, with the purpose of assessing the project performance and to balance the cash flow between partners (in case of annual payment started at the beginning of the project). Such monitoring activities are supposed to identify any change of the size of the afforested area included in the project, any major damage that may disturb significantly the carbon accumulation process and to actually quantify the carbon stocks. Monitoring activity should be carefully considered in terms of costs and desired objectives, since an increase in precision would imply a larger number of permanent monitoring plots, which leads to an increase in the cost. Carbon estimation through monitoring must consider the Marakesh pools, as previously concluded by project parties, i.e soil organic matter, dead organic matter, trees stem, branches, foliage and roots. In the monitoring year, the right moment for biometrical and soil measurement should be the one showing stable accumulation of carbon in the ecosystem parts, which is the end of the summer, just before the leaves fall (15 July to 1 September in temperate regions).

Annual or periodic reporting manifests itself as a tool to assess the performance of a project, and it has a strong component of communication amongst project partners. Also, it includes avoiding double accounting and transfer of carbon offsets to relevant partners.

22.2.10.4 Biodiversity assessment

There is no baseline for biodiversity, but it is assumed that it correlates to land use. Still an Environmental Impact Assessment (EIA) is performed before the start of the project and sensitive areas are identified and excluded or mitigation impact strategies must be approached. Biodiversity change generated by afforestation should be also assessed over the monitoring. Simple and economically key parameters should be considered for assessment over the project period; the biodiversity gains generated by land use change from degraded land to forest plantation, would likely require an in depth multilateral research and assessment, beyond the pragmatic monitoring purposes in order to fulfill the Kyoto requirements. A key for biodiversity monitoring would be end-of-food chain species in the ecosystem (e.g. raptors, birds). Measures to mitigate the impact on local species and associations could include connecting existing forest patches; partially preparing the site in order to allow existing vegetation to continue living; soft site preparation technologies and reliance on existing vegetation as nucleus for further improvement of stand structure; implementing management plans for wildlife; forbidding and guarding against grazing or illegal cuts; and assessing traditional knowledge in order to balance the needs of local populations in certain species or a specific product.

22.3 Conclusions

Afforestation is accepted as a key solution for "healing" the degraded lands that occur almost all over the world, but with a higher occurrence in dry and drought affected areas. Afforestation projects or programs suppose a range of actions and arrangements that imply institutions, legal and technical expertise and adequate funding that assume associated and relevant risks, as well. One way to ensure financial support is via carbon transactions that may cover a good share of total project cost, under the relevant articles of the Kyoto Protocol (3.3, 3.4, 6 or 12) which may act as an incentive for national resource mobilization. Direct and synergetic benefits of the afforestation toward local population and local environment remain key objectives, to which global benefits of carbon sequestration could be added. Improvement of land use by afforestation contributes substantially to the environmental integrity of the Kyoto Protocol and the mitigation of the climate change effects.

References

Abrudan I, Blujdea V, Pahon u C (2002) Afforestation of degraded lands in Romania in the context of the efforts to mitigate the impact of climate change (in Romanian). Rev Pad 3: 1-5

Abrudan I, Blujdea V, Brown S, Kostuhin V, Pahontu C, Phillips H, Voicu M (2003) Prototype Carbon Fund: Afforestation of degraded agricultural land in Romania. Rev Pad 118, 1:5-17

Blujdea V, Abrudan I, Pahontu C (2003) Afforestation of bad lands financed through Joint Implementation projects, Seminar FAO/ECE on Strategies for the sound use of wood, 24-27 March 2003, Poiana Brasov, Romania (TIM/SEM.I/2003/R.23)

Blujdea V, Rosu C (2002) Forest aspects of climate change impacts (in Romanian), In: Proceedings of Transilvania University Scientific conference on sustainable forest development, 2002, Edt. Universitatii Brasov, pp. 39-42

Brown S, Phillips H, Voicu M, Abrudan I, Blujdea V, Pahontu C, Kostyuhin V (2002) Romania Afforestation of degraded agricultural land project – Baseline study, Emission reductions projections and monitoring plans, Report prepared for the World Bank, 2002, 144 pp.

Geambasu N, Blujdea V (2002) Afforestation actions in desertification risks areas, In: Proceedings of the Romanian-Spanish Symposium on "Preventing and Combating Desertification in Romania", December 2002, Bucharest, pp.12-18

Houghton J (2003) Revised estimates of the annual flux of carbon to the atmosphere from changes in land use and land management 1850-2000, Tellus B, 55:378-390

Liski J, Perruchoud D, Karjalainen T (2002) Increasing carbon stocks in the forest soils of western Europe. Forest Ecol Manag 169:159–175

Masera, O., Garza-Caligaris, J.F., Kanninen, M., Karjalainen, T., Liski, J., Nabuurs, G.J., Pussinen, A. & de Jong, B.J. 2003. Modeling carbon sequestration in afforestation, agroforestry and forest management projects: the CO2FIX V.2 approach. Ecological Modelling 164: 177-199.

Nabuurs, G.J., Garza-Caligaris, J.F., Kanninen, M., Karjalainen, T., Liski, J., Masera, O., Mohren, G.M.J, Pussinen, A., Schelhaas, M.J. 2001. CO2FIX V2.1 – manual of a model for quantifying carbon sequestration in forest ecosystems and wood product. ALTERRA Report 445. Wageningen, The Netherlands. 48 p.

Smith P (2005) An overview of the permanence of soil organic carbon stocks: influence of direct human-induced, indirect and natural effects. Eur J Soil Sci 56:673-680

UNCCD (2000) Land Degradation in Central and Eastern Europe: Proceedings of the Workshop on Land Degradation/ Desertification in Central and Eastern Europe in the context of the UNCCD, held between 8 – 9 May 2000, Brussels, Belgium, available on www.unccd.int/regional/centraleu/meetings/regional)

CHAPTER 23

The EU-Funded Medcoastland Thematic Network and its Findings in Combating Land Degradation in the Mediterranean Region

Pandi Zdruli, Cosimo Lacirignola, Nicola Lamaddalena, and Giuliana Trisorio Liuzzi

Abstract. Land degradation in the Mediterranean is as old as its history. There is ample evidence for instance showing that ancient Greeks cut their forests to expand cultivation on the sloping lands causing thus extreme erosion and leaving behind abandoned badlands. In the area of Aleppo, Syria called "hundred dead seas", archaeological surveys demonstrate that 1-2 m of soil was washed away during the first century AD following invasion of several armies and massive deforestation. The same is true for eastern Turkey, Jordan and Lebanon showing evidence of forest clearing since Roman times. Lebanese cedars reached not only the Egyptian Pharaohs but they were used even in the Balkans for building deluxe homes.

In its closest meaning land degradation brings inefficiency to the natural ecosystem in performing its functions and services, including both productivity and environmental ones. The resource base is made of several components, including climate, biosphere, water, soils, etc, and is under continuous pressure from natural events (some of them disastrous) as well as from human-induced pressures. These last could mitigate/reverse or accelerate the intensity of degradation. As long as all the components of the resource base are included in the analyses, we are discussing *land degradation*. Once the same pressures are imposed only on the *soil* component, then we are talking *soil degradation* that in its narrow sense means physical, chemical and biological degradation that inevitably brings inefficiency to the soil itself to perform its productivity and ecological functions.

Desertification is also land degradation but according to the United Nations Convention to Combat Desertification (UNCCD) is confined within well-defined climatic domains that include arid, semi arid, and dry sub humid regions of the world resulting from various factors including climate variation and human activities. More closely desertification relates to drylands having an aridity index of 0.05-0.65 (excluding polar and sub-polar regions). Aridity index is calculated as the ratio of mean annual precipitation (PPT) to mean annual potential evapotranspiration (PET). Experience shows that scientists and policy/decisions makers alike use the terminology that better fits their agendas (including political ones). All the abovementioned forms of resource base degradation are present in the Mediterranean.

The European Commission (EC) has been very active in its Mediterranean policies and has tackled a number of environmental issues dealing with sustainable growth, natural resources management and integrated rural development, to point out a few. The need for these interventions derives from a set of factors ranging from food security, migration, economic development, as well as peace and political stability in the region.

One of the projects funded by the EC under the 5th Framework Programme is also the MEDCOASTLAND Thematic Network whose main goal is *Mediterranean coordination and dissemination of land conservation management to combat land degradation for the sustainable use of natural resources in the region with special emphases on coastal areas*. The network brings together 13 countries (from northern Mediterranean Europe, North Africa, Middle and Near East) making a total of 32 partners, of whom 17 are research and educational institutions, 7 represent decision makers and the remaining 8 are farmer's associations and/or non governmental organisations (NGOs). The International Centre for Advanced Mediterranean Agronomic Studies (CIHEAM) through the Mediterranean Agronomic Institute of Bari (MAI-B), in Italy is coordinating the project that runs from October 2002 until May 2007.

MEDCOASTLAND endorses the *ecosystem-based approach* in natural resource management by giving equal importance to both biophysical and socio-economic features. Conclusions show that the fight against land degradation could be successful if land users meet their basic needs through income generating activities and if a good balance is found between bottom-up and top-down decision making and last but not least, if policy, legislation, and the institutional framework make their way towards implementation. Above all a stakeholder approach is needed where every one is aware of its duties and responsibilities.

23.1
Land resources and population pressure in the Mediterranean

The stakes for the very existence of the Mediterranean people have been continuously the same: scarcity of land and water resources. Only 13 percent of the Mediterranean land is considered fit for agricultural use (FAO 2000) and around 5 per cent of the land resources included in the North African and the Middle Eastern countries are suitable for agriculture; the rest is made of pastures, forests, shrubs, urban zones, badlands, rocky areas, and deserts (Fig. 23.1).

Egypt alone cultivates something like 5.4 % of its land (Kader 2004), mostly located in the Nile Delta; the rest is desert sands, shallow, saline, waterlogged, gypsic soils or rock outcrops. Similar scenarios are present throughout the region. Controversially, options for agricultural expansion at the expense of forests or pastures (as it happens in the Tropics) are limited or nil in the Mediterranean. Even if land is reclaimed for agricultural production (through terracing for instance), chances are that it will be of poor quality and it will require intensive investments to be productive or maintain its productivity. Hence, the challenge of sustained agricultural production relies by large upon proper use and management of existing land and water resources that undoubtedly complement each other in the cropping production system. If water would be available, then options for cultivating crops are largely increased, as it is presently happening in Egypt or elsewhere.

A person is considered food insecure, or hungry if food availability or access to food fails below FAO's recommended average calorie intake level of approximately 2,100 calorie day^{-1}, depending on the region. According to this criterion, food security is not a "critical" threat for the region but it may become relevant due to in-

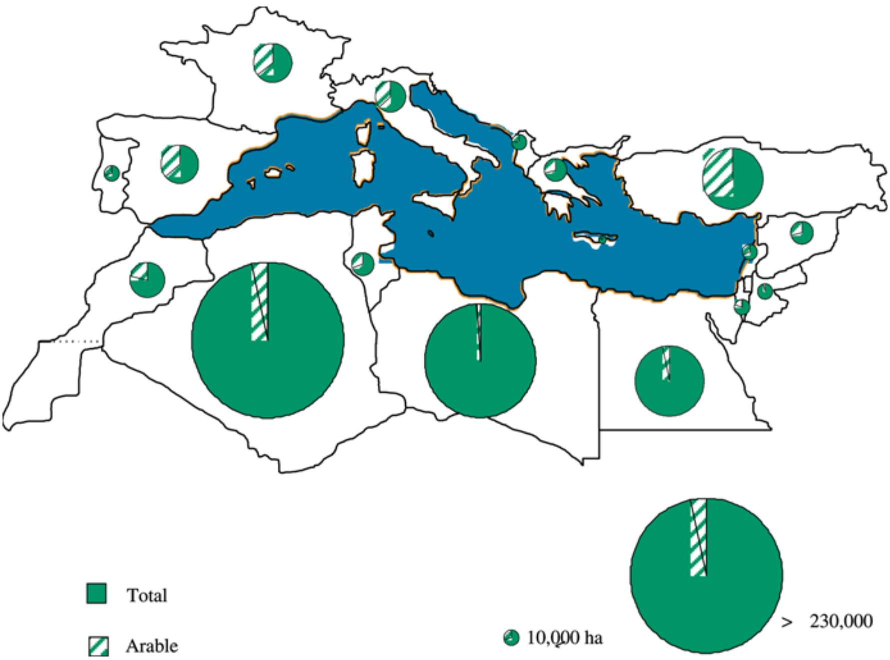


Fig 23.1. Availability of arable land against total land area per country in the Mediterranean (Source: Elaborations of MAI B based on FAO 2001 data)

creasing population and degradation of natural resources. It should be noted however that many countries use substantial revenues derived from the oil (typically Algeria) or tourism industry to meet their food needs. In North Africa in 2005 imports contributed for about 45% of food supplies and the share is expected to increase (USDA ERS 2005). If internal agricultural production would be sufficient, these resources may be otherwise used to improve public health or invest in social programmes. Despite the fact that soil and water resources are extremely limited, they are being rapidly depleted and degraded partly by human activities, and it is mainly the marginalized people, especially women, who bear the brunt of this resource depletion.

According to the World Resources Institute (UNDP, UNEP, The World Bank, World Resources Institute 2003), all of the countries in North Africa and most of those in the Middle East are water stressed and there is little or no additional resource to tap. Most analysts would agree that widespread land degradation and desertification, inefficient and inequitable use of water lie at the root of the problem, for which effective solutions are still pending. Almost one million ha of the irrigated area are salt-affected in Egypt (Gomma 2002) due to poor quality water used for irrigation. It is equally clear that increased food and water security through equitable, productive and sustainable utilization of land and water resources would provide a measure of relief, and increase especially the well being of the most vulnerable people in the region.

Even though the size of the Mediterranean basin is relatively small, there are several hundred million people living in it of which 286 million currently live in North Africa and the Middle East. Overall there are 428 million inhabitants in the region (Blue Plan 2005). The population has increased by 50% over the last 30 years and the trend remains high especially in the southern part of the basin at 2.1% change annually while the population increase in the urban areas of North Africa and the Middle East reach as high as 4% and is mainly concentrated in the coastal zones. The population in the southern and eastern part of the basin could reach 300 million people by the year 2020 (Blue Plan 2005). Another typical Mediterranean characteristic is that between 50 and 70 per cent of the population lives with 60 km from the coast.

Due to the increased population pressure and continued pace of land degradation, it is expected that the available arable land per capita in the whole Mediterranean would decrease from 0.48 ha per person in 1961 to 0.22 ha in the year 2020. The figure is quite stable for Mediterranean Europe, but drastic changes are foreseen for the southern and eastern countries (Figs. 23.2 and 23.3).

Population pressure is exacerbated also by the tourism industry. The Mediterranean is the third most preferred international tourist destination and the first for European tourists, accommodating around 218 million visitors every year. According to the World Tourism Organisation, tourists' flows in the Mediterranean would increase. By 2025 the region would receive annually about 396 million international and 273 million domestic tourists. France, Italy and Spain alone would accommodate more than 75% of the international tourists while Turkey would become the fourth destination in the Mediterranean with about 34 million international visitors per year (Blue Plan 2005).

To these figures should be added many more million domestic tourists who will spend their holidays or weekends on the coast. A typical example is Malta, an EU country with less than half a million inhabitants receiving on average 1.2 million tourists per year. The tourism industry plays an important role in the Mediterranean economy and its share is predicted to increase. However, the industry has created a number of environmental problems ranging from loss of agriculture lands, pollution, coastal erosion, and increased water consumption.

23.2 The MEDCOASTLAND methodological framework

During the 70s and the 80s, scientists dealt mainly with *soil degradation* and tried to quantify degradation on physical terms, most typically tons per hectare per year ($t\ ha^{-1}\ yr^{-1}$) in the case of erosion studies. Between the 80s and the 90s the concept of land was largely endorsed, especially by the FAO (1998) that by land meant "A delineable area of the earth's surface, encompassing all attributes of the biosphere immediately above or below this surface, including those near the surface, the climate, the soil and the terrain forms, the surface hydrology (including shallow lakes, rivers, marshes, and swamps), the surface sedimentary layers and associated groundwater reserve, the animal populations, the human settlement pattern

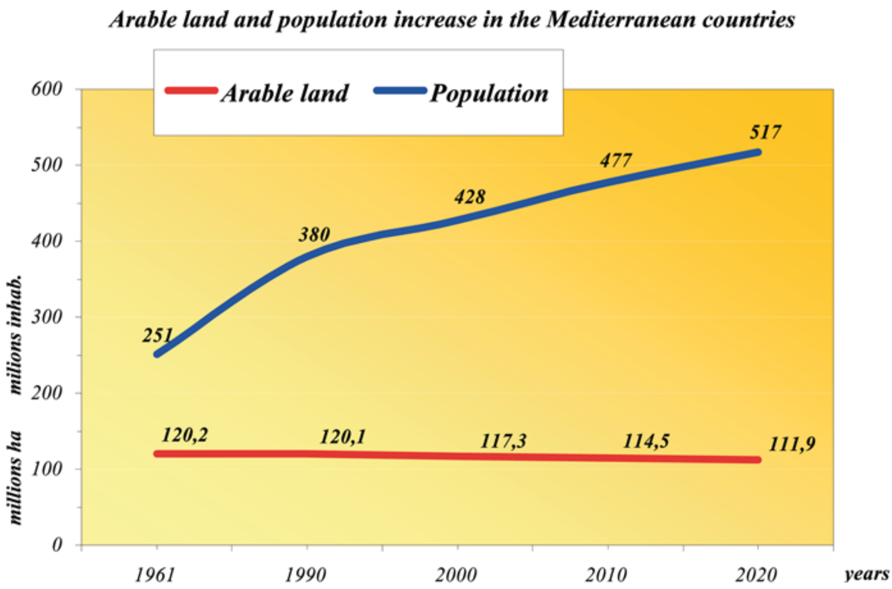


Fig.23.2. Trends of population increase and arable land decrease in the Mediterranean

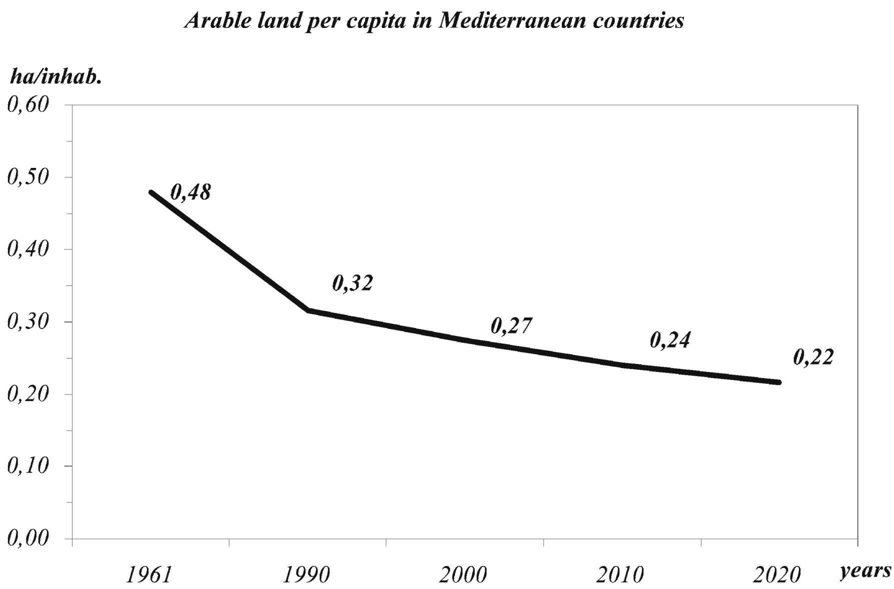


Fig. 23.3. Trends of arable land per capita decrease in the Mediterranean (Source: Elaborations of MAI B based on Blue Plan's 2005 data)

and the physical results of past and present human activity (terracing, water storage or drainage structures, roads and buildings, etc..)".

At this time the wording *land degradation* was the mainstream.

After the 90s a number of national and international organizations, especially the UNCCD and the Convention on Biological Diversity (CBD), endorsed the ecosystem-based approach in combating resource base degradation through preservation and enhancement of ecosystem functions and services. Eswaran et al. (2004) emphasize in particular the role of anthropogenic pressures in accelerating land degradation and desertification. MEDCOASTLAND is based on the same biophysical and human induced factors when dealing with resource base degradation.

Seven Work Packages (WP) support the methodological framework of the project (Figure 23.4). They are all linked to each other in a sequential manner that starts with the identification of the problem (land degradation) (task of WP2); identification of methods to reverse the problem (*i.e.* income generating) (task of WP3); finding the best equilibrium on decision making (through participatory management) (task of WP4); development and implementation of guidelines and regulations that support sustainable land management (legislative framework) (task of WP5); finding ways to ensure continued collaboration among partners (but not only) even after the lifetime of the project (*i.e.* by endorsing a Memorandum of Un-

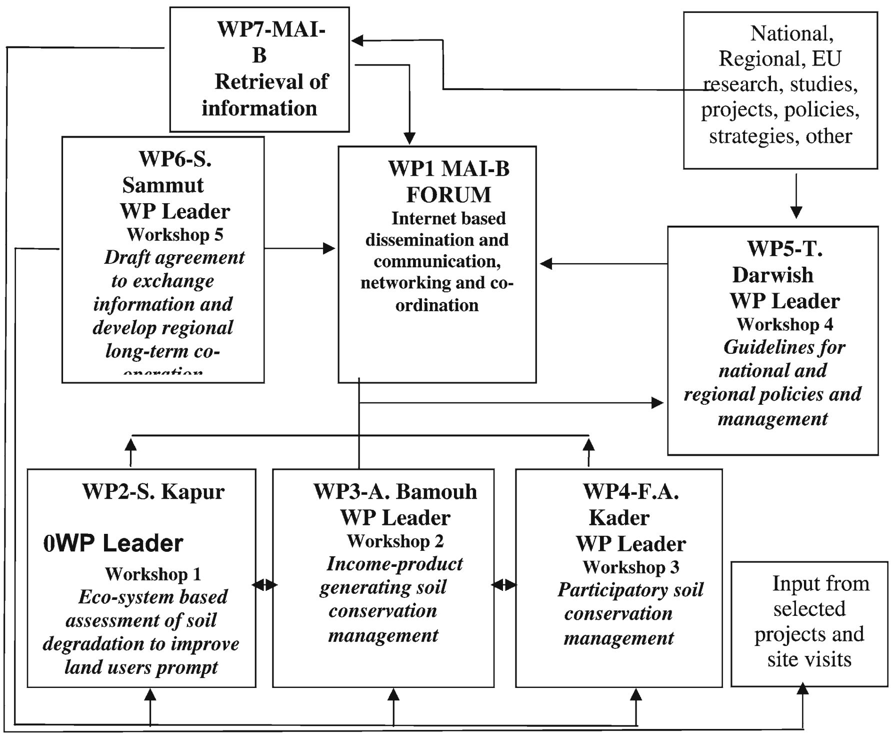


Fig. 23.4. Organisation of Work Packages

derstanding) that was developed by WP6. All the abovementioned activities were strongly supported by WP1, which covered managerial and communication actions, including the creation and updating of the Internet based Knowledge Database and creation of the virtual forum on land degradation. Finally in the context of WP7 almost 3,000 files of information retrieval were collected and downloaded into the Internet-based Knowledge Database.

In addition the project has published five books totalling more than 3,000 pages, eight newsletters, several technical reports and has made available a number of videos showing best management practices and interviews with various stakeholders. The MEDCOASTLAND approach was presented in different international events, including the 18th World Congress of Soil Science held in July 2006 in Philadelphia, USA, in meetings at FAO headquarters in Rome and elsewhere in Europe and beyond.

23.2.1 Partnership

The strength of MEDCOASTLAND stands on its composition that provides the best platform of bringing together researchers, educators, decision/policy makers, and farmer associations along with environmental NGOs. In total the project includes 32 partners representing thirteen Euro-Mediterranean countries (Figure 23.5) of which 17 are research and educational institutions, 7 represent decision makers and the remaining 8 are farmer's associations and/or NGOs. In other words this partnership only reinforces the stakeholder approach.

23.2.2 Objectives

The main objective of the project is *Mediterranean coordination and dissemination of land conservation management to combat land degradation for the sustainable use of natural resources in the Mediterranean region with special emphases on coastal areas.* Other objectives include the establishment of a Mediterranean-wide permanent communication structure between researchers, decision makers, land users and non-profit organisations involved in combating land degradation. In addition there is the identification of major gaps in information and knowledge-base to reach a proper regional understanding of sustainable land management, the formulating of an ecosystem-based assistance methodology for land users, the development of an income-product generating approach in soil conservation management, and the promotion of participatory management of the land system through the drafting of appropriate policies and guidelines to support sustainable land management and to provide a framework that assists in regional planning and on the future EU involvement in natural resources management in the Mediterranean (Zdruli et al. 2006a).

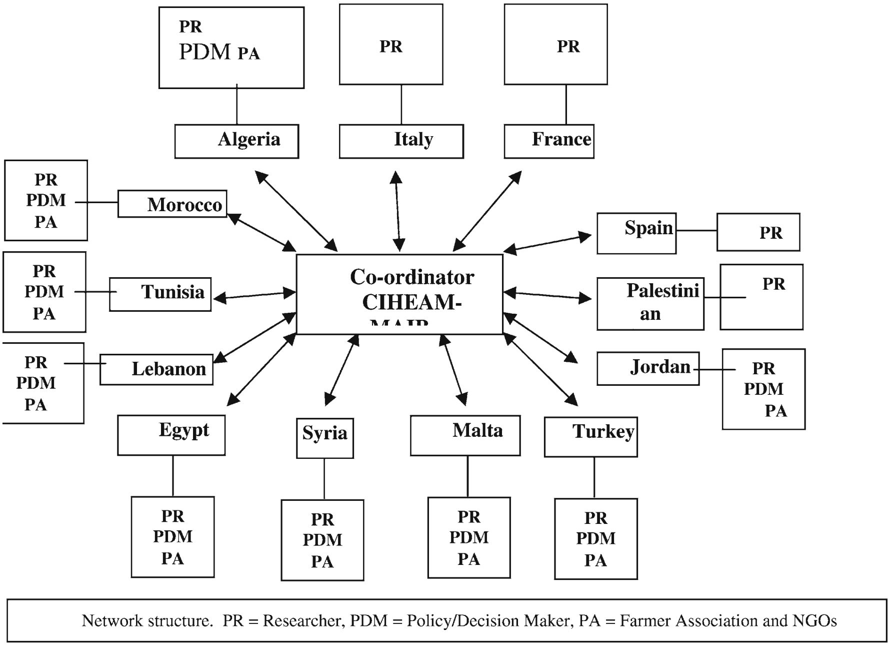


Fig. 23.5. Consortium composition

23.2.3 Results

As of February 2007 the project has completed five workshops held in Adana, Turkey (June 2003), Marrakech, Morocco (February 2004), Alexandria, Egypt (October 2004), Bari, Italy (September 2005), Malta (January 2006) and one Euro-Mediterranean conference held in Beirut, Lebanon (June 2006). A last event would be the Mediterranean wide conference to be held in Tunisia in May 2007 whose theme is: "Status of Mediterranean soil resources: actions needed to promote their sustainable use".

23.2.4 Lessons learnt: The problems

The project has identified water and wind erosion, soil sealing and urbanisation, loss of organic matter and biodiversity decline, nutrient mining, chemical pollution and contamination, floods and landslides, salinisation, overgrazing and degradation of vegetation cover as well as unsustainable irrigation practices as the main land degradation factors in the Mediterranean (Zdruli et al. 2006b). It is clear that interactions between land-based processes on the upper inlands of the watershed augment the pressures on the coastal zones and overall anthropogenic pressures play a crucial role in the whole process. While the economic costs of major threats to European soils like erosion or organic matter decline for instance at EU level are well documented (COM (2006) 232) such estimates remain scattered in the Mediterranean. Country estimates do exist but they are made on locally developed methods and it becomes difficult to compare their results with similar ones in bordering countries.

Major handicaps in land degradation studies in the Mediterranean derive also from the simple fact that there is not yet a comprehensive study to show the real extend (preferably in quantitative terms) of the problem at regional scale. However, it is evident that the problem exists in both European rich Mediterranean countries as well as in the poorer ones on the South and East. Other associated problems include the confusion between actual and potential degradation that various national studies show. Moreover and often national estimates do not include in their assessments socio-economic indicators. There is also overall agreement in many scientific circles that monitoring systems to trace the trends of land degradation and desertification are weak or missing. MEDCOASTLAND shares the same view. Its findings show that yet the communication between several stakeholders involved in the process is still weak not only at regional level but also at national ones, however land and water issues are at the core of the natural resources degradation problems in the region. It should be noted also that costs for ameliorating degraded lands are higher than preventing them of being degraded. Finally, there is an understanding that political stability is a prerequisite for achieving sustainable development and enhancing environmental protection. The events of the summer 2006 in Lebanon are yet another proof of this.

23.2.5
Climate change and its possible effects in the Mediterranean

There are sets of indicators that could be considered in these analyses. One direct link could be found in soil organic matter content. Studies have shown that land use changes and intensive cultivation could decrease the amount of soil organic carbon up to 60% in less than four decades (Zdruli et al. 1995). Typical Mediterranean climate characteristics are less precipitation (almost 80% registered from October to March) and higher temperature values compared to temperate regions. This means higher organic matter mineralization rates consequently lowering the soil fertility level and the water storage capacity of the soil (Zdruli et al. 2004).

If climate change scenarios would be proven right (apparently there is ample evidence nowadays on this), the Mediterranean would suffer from a number of consequences. A study named Modelling Impacts of Climate Extremes (MICE Project 2005) funded by the European Union found out that the Mediterranean is expected to become drier with prolonged droughts in summer and reduced winter rainfall. Other findings show that heavy rainfall events would be accompanied by flash flooding, urban drainage, erosion, slope stability and ground water recharge. Agricultural production is expected to decline, due to shorter growing season, extreme events during developments stages, heat stress during flowering, and rainy days during sowing. The temperature in the Mediterranean may increase by 0.3-

0.7 °C per decade and summer rainfall may decrease by 16% causing even more desertification. Sea level rise may invade substantial areas in the lower coastal zones. Italy alone may loose 6% of its territory while half of Europe's coastal wetlands may disappear. Finally, climate change scenarios would have an effect on the Mediterranean economy especially on tourism as due to hotter temperatures tourist may shy away and look for cooler destinations.

23.2.6
Lessons learnt: Responses

Strengthening the links between all the Mediterranean countries is not merely a political question related to migration and social problems. It is a question of stability and long-lasting development of the region. The European Union is convinced about this fact and since many years has been very active in its Mediterranean policy. The first Intergovernmental Conference on the Protection of the Mediterranean was held in 1976 in Barcelona where the Mediterranean Action Plan was approved. This was followed by a series of conferences and treaties.

One of the most important events, again held in Spain, was known as the Barcelona Convention for the Protection of the Mediterranean that was signed in 1995. The initial Barcelona Convention of 1976, which entered into force in 1978, and amended in 1995, and the Protocols drawn up in line with this Convention aim to reduce pollution in the Mediterranean Sea and protect and improve the marine environment in the area, thereby contributing to its sustainable development. In 1996 the governments of the region and the European Community put in place the Mediterranean Commission on Sustainable Development (MCSD) with a very broad and ambitious mandate in terms of sustainable development strategy. Additionally the EU has funded a large number of research projects through the International Cooperation in the Mediterranean (INCO and MEDA Programmes). The EU strongly endorses recently the European Neighbourhood Policy with all the countries of the region. All the abovementioned protocols and agreements have contributed in enhancing sustainable development and environmental protection. The EU funding for the region for the period 1995-2005 is estimated at some 11 billion euros (Corriere della Sera 2005).

Additional funding was also received from various international donors including the United Nations Agencies (*i.e.* FAO, UNDP), the International Fund for Agricultural Development (IFAD) and the Governments of rich countries. In addition, national Governments have invested substantially in natural resources management projects. The Government of Morocco alone intends to spend 405,000 million DH (dirhams local currency) for the period 2004-2009, in co-funding with the World Bank for integrated rural development in the area of Bour (DRI-MVB) with strong components in natural resources management. Similar projects are being implemented through the National Action Plans to Combat Desertification in Algeria, Tunisia, Egypt, Syria, Palestinian Territories, Lebanon, Turkey and Jordan (MEDCOASTLAND database 2007).

The main areas of intervention have been capacity and institutional building. It is worth mentioning that the international and national funding has permitted the establishment of highly qualified institutions and staff in all the countries of the region.

23.2.7 Lessons learnt: Impacts

Findings of the project show that impacts of interventions vary between countries, but are very much linked with the direct involvement of national and local decision makers alike. Experience shows that international community should not consider itself only as a donor, but also as stakeholder assuming full responsibility for the successes and failures of research, cooperation and development projects especially those implemented in the developing countries.

Moreover, every country has its own profile and national characteristics that should be respected and preserved. In this context, the impacts of agro-technology transfer for example have not always been successful as in the case of cotton expansion cultivation under irrigation in the Syrian steppe that was followed by accelerated wind erosion and salinity build-up or the massive irrigation schemes implemented in South Eastern Turkey in the GAP project where salinity is on the rise putting at risk extensive investments and the overall sustainability of the project.

Impacts are by large positive, when the local traditional knowledge is valorised and enhanced (Akca et al. 2005). The Mediterranean is the birthplace of agriculture and is extremely rich in indigenous technical knowledge on sustainable land and water management (Kapur and Akca 2003; Kapur et al. 2004). MEDCOASTLAND findings show that when this precious knowledge is used appropriately, it brings inevitably results as in the case of the management of coastal dunes and the surrounding anthroscapes of Adana in south-eastern Turkey (Akca et al. 2005). Similar examples are available in the management of sloping lands through terracing in Morocco, Malta, Syria and Lebanon.

Continued collaboration is also an important aspect in the process. Impacts could be thus propagated longer if all the necessary instruments are explored to ensure that what was painfully built continue to survive. There are many examples showing that a large number of project cease their activities once they come to the end and funding is no longer available. MEDCOASTLAND has been able to build solid partnerships and a precious human social capital that would continue to thrive with time.

23.2.8 Lessons learnt: Future outlook and recommendations

Assessment of land degradation and desertification in the Mediterranean and especially of its economical damage should be based on benchmarks and indicators and on real data derived through collaborative efforts of national and international institutions. The time has come to replace *ad hoc* “quick and dirty” assessments with scientifically proven results.

Developing and adopting a common methodology to make harmonised estimates of land degradation throughout the region could be a first step to perform and apply regional environmental impact assessments. Addressing different scales and allowing for data compatibility by making the best use of available information should be supported.

Quantitative indicators should be used to assess ecosystem and natural resources degradation by identifying points of reference and unify criteria for assessing degradation and desertification. A consensus on the use of standard sets of indicators has not yet been reached. Most standards are based on bioclimatic or aridity index and on indexes related to soil type or soil erosion. In order to perform sustainable ecosystem management it is necessary to integrate the main components of ecosystem functioning, e.g. biodiversity and species composition, ecosystem fragmentation, socio-economic driving forces, geochemical cycles and global climate change. Establishment of monitoring networks and promotion of data collection through common standards should be promoted to assess the success or failures of actions combating land degradation, desertification and drought.

The use of contemporary tools such as Remote Sensing (RS) and Geographic Information Systems (GIS) and data derived from them should be encouraged to evaluate and monitor land degradation. However, ground data, field surveys and future databases should be combined with these tools to provide valid and accurate results on the degradation process. Harmonization and standardization of RS data is urgently needed. Standard methods of radiometric and atmospheric corrections are necessary to generalize results of research and enable comparison between different countries.

Extensive experience in Participatory Irrigation Management (PIM) should be expanded in Participatory Land Management (PLM) and finally into Integrated Natural Resources Management (INRM). Participatory Land Management at Mediterranean region should involve both identification of threats to the ecosystem and the ways to confront these threats by assuring the direct involvement of the local communities as this process empowers them in enhancing their skills, knowledge and experience leading to greater self-reliance. The institutional capacity of National Resource Management Projects should be strengthened to realize integration and coordination among local institutions.

Local Development Strategies (LDS) should involve new approaches and common features of bottom up, multi-sectoral partnerships, participation, and institutional support. Local governance as an institutional environment should work with other stakeholders to move towards a more integrated approach that involve: creation of an enabling environment; identification of roles and responsibilities of stakeholders; enhancing communication; empowerment through capacity building; efficient mobilization and allocation of resources; participatory evaluation and monitoring; and finally strengthening local governance.

Social Capital Development (SCD) is the core of the sustainable development that focuses on sustainable land management and local development. SCD deals with the creation of networks that enable collective actions and enhance project's effectiveness and sustainability. The social capital development should be built on the bases of trust and solidarity, collective action and cooperation, social cohesion and information communication.

The relation between effective land management and farmer's or land user's active participation is crucial for success. Farmers alone could not bear the burden of land degradation. Top-down decision-making is also dangerous as could ignore real problems; therefore a compromise should be found between bottom-up and top-down approaches.

Drought Risk Management is another important aspect of future research. National-level integrated drought monitoring systems are not operational in the region. There has been limited regional coordination among irrigation authorities, agricultural extension services, meteorological departments, and NGOs, about the extent and impact of drought. The region has an overwhelming need for modern and effective drought early warning systems.

Landmines and unexploded ordinance (UXO) dating since World War 2 and after, affect large areas in the Southern Mediterranean, especially in Egypt. They hinder significantly the regional agricultural, industrial and tourist developmental programmes. There are no databases in geo-referenced digital form for the landmine-affected and de-mined areas that ensure the implementation of sustainable integrated developmental programmes. National humanitarian de-mining programmes should be further strengthened.

Studies are needed to endorse productive farming systems that mostly promote reduced fertiliser use, backing of organic farming, conversion of arable land to grassland, cover crops and strips preventing erosion and fires, preserving areas of special biodiversity, maintenance of existing conservation systems, and preserving farmed landscapes.

Endorsement of non-productive land management measures including set-aside land, up-keep of abandoned land and woodland, maintenance of landscape features including ancient terraces and supporting training, farm income increase, employment and societal attitudes should be encouraged and better explored.

Future rural development projects should promote sustainable agricultural intensification and diversification, strengthen rural education by targeting the rural poor and achieve a better balance between genders towards sustained development and societal equity agreement. Policy briefings could serve as guidance for countries updating or developing policies on sustainable management of natural resources, codes of conduct, and implementation of laws and regulations.

It is of utmost importance to identify and establish the link between soil conservation measures, income-product generating activities and farmer's involvement. Much needs to be done in determining an income-product generating approach for soil conservation management in relation to economic and production aspects generated by the sustainable land management practices.

There is rarely a better place other than the Mediterranean where land and water could complement each other in terms of scarcity and impacts on every day life. Hence, they should receive equal attention. It is impossible to divide the techniques of water harvesting from soil erosion control and waterlogging from flooding and salinisation, just to mention a few examples.

The slow process of policy implementation otherwise known as the "Mediterranean syndrome" (La Spina and Sciortino 1993), characterised by the lack of comprehensive plans or programmes to combat environmental problems and poor cooperation between the various administrative sectors, is hampering sustainable development in the region. Policies and regulations should find their way towards implementation and the support of the scientific community in policy development is essential and should be strengthened.

Addressing sustainability concerns in natural resources management requires the adaptation of an ecosystem based management approach that considers both natural conditions and socio-economic factors. This approach should be ecologically sound, economically viable, socially just, culturally appropriate, humane and based on a scientific holistic approach. Consequently, sustainable natural resources use and management in the region is not a choice but a prerequisite to secure prosperity and improve the livelihoods of its people by establishing societal responsibilities and priorities in this crucial process.

To support and strengthen future activities in natural resources management in the Mediterranean, the CIHEAM MAI-B has taken the lead to establish the Regional Office for Sustainable Land and Soil Management in the Mediterranean (ROSOM). There is agreement among the MEDCOASTLAND partnership that such entity could be instrumental in promoting sustainable use of Mediterranean land resources. A first task could be the completion of the Euro-Mediterranean soil database at 1:1 Million scale (Lambert et al. 2001) followed by a first quantitative assessment of land degradation in the region through a combination of remote sensing techniques and ground truthing. ROSOM could also organise summer schools on soil survey, field assessment of land degradation and practical applications of soil conservation measures. These activities are in accordance also with the EU Thematic Strategy for Soil Protection.

Responsible persons

Cosimo Lacirignola, *IAMB Director*
Gerasimos Apostolatos, *EC Scientific Officer*
Giuliana Trisorio Liuzzi, *Coordinator*
Pandi Zdruli, *Project Manager*

References

Abdel-Kader F (2003) Land degradation and conservation measures in Egypt. In: Zdruli P, Steduto P, Kapur S, Akça E (Eds) Proceedings of the 1st MEDCOASTLAND workshop: Ecosystem based assessment of soil degradation to facilitate land users' and land owners' prompt actions. Adana, Turkey 2-7 June 2003. Number 1. MEDCOASTLAND series of publications. CIHEAM-IAM Bari, Italy. ISBN 2-85352-291-1, pp 456

Akca E, Pekel M, Kapur B, Zdruli P, Eswaran H, Kapur S (2005) The upstream and downstream integrated resource management of the Adana anthroscape. In: Zdruli P, Liuzzi T (eds.)

Promoting participatory management of the land system to enhance soil conservation". Workshop proceedings, Alexandria, Egypt 9-13 October 2004. Number 3. 390pp. MEDCOASTLAND series of publications. CIHEAM-IAM Bari, Italy. ISBN 2-85352-324-1

Barcelona Convention (1976) http://www.unep.ch/regionalseas/regions/med/t_barcel.htm

Blue Plan (2005) A Sustainable Future for the Mediterranean, The Blue Plan's Environment & Development Outlook, (Eds. Benoit and Comeau), Earthscan, ISBN –13: 978-1-84407-259-0, pp 5-6

COM (2006) 232 of 22.9.2006. EU Thematic Strategy for Soil Protection, http://ec.europa.eu/environment/soil/index.htm

Corriere della Sera (2005) Editorial of 28 November 2005.

Eswaran H, Reich P, Vearasilp T (2004) Perspectives on desertification during the Anthropocene. In: Invited Lectures and Abstracts. Fourth International Conference on Land Degradation, Cartagena, Murcia Spain, September 2004. Angel Faz Cano, Roque Ortiz, Gregorio Garcia (Eds) ISBN 84-95781-42-5. Spain. p 25-42

FAO (1998) Terminology for integrated resources planning and management. Choudhury K, Jansen LJM (eds) Food and Agriculture Organization of the United Nations, Rome, Italy

FAO (2000) Land Resource Potential and Constraints at Regional and Country Levels. World Soil Resources report 90, Food and Agriculture Organization of the United Nations, Rome, Italy

Gomma M (2002) Land and water resources information system in Egypt. In: Proceedings of the Workshop on Land Resources Information Systems in the Near East, Cairo, Egypt 3-7 September 2001. Food and Agriculture Organization of the United Nations, Rome, Italy

Kapur S, Akca E (2003) Environmentally friendly indigenous technologies. Encyclopaedia of Soil Science. DOI: 10.1081/E-ESS 120006648. Marcel Dekker

Kapur S, Zdruli P, Arnoldussen A, Gencer O, Kapur B, Ozturk, Eswaran H (2004) Anthroscapes of Turkey: sites of holistic sustainable land management. Proceedings of the 2nd SCAPE workshop 13-15 June 2004, Cinque Terre Italy. pp. 71-79

La Spina A, Sciortini G (1993) Common agenda, souther rules: European integration and environmental change in the Medietrranean states. In: Liefferink JD, Lowe PD, Mol AP (eds) European Integration and Environmental Policy. Belhaven, London, pp. 217-236

Lambert JJ, Daroussin J, Eimberck M, Jamagne M, King D, La Bas C (2001) Instruction guide for elaboration of the soil geographical database of Eurasia and the Mediterranean countries at 1:1 million scale. INRA and Joint Research Centre. Office for Official Publications of the European Communities, Luxembourg, pp. 56

MEDCOASTLAND database (2007) http://medcoastland.iamb.it/index.php

MICE project (2005). http://www.cru.uea.ac.uk/projects/mice/

UNDP, UNEP, The World Bank, World Resources Institute (2003) World Resources 2002-2004: Decisions for the Earth, Balance, Voice and Power. Washington DC 2003, ISBN 1-56973-532-8, pp. 315

USDA ERS (2005) Food Security Assessment 2005/GFA-17, using FAOSTAT (http://faostat.fao.org) and World Food Programme data, Economic Research Service, United States Department of Agriculture, Washington DC, USA

Zdruli P, Eswaran H, Kimble J (1995) Organic carbon content and rates of sequestration in soils of Albania. Soil Sci Soc Amer J 59:1684-1687

Zdruli P, Jones R, Montanarella L (2004) Organic matter in the soils of Southern Europe. European Commission, Joint Research Centre -European Soil Bureau; Expert Report prepared for DG ENV/E3 Brussels. EUR 21083 EN, Office for Official Publications of the European Communities, Luxembourg, pp. 16

Zdruli P, Steduto P, Bogliotti C (2006a) Fostering networking and exchange of information in the Mediterranean region: The MEDCOASTLAND Thematic Network. In: Kepner WG, Rubio JL, Mouat DA, Pedrazzini F (Eds.) Desertification in the Mediterranean Region. A Security Issue. 2005. NATO Programme for Security through Science Series, Volume 3, Springer Publishers, Germany. ISBN 1-4020-3759-7/ISSN 1871-4668. pp. 385-400

Zdruli P, Liuzzi T, Lacirignola C (2006b) Lessons learned from a Thematic Network dealing with land degradation assessment and soil conservation management in the Mediterranean region, Extended Abstracts, 18th World Congress of Soil Science, 9-15 July 2006, Philadelphia, USA.

Managing Land Use, Protecting Land and Mitigating Land Degradation: Tanzania Case Study

R. S. Muyungi

Abstract. For the United Republic of Tanzania, efforts to combat desertification and land degradation generally, are part and parcel of the national efforts to address poverty and ensure sustainable development. More concerted efforts to ensure sustainable land management and combat desertification came after the Rio Conference in 1992. Since then, major milestones include: the 1994 National Environment Action Plan (NEAP) prepared to carry out a national analysis and provide a framework to incorporate environmental considerations into government decision-making processes; the 1997 National Environmental Policy (NEP) formulated to define national goals and strategic objectives in environment; the National Action Programme (NAP) to combat desertification prepared in 1999 under the UN Convention to Combat Desertification (UNCCD); and the 2002 Institutional Framework for Environmental Management (ILFEMP) in Tanzania. The National Strategy for Growth and Reduction of Poverty (NSGRP) of 2005 provides a close relationship between reduction of poverty and the sustainability of the productive sectors, particularly agriculture that counts for 45% of the GDP and about 60% of the export earnings as well as livelihood to over 80% of the population. The NSGRP also views energy as critical for the attainment of the NSGRP and MDG targets. Hydropower, which depends on the functioning and wellbeing of the major water catchments and ecosystems including the dry land ecosystems, is the major source of energy in Tanzania accounting for over 70% of the total national energy sources.

In Tanzania, the impacts of global warming are already vivid. Measurements from 21 meteorological stations have shown a steady increase in temperature for the past 30 years. Because of this temperature increase/global warming, adverse impacts are now felt in almost all sectors of the economy. Severe and recurrent droughts in the past few years have triggered the recent devastating power crisis. The drop in water levels of Lake Victoria, Lake Tanganyika, Lake Manyara and Lake Jipe in recent years, and the dramatic recession of 7 km of Lake Rukwa in about 50 years, are a manifestation of climate change. Eighty per cent of the glacier on Mount Kilimanjaro has been lost since 1912. It is projected that the entire glacier will be gone by 2025. The intrusion of sea water into fresh water wells along the coast of Bagamoyo and the inundation of Maziwe Island in Pangani is yet another evidence of the sea level rise.

Climate change coupled with unsustainable land management and destruction of the water catchments has aggravated the energy crisis and environmental degradation, particularly in the central semi arid areas and the dry sub-humid areas in the southern highlands. In order to address these challenges, the United Re-

public of Tanzania has recently enacted a National Environmental Management Act (EMA 2004) as a framework environmental law to provide a coherent environmental management approach including sustainable land management and the management of water catchment areas. More importantly in March 2006, the Government adopted a National Strategy for Sustainable Land Management and protection of water catchment areas. This is a comprehensive five year programme, intending to address twelve identified challenges, with an estimated budget of about US$ 30 million. For the first year, the government has already committed about US$ 9 million. The exemplary commitment of the government to address sustainable land management through this strategy, has already resulted in tangible outputs. Almost all pastoralists who had invaded the important catchment areas of Usangu (one of the largest catchment areas for hydro power production in the country) in the southern Highlands, have been relocated, and important catchment areas have been declared national reserves, putting them under legal protection from any more encroachments. Each District council has been requested to plant and care for 1.5 million trees annually. Under the strategy, each village has to have a title deed, with land set aside for livestock keeping and for crop production. Other measures, include the promotion of renewable energy as well as alternative sources of energy, particularly in the dryland areas, as a way of addressing the chronic problem of deforestation for energy needs.

24.1 Introduction

Efforts to Combat land degradation and conserve water catchment areas and related ecosystems in Tanzania are linked to the overall national efforts towards poverty eradication and sustainable development. The National Strategy for Growth and Reduction of Poverty (NSGRP) of 2005 provides a close relationship between reduction of Poverty and the sustainability of the productive sectors, particularly agriculture that accounts for 45% of the GDP and about 60% of the export earnings and provides livelihood to over 80% of the population. The NSGRP popularly known as *Mkukuta* in Kiswahili, also views energy as critical for the attainment of the NSGRP and UN Millenium Development Goals (MDG) targets. It is important for productive activities in industry, agriculture, transport and water supply and in the provision of social services such as education and health services. Hydropower, which depends on the functioning and wellbeing of the major water catchment areas and ecosystems including the dryland ecosystems, is the major source of energy in Tanzania accounting for over 70% of the total national energy sources. Energy supply is also therefore dependent on the existence of well functioning and unexploited water catchments, dryland areas and related ecosystems, much as agricultural productivity and sustainability are dependent on sustainable land management, particularly land degradation in the drylands. The challenge is how to make these sectors, individually and collectively, contribute more to poverty reduction and sustain the economic growth envisaged to achieve the national 2020 vision of a country with a transitional economy.

Apart from *Mkukuta*, Tanzania has developed and implemented various policies and strategies to promote environmental and sustainable land management in the dryland areas since independence. Serious involvement in environmental issues and sustainable land management came after the Rio Conference in 1992. Major milestones since Rio include: the 1994 National Environment Action Plan (NEAP), prepared to carry out a national analysis and provide a framework to incorporate environmental consideration into government decision-making processes; the 1997 National Environmental Policy (NEP) formulated to define national goals and strategic objectives in environment; the National Action Programme (NAP) to combat desertification prepared in 1999 under the UN Convention to Combat Desertification (UNCCD) and the 2002 Institutional Framework for Environmental Management (ILFEMP) in Tanzania.

In 2000, a National Parliamentary Committee on Environment was formed to enhance awareness of policy makers on the importance of environment and its integration in the overall development frameworks at national level.

Several other key macro and sector policies have been reviewed and adopted to reflect increased accent towards environmental quality objectives. These include: the Mineral Sector Policy; Wildlife Policy; Fisheries Policy; Forestry Policy; Water Policy, Agriculture Policy, Energy Policy of 2003 and the National Land Policy.

Beyond these, Tanzania has put in place several legislations to promote effective environmental management. More recently, a National Environmental Management Act (EMA 2004) became operational in 2005, as a framework environmental law to provide a coherent environmental management approach including sustainable land management and the management of water catchment areas (Fig. 24.1). A number of other laws and legislations have also been enacted and or reviewed that have incorporated sustainable environmental management practices including water catchments management and the management of degraded lands. These include the Water Act (1999), Mining Act (1998), Forests Act 2002 (Act No. 7 of 2002, Forest Resources Management and Conservation Act No. 10 of 1996) and Land Act and Village Land Act (1998). The Local Government Act (1982) amended in 1992, among others, includes environmental management into the statutory responsibilities of districts and urban authorities.

24.2
Strategy on Urgent Actions to Combat the Degradation of Land and Water Catchment Areas in Tanzania

While the aforegoing policies, legislation and the resulting regulations have worked, to some extent, to address the problem, degradation of land and water catchment areas has continued unabated. Over 60% of the land area of Tanzania is facing the threat of serious desertification. Unsustainable livestock keeping/pastoralism and agricultural activities, among other factors, have exacerbated land degradation and the degradation of water catchment areas and the erosion of the otherwise rich biodiversity of Tanzania.

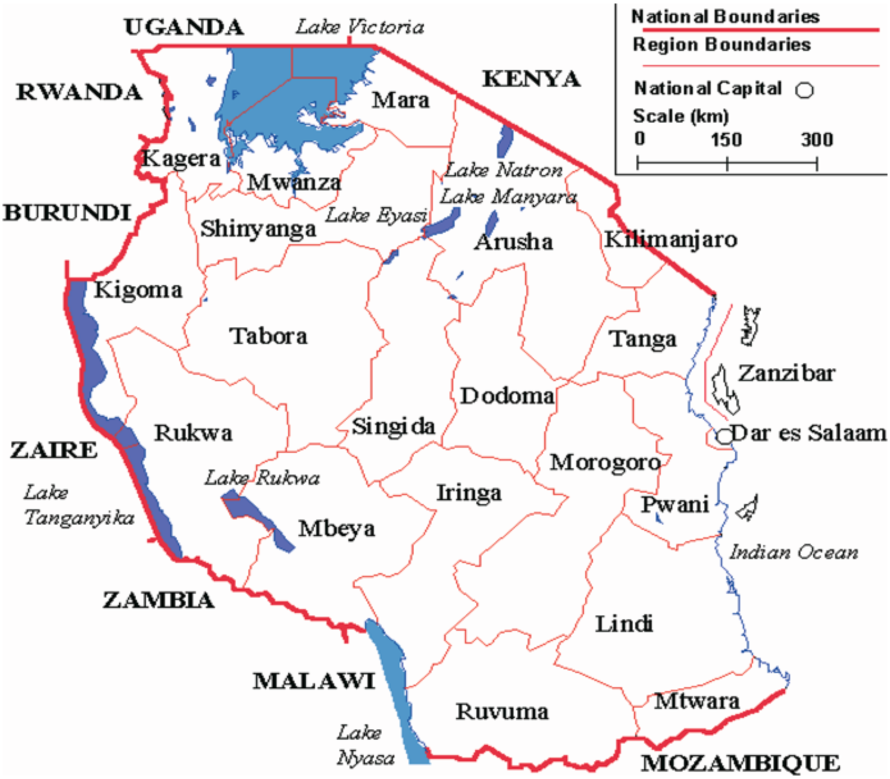


Fig. 24.1. Tanzania: Administrative boundaries and major water bodies/catchment areas

It is from this context that the government in April 2006 decided to launch a unique, country driven, National Strategy on Urgent Actions to Combat the Degradation of Land and Water Catchment Areas in Tanzania.

A Cabinet Committee on Environment, comprising of all key sectors (Vice President's Office, Ministries of Lands, Housing and Human Settlement; Forestry and Natural Resources; Agriculture, Cooperatives and Food Security; Finance; Planning and Economic Empowerment; Water; Livestock; Local Government; and Community development) has been formed to provide general oversight and guidance over environmental protection. It also monitors the progress in the implementation of the Strategy.

24.2.1 Challenges

The Strategy identifies specific challenges on land and water catchment degradation in the country. It identifies areas affected, measures/strategic actions required to address the challenge, the timeframe for the actions and responsible institutions. The Strategy seeks to address the following challenges:

24.2.1.1
Environmental degradation arising from the encroachment of water sources and catchment areas by livestock keepers/herdsmen

To address this challenge, the strategic actions include the following:
- Identification and mapping of all of water sources countrywide.
- Identification of stressed water catchment areas encroached by large numbers of livestock .
- Identification of areas suitable for livestock development to which such livestock can be relocated.
- Information regarding the type of livestock, quantities/numbers, and carrying capacities of the land.
- Drawing an implementation plan to relocate and resettle livestock keepers
- Identification, popularization, and use of traditional methods and indigenous knowledge for environmental protection. Examples include Ngitiri in Shinyanga and Alalili in Masailand.
- Ban of unauthorized movement of livestock.
- Identification, supervision, monitoring and management of permitted livestock transfer routes.
- Construction of chacos, and provision of alternative water sources for herdsmen.
- Continuous education and creation of awareness on livestock carrying capacities and maintenance and use of water infrastructure.

24.2.1.2
Environmental degradation arising from illegal human activities related to agriculture and human settlement along steep slopes of mountains and mountain ranges, near river banks and around water sources

Strategic actions being undertaken are:
- Identification of encroached and severely degraded areas.
- Removal of illegal occupiers of areas concerned.
- Determination of boundary of mountain ranges above which no human activities will be allowed.
- Popularisation of rain water harvesting technologies and implementation of programmes and projects associated with rainwater harvesting.

24.2.1.3
Environmental degradation due to deforestation and massive tree cutting for fuel wood and charcoal and construction in urban areas (excessive use of wood poles, timber, etc.)

Strategic actions include:
- Require institutions such as prisons, schools, and training institutions that use massive amounts of wood, to have wood plantations.
- Establish nurseries for appropriate tree species.
- Sensitise villages and urban centres to establish forest farms for firewood and charcoal.
- Encourage research, development, and application of alternative energy sources and appropriate technologies.
- Promote then use of kerosene, gas and coal as alternatives to wood fuel.

24.2.1.4
Unsustainable small and large scale irrigation projects and programmes, with negative consequences on biodiversity and general water availability

The strategic actions include the implementation of regulations and procedures related to:
- Water rights.
- Maintenance of irrigation infrastructure and regular inspecting of the said irrigation canals such that excess water returns to the main water sources.

24.2.1.5
Inadequate and inaccurate data and information at district level regarding water sources and land use

Actions are to ensure that:
- Identification of all water sources and assessment of their environmental status.
- Development, dissemination and implementation of land use master plan.
- Giving title deeds to water source areas for proper protection.

24.2.1.6
Environmental degradation due to wild fires

Actions include:
- Awarding individuals or organizations that provide information on forest or rangeland fires.
- Empowering local leadership in the prevention and control of such fires in their areas of jurisdiction.
- Creating a data/information base on incidences of wild fires.

24.2.1.7
Land and water degradation resulting from use of alien and exotic tree species

The Strategic Actions include the following:
- Identification of such unsuitable tree species.
- Development of a community participatory programme for the removal of such species.
- Identification and promotion of tree species suitable for the protection and conservation of land and water sources, countrywide.

24.2.1.8
Desertification and drought in many parts of the country

The actions that are being undertaken include:
- Preparation of further guidelines for continued implementation of a National Tree Planting and Maintenance Campaign.
- Continuing efforts to sensitise the public on the Tree Planting and Maintenance Campaign.
- Establishment of tree nurseries, with each district required to plant and maintain 1.5 million trees per year.
- Preparation and gazetting of a list of types of protected indigenous flora (trees and other plant species).

24.2.1.9
Public awareness and involvement in environmental protection and sustainable utilization of natural resources

Strategic actions include:
- Preparation and implementation of a countrywide Environmental Education and Public Awareness Programme.
- Monitoring and evaluation of the programme.

24.2.1.10
Land use conflicts among various stakeholders

Actions on this area include the following:
- Preparation of environmental conservation and participatory land use plans for every district.
- Determination of livestock carrying capacities in villages and districts
- Surveying and mapping 6000 villages.
- Mainstreaming the Environmental Management Act 2004 into sector environmental laws and overseeing their implementation.

24.2.1.11
Environmental degradation arising from mining activities

The strategic actions are:
- Evacuation of all illegal miners from water catchment areas.
- Putting in place surveillance and monitoring mechanisms to ensure that these areas are not re-invaded by illegal miners.

24.2.1.12
Environmental pollution due to plastic wastes

Actions are:
- To ban the manufacturing, importation, selling, buying, and use of plastic bags under 30 microns (or 0.03 mm) thickness and those with 65 microns (or 0.065 mm) thickness used for water and juice packaging by October 2006.
- To surtax other types of plastic bags (commonly known as Rambo in Tanzania) with 30 microns (or 0.03 mm) thickness and above, by more than 100%
- To encourage industry owners and investors to promote the production of alternative bags, such as paper manufactured bags.
- District, Town, Municipal and City Councils to ensure all plastic wastes are collected and disposed appropriately.

As noted, this is an ambitious and comprehensive strategy. It requires substantive resources for its implementation in order to attain the expected impacts. Already the implementation has started and already there are positive results particularly with the removal of nomadic pastoralists from water catchments areas and tree planting exercise. The envisaged budget for its implementation is US$ 30 Million per year for 5 years. The Government has committed US$ 9 million for this financial year (2006/2007) in order to kick start its implementation. We believe the international community through the UNCCD and the GEF (through the Sustainable Land management Operational Programme) will support these national efforts by providing the needed additional financial resources to achieve the intended objectives.

It is important to note also that while the government is committed to addressing land degradation through this strategy as well as through the implementation of other activities identified in the NAP, climate change is emerging as a new challenge and threatening to undermine all these efforts. The impacts of global warming are already vivid. Measurements from 21 meteorological stations have shown a steady increase in temperature for the past 30 years. Because of this temperature increase/global warming, adverse impacts are now felt almost in all sectors of the economy. Severe and recurrent droughts in the past few years have triggered the recent devastating power crisis. The drop in water levels of Lake Victoria, Lake Tanganyika, Lake Manyara and Lake Jipe in recent years, and the dramatic recession of 7 km of Lake Rukwa in about 50 years, are a manifestation of climate change. Eighty per cent of the glacier on Mount Kilimanjaro has been lost since 1912. It is projected that the entire glacier will be gone by 2025.

Climate change impacts have direct effects on local communities and economic development. It was initially projected that Tanzania's GDP would grow by 7.5% in 2006. The growth was only 5.8%. This drop was attributed to severe drought that affected most parts of the country triggering food shortage and a power crisis. Recent surveys indicate that malaria (a climate-related disease) prevalence has been reported in areas where it was not commonly found (e.g. some parts of Kagera Region, Rungwe in Mbeya Region, Lushoto and Amani in Tanga Region). Climate change may thus undermine national efforts to attain the Millennium Development Goals thus placing poverty reduction efforts in jeopardy. Recent floods have devastated most of the infrastructure, forcing the government to look for more than US$ 30 million for emergency rehabilitation of the central road system.

24.3 Conclusions

Sustainable land management can be achieved by integrating international and national efforts at different levels. The UNCCD, GEF and the international community need to increase financial support to countries that have shown clear commitment to address land degradation. Tanzania has put in place the strategy described in this paper which is a clear indication of its total commitment to combat land degradation and mitigate the effects of drought and partly as a way of commemorating the International Year of Deserts and Desertification (IYDD). The UNCCD remains an important multilateral environmental agreement in combating desertification and land degradation. There should a renewed commitment from developed countries to support the implementation of NAPs and the strategy through the UNCCD. As a link between UNCCD and UNFCCC, sustainable afforestation and reforestation can address land degradation through carbon trade incentives from afforestation and reforestation as well as avoiding deforestation. However, national ownership of carbon trade using such activities is a pre requisite.

Agriculture also offers other avenues for carbon trading, such as the use of renewable biomass for energy generation, management of nitrous oxide through better fertilizer use as well as reduction of methane emissions from lowland paddy production and agro industrial processes. Capacity building in terms of having a critical mass of government institutions and nongovernmental actors that can venture into carbon trading is critical.

Reduced rate of desertification through enhanced growth of natural vegetation can lead to reduced conflicts between pastoralists and farmers. Efforts towards better land use planning and land reforms are very important. This is what the strategy advocates and needs to be supported by the international community.

References

EMA (2004) Environmental Management Act, Republic of Tanzania.

Implementation of Initiatives for Addressing Climate Change and Land Degradation: A Look at the Philippine Context

Rodrigo U. Fuentes and Roger Concepcion

Abstract. Climatic change and land degradation are serious environmental issues for the Philippines given their implications to economic growth and millions of people, particularly the marginal poor. The location and topographic configuration of the Philippines makes it more susceptible to climatic anomalies. For years its people have developed coping mechanisms to the climatic changes in the country, in particular drought during dry spells and flooding during monsoon seasons. These capacities however, are becoming inadequate as the drive for economic growth, uncontrolled population increase, urbanization and changing consumption and production patterns are combining to create intense pressure on the country's limited carrying capacities. The government fully recognizes the imperative for addressing these issues and has formulated strategic frameworks with the involvement of critical stakeholders that are directed to responding to these concerns. Current efforts are being pursued which are within the ambit of the climate change, land degradation and desertification and, biodiversity conventions. However, in all of these efforts, the role of scientific information particularly the collection, analysis and dissemination of climatological data cannot be understated. Not only is it critical for predicting climatic events but, more significantly the application and use of scientifically derived information is critical to devising adaptive measures especially for rural communities that would enable individual farmers cope with climate induced disasters including the arrest of further land degradation.

25.1 Introduction

The historic United Nations Conference on Environment and Development (UNCED) held in 1992 at Rio de Janeiro, apart from having launched sustainable development as the blue print of development for countries, also produced three important multilateral environmental agreements (MEAs): the UN Convention on Biological Diversity (UNCBD), the UN Framework Convention on Climate Change (UNFCCC), and later the UN Convention to Combat Desertification (UNCCD). Both developed and developing countries in the Asia region have committed themselves to the sustainable development agenda, including that of meeting country obligations to the three MEAs. The progress achieved by far had been mixed, with some countries able to demonstrate positive gains, albeit modest, in balancing economic, social and environmental objectives in their development agenda.

But the challenges ahead remain formidable. There is that gnawing reality that countries still fall short of the desired goals of sustainability, especially when the Millennium Development Goals (MDG) are used as benchmarks for progress. MDGs are the most broadly supported, comprehensive, and specific poverty reduction targets the world has ever established– is a global agenda of eight development goals directed at cutting world poverty in half by 2015, improving health, and promoting peace, human rights, gender equality and environmental sustainability. Even with the best-performing economies in the region, the high economic growth has not necessarily been translated to improvements in the environment that can lead towards sustainability. The degradation of land and natural resources depletion remains unabated and is even expanding, poverty continues to be an insidious issue and, capacities to cope with the impacts of climatic changes or climatic pattern variability are found to be inadequate highlighting that the pursuit of sustainable development will be a steep challenge for many developing countries like the Philippines. Taking into account the objectives of this workshop, the paper will highlight the Philippine experience in linking climate change initiatives with combating land degradation, taking into context the general trend of the Asian region.

25.2 Growth and environmental sustainability: the development challenge in the Asian context

The decline in environmental sustainability in the Asian region is driven largely by key trends that are linked to economic growth. The 2005 State of the Environment Report of the UN Economic and Social Commission for Asia and the Pacific (UNESCAP) cited that unrelenting pressures on the environment is a result of unsustainable patterns of production and consumption driven largely by four key trends: the unprecedented expansion of industrial activities; the intensification of agriculture; urbanization and changing consumption patterns; and a heightening demand for raw materials, energy and water (ESCAP 2006a). Following UNCED, many governments have been able to enact new legislations and have strengthened institutions that resulted in significant improvements in environmental performance, particularly with respect to pollution control. But these achievements are overwhelmed by the rising environmental pressures owing to largely expanded consumption and production activities and resource-extraction processes. The manifestations of unsustainable growth patterns are unmistakable: high infrastructure costs, a growing society of waste generators, and the relentless decline of the region’s natural capital are just some of these examples. It would be a gross mistake to believe that environmental sustainability is achieved by just improving environmental performance. This premise creates a false sense of security and has distracted attention from the critical need to improve the environmental sustainability of economic growth patterns.

The general context of environmental sustainability refers to the capacity of economic growth and social change processes to ensure that natural resources are not depleted faster than they can be regenerated, and that ecological systems remain viable. For economic growth to be environmentally sustainable, the demand for ecological products and services should not exceed the maximum ecological products and services that can be provided sustainably in a particular area (ESCAP 2006b). Any excess demand reduces the ability of the natural environment to provide ecological goods and services to support a particular society. Actions to improve environmental sustainability focus on reducing the environmental impact of systems and patterns of development to a level within environmental carrying capacity. The links between environmental sustainability and environmental performance are essential to understanding the development focus of almost all countries in the Asian region. It is also in the same light that the inextricable connections between land degradation and climate change should also be understood.

25.3 The inextricable links between climate change and land degradation: the evidence of intense pressure

The unprecedented scale of growth in Asia and the Pacific region has left indelible marks on many of its natural ecosystems. Current production systems generally have been carved out of the natural systems which used to provide a wealth of goods and services prior to conversion. From critical habitats of high biological diversity in forest areas to valuable of coral reefs and mangroves in coastal zones, many of these areas have been converted to other land uses or destroyed due to the intense pressures coming from both intensive and extensive agricultural land conversion and fishery production. For several decades red flags have already been raised on the consequences of mismanaging the natural capital. However, it is only in recent decade that the extents of the pressure have been fully realized.

25.3.1 Agriculture and climate change

Agricultural activities contribute to global climate change in both positive and negative manner. The positive contribution of agroecosystem is that its soils are good *"sinks"* of carbon which can be further enhanced through proper farm tilling and soil conservation management. On the other hand, its negative influence is that the industry is a major source of greenhouse gases (GHG). Studies conducted in China (Dong et al. 2000), Japan (Tereda 2000) and the Philippines (Lantin and Villarin 2000) have shown that livestock-raising, particularly involving ruminant animals (buffaloes and cattle) and cultivation of rice are significant sources of methane while the main source of nitrous oxide emissions are coming from the use of nitrogen fertilizers. Given these challenges, governments face several policy dilemmas for promoting sustainable agriculture in the region which focuses on the following: policies that would further improve agricultural productivity while easing up the pressure on the ecosystems; policies that address global environmental concerns that are cost effective and do not have cost implications to small-scale farmers; and a practical strategy for educating many farmers on the benefits of sustainable farm practices.

The emissions of ammonia from livestock manure are a major source of air pollution in agricultural areas. Very little research has been done in the region on the possible implications of air-borne ammonia which often is considered more as a *"nuisance pollutant"* because of the odor that is generated. It is projected however, that it could pose serious environmental concern in the future. Air-borne ammonia can acidify soils and eutrify water bodies when carried downwind. This observation is based on the estimates made in OECD countries of the total nitrogen loading to the environment (air, soil and water) coming from livestock production which is projected to grow by 30 per cent between 1995 and 2020 (OECD 2001).

25.3.2 Forests and watersheds: the critical influences to agriculture and climate change

Agriculture, forestry and watershed management have long established linkages but are generally taken for granted because of the subtle physical interface that is manifested. The protective function of forests provides the base for sustainable agriculture and no aspect of the forest ecosystem function is more crucial than its watershed functions (FAO 1999). Forest ecosystems and agroecosystems are understood to be intimately linked hydrologically. There is a continuing effort to empirically establish the hydrological evidence that would link forests and watershed protection functions. At this stage it is difficult to generalize that forest is the better ecosystem and that its removal will lead to the diminution of the watershed capabilities to effectively controlling water flow. Because of the over simplification of such understanding, there is a commonly held belief among practitioners and planners that planting more trees in denuded watersheds can and will in due time conserve water resources. Recent documentation is disproving this long-held view but instead stresses that appropriate management of watersheds needs to account for all the needs of the users of the resources including those who are in the uplands who most of the time are perceived to be the culprits for the forest or watershed/s denudation. As such adverse land use changes in the uplands, particularly the removal of any vegetative cover, inevitably impacts on the productive potential of lowlands. The region is replete with examples of how denudation and poor land-use practices in watershed areas have often lead to reduced storage capacity in reservoirs, lowered irrigation potential and magnified the impacts (damage) of flooding especially on agricultural crops. In the Philippines the massive denudation of watershed areas such as Pantabangan, caused severe erosion and siltation, shortening the lifespan of the dam that is supposed to feed the irrigation needs of Central Luzon, the food basket of the main island of Luzon. Same pattern of degradation are common all over the Asia region.

These factors give the more reason for the agricultural sector in the lowlands to look for measures that would promote water efficiency use. As the competition for water use will grow more intense along with the demand for increasing food production, every resource needs to be optimized to get full benefit from its use. Fortunately, there are many practical alternatives which are fully developed and can be adopted on a wider scale. For example, in dryland areas rainwater harvesting and alternative forms of tillage can be adopted, in rice farming rich countries rice –fish farming can be applied (FAO 2003).

With respect to climate change, land-use change and forestry activities are accounted for separately when determining their (significant) role in climate change, particularly in the emission of GHGs. The management of forest resources which covers activities including the establishment of plantations, reforestation and afforestation, the commercial harvesting of timber resources and fuel-wood gathering, impacts on climate change. The conversion of forest lands for agricultural use and the abandonment of these areas as practiced in swidden, or slash and burn, agriculture not only contribute to the environmental degradation of these areas but also affect their carbon storage capacity. Forests store 40 per cent of all the carbon in the terrestrial biosphere, more than any other ecosystem (FAO 2001). The storage of carbon in the ecosystem varies depending on the type of forest: temperate forests store carbon in their soils, while tropical forests store it in vegetation (FAO 2001). The growth and re-growth of forests in temperate countries can provide sinks to absorb carbon dioxide emissions from fuel combustion. Conversely, deforestation of tropical forests and their conversion to other land uses releases an estimated 2 billion tons of carbon into the atmosphere annually, equivalent to 25% of the emissions from fuel combustion (FAO 2005). Since most developing countries in the Asian region have tropical forests, and the pressure to exploit these resources is intense, the likelihood of deforestation and land conversion increases, leading to increased carbon emissions.

25.4 Initiatives for addressing land degradation and climate change: a Philippine perspective

The Philippines makes an interesting case in examining its strategies for pursuing growth while at the same time designing initiatives that are directed towards addressing two of the most serious environmental issues which have global and localized implications.

The Philippines, as an archipelago is made up of more than 7,000 islands, and particularly vulnerable to the impacts of climate variability and change. The country is located near a zone where the dynamics of the Earth's heat and moisture distribution system take place making it a gateway for typhoons and hurricanes to mainland Asia. The country is visited on an average by 20 tropical cyclones many of which becoming typhoons that can cause billions of pesos in damage and thousands of deaths. The country has a humid equatorial climate marked by high temperatures and heavy annual rainfall. It has two distinct seasons: summer (southwest) monsoon which brings heavy rains to most of the islands from May to October and the winter (northeast) monsoon which brings cooler and drier air from December to February. Annual rainfall measures as much as 5,000 mm in the mountainous east coast but less than 1,000 mm in the sheltered valleys. The country also sits along the Pacific "ring of fire" making it vulnerable to earthquakes, volcanic eruptions and tsunami. Its topography is characterized by largely mountainous terrain, narrow coastal plains, interior valleys and plains. The country has three (3) major island groups namely: Luzon, Visayas and Mindanao. Around 1,000 of its islands are considered inhabitable.

The Philippines in general is endowed with rich natural resources. Its forest resources are considered to be one of the most diverse in the world with a high level of endemism. From its terrestrial ecosystem to the marine ecosystem, the Philippines have hundreds of species of flora and fauna that cannot be found anywhere else in the world. However, decades of abuse and misuse of the natural resources have diminished this vast natural wealth. The country's forest resources have now gone down from 15 million ha in the early 1950s to just about 5.4 million ha as of 1997; 69% of its wetlands are in the moderately to highly threatened status; and its marine ecosystems particularly the coral reefs are continuously being degraded and destroyed. As common in the Asia region, pushing intense pressure on the country's resources is the drive for economic growth, expanding population, and an increasing urbanization. These factors combine which in effect contributes to making the country vulnerable to environmental instability as influenced by degrading land resources and climate change (Fig 25.1). The chronology of historical eras of how the country's natural and agricultural resources have been managed over the past fifty years is presented in Table 25.1.

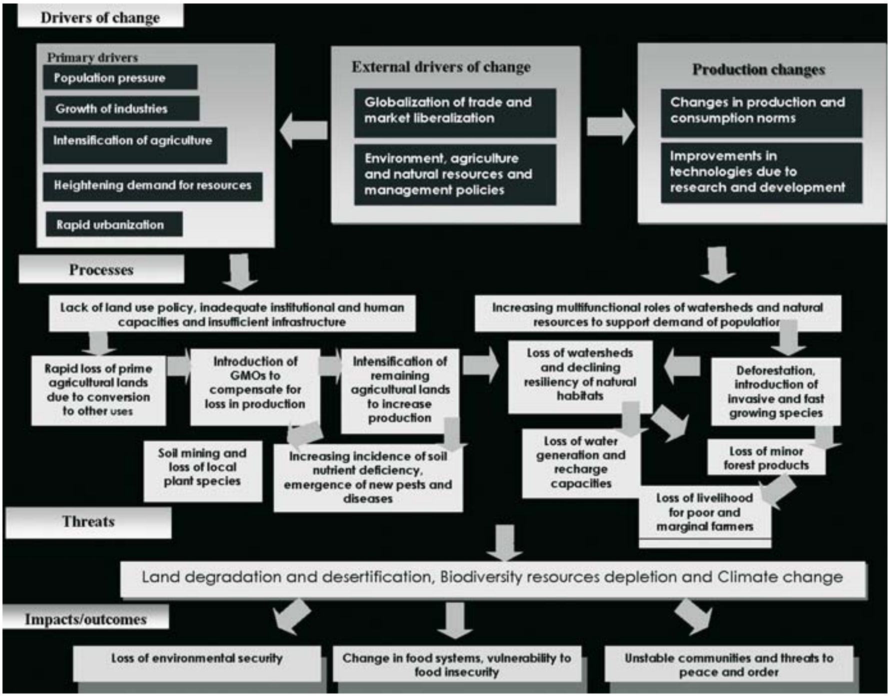


Fig. 25.1. Key influences for land degradation and vulnerability to climate change and variability in the Philippines

25.4.1
Imperatives for addressing land degradation and climate change issues

Interest to address land degradation and climate change concerns is compelled by the need to arrest the further deterioration of the country's land resources and reduce the impacts of drought and El Niño phenomenon or floods especially in areas and communities where food insecurity is a key issue. As noted by experts, there is an increasing frequency of occurrence of drought and El Niño in many parts of the country. Recently agriculturists have noted an emerging climatic anomaly as experienced in many of the provinces called seasonal aridity.

Vulnerability to extreme climatic variability and land degradation cannot be understated in a country like the Philippines where run away population and poverty, especially in rural areas, are critically serious problems. The acceleration of land use conversion, deforestation coupled by unsustainable land use practices have forced subsistence farmers to even go to marginally productive lands. Farmers tilling these areas have very low food production and income generating capacities, which do not liberate them from the stranglehold of poverty. Table 25.2 shows the level of poverty in the Philippines as of 2003. In general provinces which are experiencing seasonal aridity are also noted to have high poverty incidence.

25.4.2
Extent and distribution of land degradation

About 45% of the arable land in the Philippines is moderately to severely eroded forcing subsistence farmers to cultivate marginal lands with low productivity. Approximately 5.2 million ha are seriously eroded with 30 to 50% reduction in soil productivity and water retention capacity. Concomitantly, these areas are already predisposed to the effects of drought and influences of changing climatic patterns. Table 25.3 shows the extent and distribution of land degradation in the country.

The most common form of land degradation in the Philippines is soil erosion. The process causes deterioration of the physico-chemical and biological properties of the soil rendering the land less productive. A severe case of soil erosion results in total loss of productivity, affects infrastructure and in recent years due to major landslides even caused the loss of lives.

25.4.3
Soil mining and decline of soil productivity

The intensified application of fertilizers is an agricultural practice that has long been accepted following the adoption of the green revolution programme. But the misuse in the application of chemicals has also significant environmental downside. The long term and continued use of urea alone has resulted to serious soil nutrient imbalance and contributed to the actual soil degradation. A study of the soil conditions of the country has shown that there as been an active soil mining occurring over the twenty year period with excessive use of inorganic fertilizers. The over application

Table 25.1. Significant events in environment and natural resources use and, agricultural development in the Philippines

Period	General characteristics	*Specific interventions on*	
		Land management	*Climate change*
Pre-1960's	Traditional extensive agriculture; healthy watershed; low population density; and a highly intact natural forest that has also rich biodiversity (highly endemic)	No particular intervention	No particular intervention
1961-1980	Policy conflicts between natural resource management and major infrastructure development: • Massive investments in the construction of dams for irrigation, power and for domestic consumption. Almost all of prime irrigable lands had irrigation system by the end of the period. Population growth in urban centers rapidly increasing. • Massive harvesting of forest resources that are both legal and illegal for generation of cash. Although by law reforestation is a mandatory obligation for legal loggers, the efforts were not given much serious attention. For marginal farmers upland farming followed through after a forest area has been cleared.	In the latter part of the period, efforts were launched to somewhat contain illegal logging while at the same time developed government programmes to assist upland farmers on the proper practices of land cultivation in upland areas.	No particular intervention
1981-1990	Period of massive environmental degradation characterized by: • Massive soil degradation in the lowlands caused by excessive use of fertilizers; salinization due to over irrigation; and other human-induced activities that reduced productivity of agricultural soils; • Expansion of coverage of marginal soils due to uncontrolled logging operations; • Increasing expanse of idle grasslands that is replacing the natural forests; and • Dramatic decline of biodiversity resources as more natural habitats are being lost.	The efforts to address land degradation have expanded. But no significant reversal of trend is observed. As prime agricultural land's productivity is producing lower yields more people are being pushed to farm in uplands which is causing more environmental damage.	No particular intervention

Table 25.1. *Continued*

Period	General characteristics	*Specific interventions on* Land management	*Climate change*
1991-1996	Period of irrational land use with more prime agricultural lands converted to urban development and industrialization. Key manifestations of degradation are as follows: • Deterioration of river systems and the aquifers; • Rapid deterioration of the irrigation systems that have been established in the earlier decades; • Globalization of market with many agricultural products is now imported despite the existence of locally produced products. No incentives for local producers and could not compete with cheaper imports. • Existing prime agricultural lands are not producing the desired yields.	Previous interventions are continuously pursued but with no overarching framework to consolidate and synergize efforts from various agencies. At the	The issue of linkage between land degradation and climate change was not yet recognized in the early years following the ratification by the Philippines to the UNFCCC in 1994.
1997 to present	Philippine environment and agricultural policies in transition and present policies are under review • The enactment of the Agriculture and Fishery Modernization Act which favors the establishment of strategic development zones for enhanced agricultural production; • Provision of financial resources and agricultural financing window to help farmers access funds for agricultural investments; and • Promotion of switch to non-agricultural livelihood options for marginal farmers to lessen pressures on natural resources.	A major effort to modernize agriculture is being pushed. Still a key issue is the absence of a legislated land use plan. Technical support is being enhanced and consistent with the commitment to the UNCCD, the Philippines has developed and formulated its National Action Plan which was a subject of multi sectoral consultation with national ownership. The challenge ahead is in mobilizing private sector and international funds to support the activities presented in the plan.	Following the ratification of the UNFCCC the Philippines has been undertaking activities that are consistent with commitments to the Convention as a Non-Annex I country. Except for those stipulated as primary activity of the Convention and with support from GEF, the country has just started making efforts to link climate change with sustainable land management discussions.

Table 25.1. *Continued*

Period	General characteristics	*Specific interventions on*	
		Land management	*Climate change*
1981-1990	Period of massive environmental degradation characterized by: • Massive soil degradation in the lowlands caused by excessive use of fertilizers; salinization due to over irrigation; and other human-induced activities that reduced productivity of agricultural soils; • Expansion of coverage of marginal soils due to uncontrolled logging operations; • Increasing expanse of idle grasslands that is replacing the natural forests; and • Dramatic decline of biodiversity resources as more natural habitats are being lost.	The efforts to address land degradation have expanded. But no significant reversal of trend is observed. As prime agricultural land's productivity is producing lower yields more people are being pushed to farm in uplands which is causing more environmental damage.	No particular intervention

of inorganic fertilizers has resulted to dramatic decline of soil productivity, adding burden to an already cash-strapped farmers that have shouldered the direct cost for the use of the chemicals. This is one of the reasons why many farmers are unable to competitively compete with export products as the cost of production for locally produced agricultural products are greater than those that are imported.

25.4.4
Causal factors of land degradation

25.4.4.1
Topographic variations and problem soils

The country is topographically varied and in island provinces the removal of the natural cover has even made the soils more exposed to erosion. This condition is further complicated by the presence of problem soils: those that are found in steep slopes have poor drainage characteristics (soils that are considered or are usually waterlogged), coarse textured soils (soils that have less than 18 per cent clay and more than 65 per cent sand), soils which have heavy cracking clays, and soils with fertility limitations and land with saline/sodic soils. Adding to these problem soils, the country is likewise situated in a volcanic belt (more than 200 active volcanoes) which during eruptions can affect the state and condition of the soil.

Table 25.2. Poverty incidence in the Philippines

Region	Poverty incidence (%)
Philippines	24.7
CAR	31.1
NCR-National Capital Region	5.0
Region I*	29.6
Region II*	24.8
Region III	13.7
Region IV	14.9
Region V*	49.0
Region VI	37.8
Region VII*	32.3
Region VIII	37.8
Region IX*	44.1
Region X*	32.9
Region XI*	31.5
Region XII	48.4
ARMM*	45.7
Caraga	47.3

Note: * Areas are known to experience seasonal aridity. (Source: NSCB 2003)

25.4.4.2
Human induced

Soil degradation caused by human activities has only exacerbated the already limited productive condition of the soils. With an annual population growth rate of 2.3 per cent, this translates to an additional 1.8 million persons a year. This growth rate is accompanied by an increasing demand for food, clothing, shelter and settlements. The demand for food leaves farmers with limited alternatives but to intensively use chemicals to correspondingly increase the yields of land without prejudice to the soil's long term capacity to be sustainably productive. Pressures to produce more meat and protein source are also forcing farmers to extensively overgraze lands beyond their carrying capacities. Similarly, increasing demand for human settlements and other non-agricultural use has led to the conversion of prime agricultural lands further reducing areas for agricultural production. A serious consequence of land conversion is that it pushes farmers to seek areas that are marginally productive for farming. Approximately about 74 percent of the sloping uplands are now tilled for subsistence farming just to meet the demand for food and increasing livelihood opportunities. As more upland areas are being farmed subsequent pressure on the remaining forest lands also intensifies. The inappropriate practice of slash and burn of forest lands coupled with the disregard for applying soil conservation measures and proper soil management only contributes to further land degradation of many areas in the country.

Table 25.3. The extent and distribution of land degradation in the Philippines

Island Grouping	Erosion class											
	Not apparent		Slight		Moderate		Severe		Unclassified		Total	
	Area	%	Area	%	Area	%	Area	%	Area	%	Area	%
Luzon	4.1	57.7	4.1	46.6	4.1	48.2	1.7	32.7	0.2	50.0	14.2	47
Visayas	1.2	16.9	1.7	19.3	1.5	17.0	1.1	21.2	0.1	25.0	5.6	19
Mindanao	1.8	25.4	3.0	34.1	2.9	34.1	2.4	46.1	0.1	25.0	10.2	34
Philipines	7.1	23.7	8.8	29.4	8.5	28.3	5.2	17.3	0.4	1.3	30.0	100

Unclassified erosion are those areas where there are quarries, river wash and those subject to open pit mining. Source: Bureau of Soils and Water Management (2004)

25.4.4.3
Policy induced

The absence of a comprehensive national land use policy has made the protection of land resources more difficult. The lack of local, regional and national land use policy which delineates major land uses for protection and production has made the conversion, improper land use and inefficient land use more pervasive. The boundaries between forestlands and alienable and disposable lands are not clearly delineated making it even more impossible to enforce land use policies and monitoring conversion to other uses. Illegal logging, encroachment of forest lands and shifting cultivation, while may have declined, remain to be a pervasive issues.

25.4.4.4
Climate induced

Drought is a recurrent event in a climatic system that defines the availability of water to supply the demands of production systems. UNCCD has defined drought as a naturally occurring phenomenon that exists when precipitation has been significantly below normal recorded levels, causing serious hydrological imbalances that adversely affect land resource production systems. In the Philippines drought can strike in any part of the region with varying degrees of severity exacerbating the conditions of degraded lands especially in areas experiencing seasonal aridity. Major drought events in the country are usually associated with the El Niño Southern Oscillation (ENSO) occurrences or warm episodes in the central and eastern equatorial Pacific. Over the last decade, El Niño events have been noted to occur every two to three year cycles against a previous five year interval. The impact of drought has a telling effect on the agriculture sector. In the 1997-1993 drought spells, estimated loss in rice production alone was placed at more than 622 thousand tons of rice valued at P4.6 billion (about US$ 93 million). Corn, which is another staple major commodity, incurred a loss of P7.7 billion (about US$ 153 million). The exact opposite of drought is excessive rainfall due to monsoon or tropical cyclones which causes severe flooding. In the year 2006 alone, there were 13 large flood events that recorded in the country (Dartmouth Flood Observatory 2007). The flooding displaced hundreds of thousand families, almost 800 people lives taken destroying agricultural crops and infrastructure valued more than US$ 60 million (Dartmouth Flood Observatory 2007). As with periodic droughts, floods and heavy rains also severely degrade lands eroding fertile flats and massive landslides significantly minimizing future productivity potentials of affected lands.

25.5 Actions taken to comply with the Conventions

25.5.1 Compliance with the UN Framework Convention for Climate Change (UNFCCC)

The Philippines have been involved in the global climate change discussions even way back during the early stages of the Intergovernmental Negotiating Committee on Climate Change (INC/FCCC). Taking cognizance of the serious implications of climate change in the country then President Corazon Aquino created the Philippine Inter-Agency Committee on Climate Change (IACC) to serve as the technical and policy body that will coordinate all climate change-related activities. In keeping with its commitment to the Convention, the Philippines strongly advocated for stringent measures to be adopted by Annex I Parties in curbing GHG emissions. It has taken voluntary steps to address the issue of climate change through policies and measures directed towards achieving the country's development objectives while at the same time contributing to the climate change objectives. The Philippines ratified the UNFCCC in August 1994.

With funding support from the Global Environment Facility (GEF)/United Nations Development Programme (UNDP) the country submitted to the Conference of Parties its 1st National Communication on Climate Change in May 2000. The country report highlighted the backbone of its strategy for addressing climate change which is summarized as follows:

- Based on the 1994 National GHG Inventory, the Philippines released a total equivalent amount of 100,864 ktons of CO_2, which is minimal relative to the GHG emissions of other countries. Discounting the contribution of the land use change in forestry (LUCF), the CO_2 emission of the Philippines is placed at 100,738 ktons (IACC 1999). The inventory estimated that the LUCF sector is able to sequester about 126 ktons of CO_2 which is 0.1% of the national total. The sources of the GHG emissions come from four major sectors: energy sector which accounts for about 49% of the national total GHG emissions; agricultural sector which contributes 33%; industries about 11% and wastes at 7%.
- A projection of the GHG emissions for 2008 is placed at 195,091 ktons of CO_2, which represents a rise of 94% from the 1994 baseline. The report however cau-

tioned that the projections made maybe be conservative as some subsectors estimates were held constant at 1994 levels.

- The vulnerability of the country to climatic change is considered very high. Using at least four Global Circulation Models (GCM) at double CO_2 concentration the scenario in the following areas are predicted:
  a. Agriculture: the simulation results showed that while a general increase in rice yields will be observed, the maturity period for the crop will decrease. Corn however will register a major decrease in their yields.
  b. Water resources: water yield for a number of major watersheds, particularly in areas where the water reservoirs are used for domestic water needs will be severely affected by climate change. As these dams are dependent on rainfall for collecting water, changes in rainfall patterns could affect the functions of these dams and reservoirs.
  c. Coastal resources: under the present levels, increasing the GHG emissions may lead to accelerated sea level rise which will aggravate the condition of an already vulnerable coastal ecosystem. It is projected that along the coast a one-meter sea level rise could inundate many communities and urban areas.
  d. Forestry: predictions indicate that changes in rainfall patterns may increase the rate of conversion of forests to agricultural lands since the degraded areas brought by drought and erosion will push people to migrate to higher elevations where soil are relatively still fertile. This conversion has further downside effect of reducing forest covered areas exposing more of the uplands to erosion during rainy or monsoon seasons.
  e. Soil conditions: a decrease in soil moisture in drier areas may accelerate forest loss while an increase in precipitation beyond evaporation demand could increase run-off resulting in soil erosion and flooding.
  f. Biodiversity: local biodiversity will also increase as extinction and inhibition of re-immigration from adjacent areas may occur.
  g. Health: an uptrend from 10% to 58% in disease incidence is projected in association with climate change.
- Adaptation measures and strategies were initially identified based on the vulnerability studies.

Taking into account the findings in the National Communication Report, the government has initiated the appropriate measures aimed at curbing GHG emissions. The measures are reflected in the various sectoral plans of the energy, transport and agriculture sectors and further elaborated in the National Action Plan on Climate Change which is in the process of adoption.

25.5.2
Compliance with the UN Convention to Combat Desertification (UNCCD)

As with the other MEAs, the Philippines has been actively participating in the discussions of the UNCCD. Since the Intergovernmental Negotiating Committee on Desertification (INCD) was established, the Philippines had been sending representation to the negotiations until the Convention took effect in 1994. The Philippines finally ratified the Convention in February 2000. The interest of the country in ratifying the Convention is driven by its desire to address the issue of preventing the further spread of land degradation and reduce the impacts of drought and the El Niño phenomenon on the loss of land productivity, especially in areas occupied by communities that are threatened by food insecurity. The country finds itself in solidarity with the global effort to support the marginalized poor in areas affected by desertification and land degradation.

Consistent with the commitment to the Convention wherein countries are to prepare their respective National Action Programmes (NAPS) which should be formulated in an inclusive and participatory manner, the Philippines have developed and submitted its NAP to the Conference of Parties in 2004.

The formulation of the Philippine NAP was influenced by the following factors:

- Experiences from the farmers
  A study conducted by the Philippine Council for Agriculture, Forestry and Natural Resources Research and Development (PCARRD) indicate that farmers have become more hardworking and resourceful in response to drought incidence. Planting of alternative crops, apart from the staples (i.e. rice and corn) such as vegetable and watermelon, were done to augment income. In addition, organizations at barangay level such as cooperatives, farmers, women, and youth organizations implemented other income generating activities, mostly service oriented (such as sewing, and selling rags, dresses, carpentry and construction jobs in other places) to supplement their incomes from the farms. These efforts were over and above the indigenous knowledge and practices adopted during El Niño occurrence such as:
  - Use of herbal pesticides/botanical spray to control drought induced diseases and pests thriving in trees and plants.
    Weeding is not done during the El Niño to conserve water
  - "Muyung" of the Ifugao tribe combines the underplanting of annual and perennial crops in a secondary forest.
  - Irrigation is done when there is no wind to preserve moisture.
  - Utilization of "ginikan" or rice straws in the cut and carry system of feeding of animals during the El Niño years.
  - Use of salts as prophylaxis.
- Institutional efforts
  - Creation of the Presidential Task force on El Niño – The Task Force serves as the coordinating body for the formulation of comprehensive action plan to mitigate the adverse effects of El Niño.
  - Approval of a National Integrated Research Development, and Extension Agenda and Program and, operationalizing the National Soil and Water Resources RDE Network. The initiative is now implementing research and development projects related to soil conservation and management throughout the country. Through the network linkages, the RDE agenda are reviewed, formulated, and prioritized. Project coordination, implementation is likewise harmonized and unified.

- Awareness programs on the character and impact of drought and land degradation. A conference on "National Awareness on Combating Land Degradation and Mitigating the Effects of Drought in Mindanao" was organized. Other efforts were directed towards the inclusion of soil and water conservation courses in colleges and universities as part of their formal education curriculum.
- Policy/legislative efforts – Legislations were reviewed in order to address underlying factors and crucial issues relevant to combating land degradation and mitigating the effects of drought These legislations include the Agriculture and Fisheries Modernization Act, Balanced Fertilization Strategy, National Integrated Protected Areas System and the Environmental Impact Assessment.

The general plan of action for the development and implementation of the Philippine National Action Plan to Combat Desertification is to be pursued under the following phases:

- Administrative collaboration and convergence – four portfolio departments (ministries) i.e. the Department of Agriculture, Department of Agrarian Reform, Department of Environment and Natural Resources and the Department of Science and Technology have committed to catalytic funding in support of the activities under the Plan. The agencies have also committed to follow through with the mainstreaming of the NAP, aligning their respective key programmes and having it reflected in the Philippine Medium term Development Program and the Philippine Medium term Development Investment Programme.
- Technical collaboration and convergence – the national focal point for the UNCCD will initiate the mobilization of resources to support the technical activities of the NAP. Efforts will focus on the following critical areas:
  a. GIS mapping and assessment of vulnerable areas and communities in seasonally arid and drought prone areas in partnership with the other technical agencies which have similar mandate, information and human resources for carrying out the tasks;
  b. Review and validation of appropriate land and water technologies to mitigate the effects of land degradation and desertification and drought all with the aim of alleviating poverty and food insecurity in marginal upland areas;
  c. Review and identification of policy gaps for effective governance and implementation of desertification control, land and water degradation prevention and poverty alleviation in seasonally arid areas; and
  d. Formulation of selection criteria for the identification of priority programs and pilot areas for implementing interventions that synergize the three conventions.
- Mobilization of local and external funding sources for the implementation of thematic programs of the Philippine NAPs; and
- Actual implementation of priority programs which includes sustainable agriculture and marginal upland development and integrated ecosystems management of the NAP. Concerned government agencies, will serve as the host institution while academic institutions, local governments, non-government organizations and private sector will be tapped as collaborating partner agencies.

Table 25.4 summarizes the context of the Philippine NAP and how it envisions complying with the commitment to the Convention:

25.6 Conclusions

The challenges of land degradation and how it can be aggravated by climate change looms large for the Philippines. Years of abuse, misuse and apathy of a country's rich endowments has not only affected the sustainability of economic growth but has critically affected the poor and marginalized communities, which unjustifiably are the first ones to suffer when natural disasters occur. The current efforts as presented in the preceding discussions are excellent springboards for action for which the government and civil society as a whole can capitalize. One of the positive aspects of the MEA process, in particular the UNCCD, UNCBD and the UNFCCC, was that it stressed the importance of an inclusive participatory process in the formulation of the strategies for addressing these pressing environmental problems. Many of the critical elements for addressing the land degradation and climate change are already contained in the action plans and strategic measures that have identified and submitted to the respective COPs.

Echoing the suggestions put forward by the Asian region for the forthcoming CRIC of UNCCD to be held in Argentina, the following focus of efforts would ensure that the linkage between climate change and land degradation is strengthened:

- Policies relating to agriculture, land use and energy systems need to be integrated and linked with climate change mitigation and adaptation policies.
- Capacity-building continues to be vital to the implementation process. Key areas for capacity development are in the areas of capacity initiatives for participatory approaches, institutional strengthening, resource mobilization, in particular for GEF funding, and most importantly on the scientific field. The role of science, research and development and monitoring and evaluation are critical capacities which countries need to address.
- Mainstreaming the national action programmes into the national development processes and economic decision-making, while remains a challenge, needs to be actively pursued.
- The current status of the NAPs should be viewed as critical inputs to the entire development process and therefore must not loose their importance and momentum in utilizing it as a programming tool for combating land degradation and desertification and climate change.
- Results from NCSA exercises should be utilized more prominently in the pursuit of synergistic implementation of the Rio Conventions at the national level.
- Policy debates on, and activities aiming at, the inclusion of the private sector should be promoted in order to systematically tap financial resources for the MEA implementation.
- Investment in developing infrastructure is a vital measure to reduce future greenhouse gas emissions and arresting land degradation. Its importance in those sectors where GHG emissions are significant, such as the energy and

Table 25.4 The Philippine National Action Plan under the UNCCD

Goal	General objectives	Thematic Programs	Program component/project
To mainstream agriculture and rural environment development programs that will prevent the incidence and spread of desertification and land degradation in deprived communities living in seasonally arid degraded lands	• To establish close implementation synergy of the UNCCD with other relevant UN Conventions (Biodiversity and climate change) • To establish ecosystems-based technology options for the development and protection of fragile landscapes and vulnerable communities • To implement community-focused RD and E and networking programs and projects on critical watershed suffering from land degradation and desertification	Sustainable Agriculture and Marginal Uplands Development Program	Land and water Technology development 1. Assessment and mitigation measures against desertification processes in the oldest irrigations system in Central Luzon 2. Arresting the soil nutrient depletion and water pollution of the strategic zones of agriculture located in seasonally arid areas 3. Precision agriculture towards sustaining optimal productivity of rice and corn in the Philippines
To institutionalize the NAP as a convergence Plan of Action of the National Government against land degradation and poverty	• To establish network of community learning centers for the promotion of community-based participatory learning and planning for critical watershed planning and development • To establish a network of institutions and farmer-experts-technician service systems for the sustainability of the community based support systems.		Local Governance and Community Initiatives 1. Promoting community-LGU Partnerships in managing Karst water in small-island provinces 2. Establishment of small water retention structures for upland agriculture and agrarian reform community development 3. Establishment of Network of Farmer expert's systems and farmers participatory learning centers for technology adaptation and development of understanding desertification, biodiversity and climate change. 4. Conservation farming villages(CFV) toward sustainable management of sloping lands enhancement of home gardens and wood sufficiency and genetic diversity especially in sand dune areas of Ilocos region

Table 25.4 *Continued*

Goal	General objectives	Thematic Programs	Program component/project
	• To institutionalize the community initiatives for local area development for effective control and prevention of location-specific desertification, drought and land degradation in the Philippines. • To establish a nation-wide harmonized GIS database and information system for desertification and land degradation. • To harmonize and systematize enabling policies an implementation strategies with a view of developing legislations for the productivity improvement of degraded lands and mitigation measures against the expansion of desertification in seasonally arid areas of the Philippines.	Integrated Ecosystems Management	Land and Water Technology Development 1. Promotion and development of community-based wilderness agriculture for improvement of forest productivity and rehabilitation. Local Governance and Community Initiatives 1. Local governance-community partnership in managing degraded and critical multiple watershed
		Cross cutting Programs	Data base Development and Harmonization 1. Village level GIS landscape grid approach for integrated land and water resources database and information development Information, Education and Communication 1. Support to the development and publication of knowledge products and tri-media materials 2. compendium of community defined useful plants, herbs, and wildlife and their niches, habitat an distribution Enabling Policy Development 1. Raw water valuation, trading and incentives for water systems.

transport sectors, cannot be understated and should be used alongside initiatives that provide access to improving technologies and enhance capacity-building.

References

Dartmouth Flood Observatory (2007) Database from Dartmouth Flood Observatory accessed on 1 January 2007 from < http://www.dartmouth.edu/~floods/>.

Department of Agriculture (2004) The Philippine National Action Plan to Combat Desertification, Land degradation, Drought, and Poverty. Quezon City, Philippines

Department of Environment and Natural Resources (1999) The Philippine's Initial National Communication on Climate Change. Quezon City, Philippines

Department of Environment and Natural Resources and the Bureau of Soils and Water Management (2005) National Capacity Needs Self Assessment for global environmental Management in the Philippines. Quezon City, Philippines

Dong H, He Q, Li Y, Tao X (2000) Livestock Production and CH_4 Emission from Enteric Fermentation of Domestic Livestock in China. Paper presented at the Workshop on GHG Inventory for the Asia-Pacific, IGES, Japan

ESCAP (2006a) State of the Environment Report 2005 for Asia and the Pacific. United Nations, New York

ESCAP (2006b) Review of Implementation Status of the Outcomes of the World Summit on Sustainable Development- An Asia-Pacific Perspective. Draft Paper for the Regional Implementation Meeting for Asia and the Pacific for the fourteenth session of the Commission on Sustainable Development (ESD/RIMAP/2006/INF.1) (Bangkok, ESCAP)

FAO (1999). Poverty Alleviation and Food Security in Asia: Enhancing forestry and Agroforestry contributions, FAO Regional Office for Asia and Pacific, Bangkok, Thailand.

FAO (2001). Forest Resource Assessment 2000. Food and Agriculture Organization, Rome, Italy.

FAO (2003) State of the Food Insecurity in the World. Food and Agriculture Organization, Rome, Italy.

FAO (2005) Climate change conference urges strategies to curb massive deforestation. Press release, December 2005, Food and Agriculture Organization, Rome, Italy.

Greenpeace (2005) Crisis or Opportunity: Climate change impacts and the Philippines, Manila.

Hardoy JE, Mitlin D, Satterthwaite D (2001) Environmental problems in an urbanizing world: Finding solutions for cities in Africa, Asia and Latin America. Earthscan, London

IACC(1999). The Philippines Initial National Communication on Climate Change, Inter Agency Committee on Climate Change, Manila, Philippines.

IIED (2002) Do forests protect watershed? Research Centre for Forest Ecology and Environment of the Forest Science Institute of Viet Nam (FSIV) and the Forest and Land Use Programme of the International Institute for Environment and Development

IPCC (2001a) Climate Change 2001: Mitigation, A Report of Working Group III of the Intergovernmental Panel on Climate Change, Cambridge University Press, United Kingdom

IPCC (2001b) Impacts, Adaptation and Vulnerability, A Report of Working Group II of the Intergovernmental Panel on Climate Change, Cambridge University Press, United Kingdom

Lantin R, Villarin J (2000) Philippine Greenhouse Gas Inventory Agriculture and Waste Sectors, Paper presented at the Workshop on GHG Inventory for the Asia-Pacific, IGES, Japan.

OECD (2001) OECD Environmental Outlook, Organization for Economic Cooperation and Development, Paris, France

Report on Aid Effectiveness: Review of Progress, Challenges, and Opportunities. Accessed at <http://www.aidharmonization.org/secondary-pages/Paris2005>.

Terada F (2000) Methane Emission Inventory from Enteric Fermentation of Ruminant Livestock in Japan and Asia, Paper presented at the Workshop on GHG Inventory for the Asia-Pacific, IGES, Japan

The World Factbook (2006) accessed on 1 December 2006 at the following site: <https://www.cia.gov/cia/publications/factbook/geos/rp.html

UNEP (2004) Global Environmental Outlook 2003 Year Book, Earth Print Ltd. Hertfordshire, England

United Nations Millennium Project (2005a) Investing in Development: A Practical Plan to Achieve the Millennium Development Goals, Earthscan Publications Ltd, London

UN Millennium Project (2005b) Environment and Human Well-being: A Practical Strategy. Report of the Task Force on Environmental Sustainability. Earthscan Publications Ltd, London.

UN Framework Convention on Climate Change accessed on 15 November 2006 at <http://unfccc.int/resource/docs/convkp/conveng.pdf>.

Woods S, Sebastian K, Scherr S (2000) Pilot Analysis of Global Ecosystem, Agroecosystems, World Resources Institute, Washington DC, USA

WRI (2001) Pilot Analysis of Global Ecosystems: Agroecosystems, World Resources Institute, Washington DC, USA

Successful Grassland Regeneration in a Severely Degraded Catchment: a Whole of Government Approach in North West Australia

P. E. Novelly and I.W. Watson

Abstract. By the 1950s, a significant proportion (over 15 000 km^2) of the Ord River catchment in north-west Australia was severely degraded through excessive grazing pressure, in particular cattle and feral donkeys. Beginning in 1960, a 'whole of government' approach to rehabilitation of the degraded area was taken by the Western Australian government. This extended regeneration program was characterized by a combination of changed government land use priorities with legislative and regulatory backing, animal control, reclamation works and sequences of years of both favourable and unfavourable rainfall. Various factors, both technical and non-technical, influenced the success of the regeneration program. These included resumption by the State government of all or part of five grazing leases (following an initial abortive attempt at rehabilitation while cattle production activities continued), a complete destocking program to remove both cattle and feral donkeys, and the initiation of a Government-funded grassland replanting program. The Government enacted specific legislation, the Ord River Dam Catchment Area (Straying Cattle) Act, 1967, which passed control of all cattle in the rehabilitation area to Government. Assessment in 2002 suggested that the regeneration program was remarkably successful, to the extent that, in 2006, the area was included in the Western Australian conservation estate. Rehabilitation of this type requires a certain combination of factors to be successful, although some, such as rainfall, are outside management control. This paper examines the rehabilitation program, assesses the factors important in its success and identifies those factors which may be relevant to other situations.

26.1 Introduction

Rangeland degradation is a common occurrence throughout the world. Australia is no different and there are multiple examples of severe degradation with varying forms of recovery (McKeon et al. 2004). Degradation typically implies a loss of the utility or potential utility or a change in the features of rangeland ecosystems. These changes are difficult, time consuming and expensive to reverse, and are associated with continuous reduction of ecosystem productivity/biomass. The manifestations of degradation are the loss of soil cover, in particular perennial grasses, and soil loss (either wind or water driven), through either surface sheeting and/or the development of often extensive gully systems. The high percentage of the world's rangelands that suffer from over use stems from the extensive, low intensity character of pastoral land use, the slow response to land management changes in arid climates, and the social and economic problems associated with reducing livestock numbers on heavily used rangelands (Narjisse 2000).

Much of the focus on land degradation appears to be on its causes ('drought', excessive grazing pressure or combinations of these and other factors) and on both the current and potential spatial extent of degraded lands. These are important issues and warrant significant research and assessment. Equally important, but generating somewhat less interest, appears to be the study of reversing degradation and, in particular, the reason behind the success or failure of regeneration programs. Perhaps this is because the costs of rehabilitation of significant areas of degraded rangelands are often considerably greater than potential returns once rehabilitation is complete. This is particularly so in areas where the predominant land use is extensive grazing of domestic stock. Another reason could be that the necessary management and time frames for large scale programs to allow full or even partial recovery are often too daunting for those with an interest in rehabilitation. Therefore, documented examples of successful large scale regeneration are rare (Pickard 2002), while the literature and anecdotal experience suggest that examples of either complete or partial failures are common.

The successful regeneration of significant areas of the catchment of the Ord River in north-eastern Western Australia, with a rehabilitated area well in excess of one million ha, is one example of a successful rehabilitation scheme. But, how typical or how unique was this program? Is it possible to identify the factors that lead to its success, or was success simply serendipity? This paper assesses the reasons for the success of this program, and for the initial impetus to conduct rehabilitation works, and discusses the relevance of these factors for similar activities elsewhere.

26.2 Background

The East Kimberley region of north-east Western Australia (in particular the Shires of Wyndham-East Kimberley (Wynd-EK) and Halls Creek – see Fig. 26.1) covers approximately 200,000 km^2, and is drained by the 650 km long Ord River and its tributaries. Following European settlement in the 1880s, cattle numbers in the region rapidly expanded, sustained by an abundance of surface waters and productive native grass species. Land was (and still is) held under pastoral leasehold tenure, with lease size ranging from 250,000 to 400,000 ha. Pastoral infrastructure development (fences and artificial water points) was limited until the 1960s and 1970s, and consequently there was virtually no control over where cattle concentrated. This situation led to significant localized overgrazing.

Cattle numbers in the areas were substantial. For example, early station records show stock numbers ranged from 85,000 to 90,000 head on the original Ord River lease (which then included Turner Station) during the years 1905 to 1915. Heavy grazing pressure was maintained well into the 1950s, during which time feral animals (particularly donkeys but also including camels and water buffalo) also increased dramatically. This further reduced the control of grazing pressure. This increase in grazing pressure was sufficient to exceed the resilience of the range-

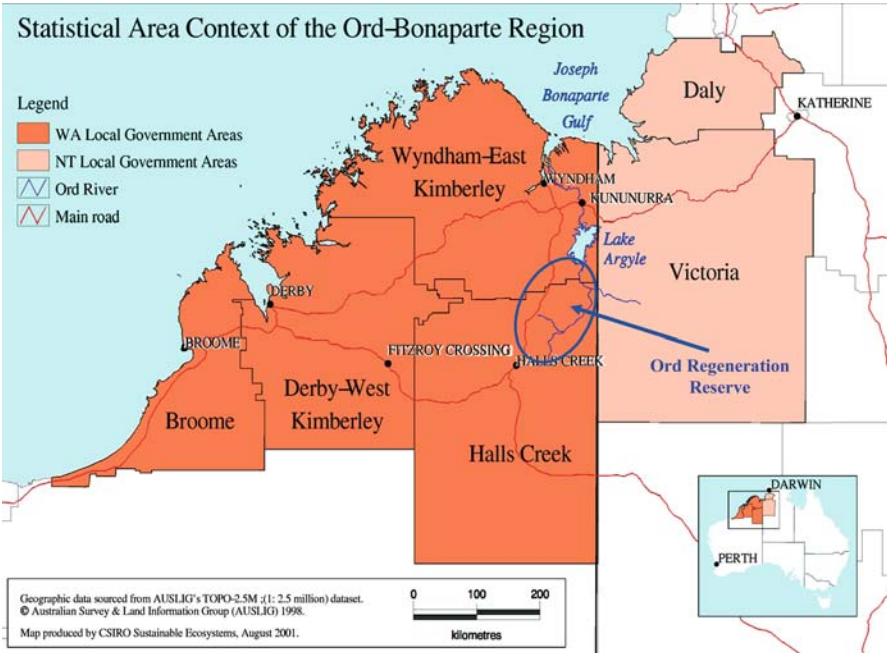


Fig 26.1. The Ord-Bonaparte region of north-west Australia illustrating the lo-cation of the Kimberley region and the Ord River.

lands, specifically parts of the Nelson, Gordon, Antrim and Elder land systems (Stewart et al. 1970). Large areas became degraded and eroded. Of the total area of the Ord catchment within Western Australia (approximately 47,000 km^2), an estimated 3,755 km^2 were subject to varying degrees of erosion (Fitzgerald 1968). The affected area straddled the Ord River and its major tributaries, the Elvire, Negri, Stirling, Panton, Turner and Nicholson Rivers. The majority of the eroded country occurred in Western Australia. However, a significant contiguous area of degradation also occurred in the Northern Territory (the adjoining jurisdiction to the east) in the catchment of the Negri River, a major tributary of the Ord River. Erosion of the friable, calcareous soils of the area contributed enormous sediment loads to the Ord River, and it was later recognised that this had the potential to silt up the reservoir of the proposed irrigation scheme.

Although erosion in the Ord River catchment was described in the 1940s (Medcalf 1944; Teakle 1944), it was not recognised as being a problem of sufficient magnitude to warrant remedial action until plans to dam the Ord River were conceived. At the time, the sediment load, estimated to average about 29 million t yr^{-1} at Coolibah Pocket near the site of the present Ord Dam (Kata 1978), was considered a sufficient threat to the long term storage capacity of the dam to necessitate a stabilisation program on the most severely eroded parts of the catchment.

The regeneration project was commenced in 1960 by the then Western Australian Department of Agriculture (now the Department of Agriculture and Food, WA (DAF)). The project commenced under a cooperative arrangement with station lessees. However, the arrangement did not prove workable and, in 1967, the Ord River and Turner River Stations and parts of the Flora Valley, Ruby Plains and Elvire Stations, an area of approximately 15,000 km^2, were resumed by the State government and the area gazetted as a Water Catchment Reserve.

26.3 Description of the project area

The project area (Fig. 26. 2), which is now called the Ord River Regeneration Reserve (ORRR) included the middle reaches of the Ord River and parts of large tributaries such as the Negri, Forrest, Nicholson, Turner, Elvire and Fox Rivers.

26.3.1 Climate

The area has a hot, strongly seasonal monsoonal climate with a five month (November-March) rainy season, and little rainfall for the remainder of the year. The mean annual rainfall (July to June) is 513 mm at the ORRR depot (now abandoned) in the north and 461 mm at Fox River Station in the south of the ORRR. Rainfall records were provided by the SILO website http://www.nrme.qld.gov.au/silo/. These data were interpolated, based on actual rainfall records from Bureau of Meteorology recording stations in the region. The SILO data may therefore differ slightly from actual readings at ORRR depot and Fox River Station. The detailed interpolation methods are described by Jeffrey et al. (2001). The mean annual rainfall declines by about 1 mm km^{-1} southwards across this part of the Kimberley (Bureau of Meteorology 1996).

Rainfall variability for any one month can be high. Annual rainfall variability is moderately reliable in the northern portion of ORRR, but less reliable further south (using the variability index of Bureau of Meteorology 1996, p. 17). The wet season generally begins with convective thunderstorms which, although isolated, can generate large volumes of run-off due to intense and sustained rainfall. Run-off is exacerbated by low infiltration rates. Mid wet season rainfall is more monsoonal and, while perhaps less intense, rainfall is generally more widespread and can be prolonged, again generating considerable run-off. Although rare, cyclones are also important because of the associated very heavy and intense rainfalls, which may cause extensive flooding, and river, channel and overland (sheet) flows.

The maximum daily rainfall recorded at ORRR depot was 194 mm in February 1995, while consecutive days of rainfall have produced over 300 mm in about 8 per cent of years. Average daily maximum temperature ranges from 27.1°C in July to 38.4°C in November. Mean monthly relative humidity at 3 p.m. is 22% in July and 20% in November. Mean monthly evaporation rates range from 183 mm in June to 360 mm in October, with an annual evaporation rate of 3,248 mm (Halls Creek records, Bureau of Meteorology 1996).

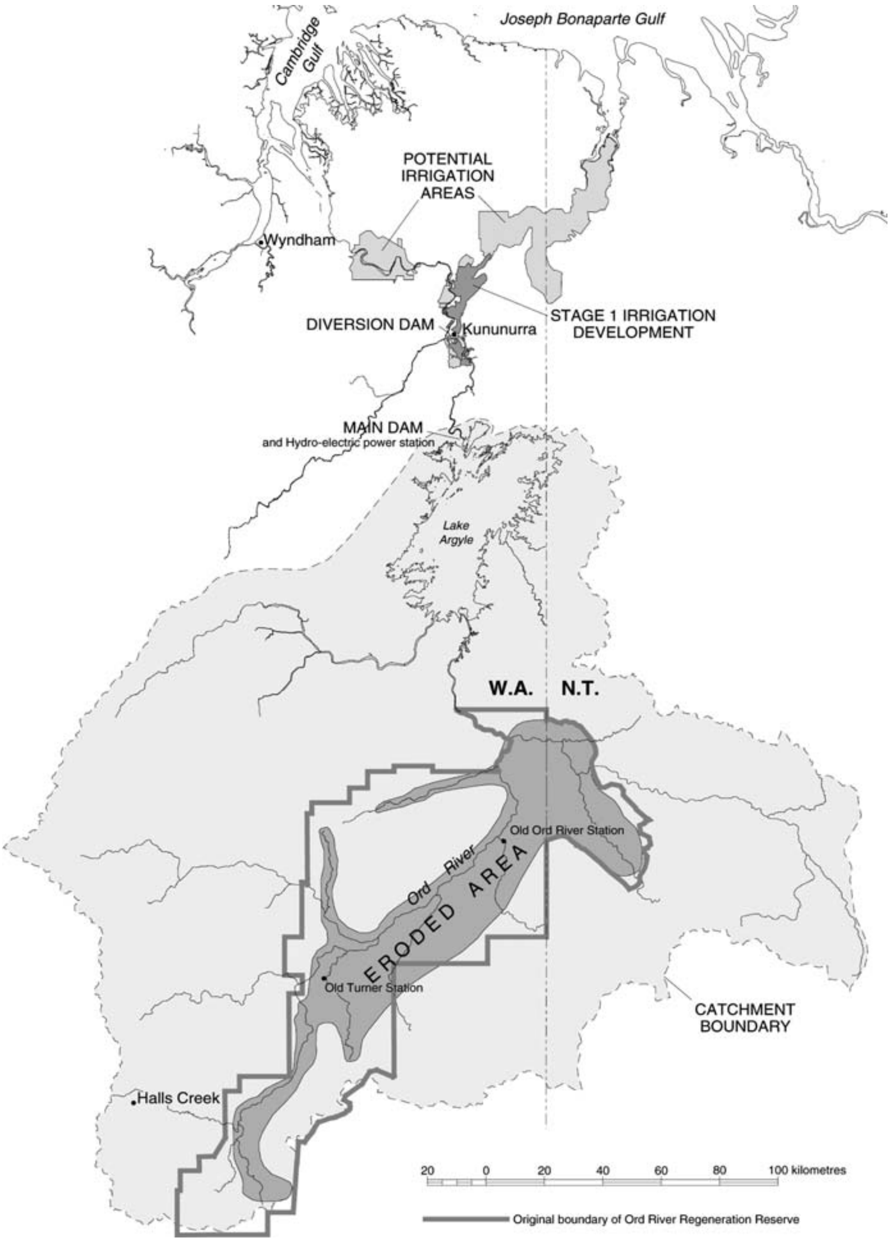


Fig 26.2. Location of the Ord River Regeneration Reserve (ORRR)

26.3.2
Landforms, soils and vegetation

The ORRR consists of extensive, level to gently undulating plains surrounded by more rugged country of limestone and basalt hills and prominent sandstone ranges. Soils include shallow stony types on hills, foot slopes and cuesta tops, cracking clays on lower gilgai ('black soil') plains, and calcareous grey brown loams and light clays over limestone and shale on undulating plains and interfluves. These latter soils are most common on the Nelson and Gordon land systems. They are weakly structured and powdery and, once bared, are particularly susceptible to erosion. Other soils are sandy red earths and alluvial types associated with juvenile alluvial deposits and levees of the major drainage lines.

Vegetation of the area is mainly tussock grassland and a grassland/savanna woodland complex dominated by perennial and annual/biennial tussock native grasses (*Astrebla* spp., *Chrysopogon fallax*, *Aristida latifolia*, *Sehima nervosum*, and *Enneapogon polyphyllus*) and trees (*Corymbia* spp., *Bauhinia cunninghamii* and *Terminalia* spp.). Some large parts of the ORRR, particularly those more xeric areas with stony soils, support hummock grasses dominated by *Triodia wiseana*, with scattered trees and shrubs.

Pasture type distribution is strongly influenced by soil type and topography. This results in a mosaic of different pastures, encouraging localised overgrazing on more favoured types. Prolonged uncontrolled and excessive grazing in the past had substantially altered some pastures both in species composition (towards annuals or short-lived perennials) and total ground cover. In specific areas, the regeneration process and the introduction of the exotic buffel and Birdwood grasses (*Cenchrus* spp.) have led to dominance by these introduced grasses.

The ORRR land systems and their component land units, soils and pastures were described by Stewart *et al.* (1970), Ryan (1981) and de Salis (1993). Two major severely degraded and eroded land systems are the Nelson system in the north and the Gordon system in the south. In Western Australia, the Nelson system is unique to the ORRR but it also extends into the Northern Territory. About 90% of the Gordon system is confined to the ORRR. Both land systems have particular land units with inherent characteristics (such as pasture type, soil types and slope) which make them highly preferred by cattle and therefore susceptible to significant over-use and erosion.

26.4
Regeneration Program

The rehabilitation on the ORRR began in 1960, and was managed by DAF. Under an agreement with the Northern Territory Administration, the Western Australian Government also carried out work on adjacent areas in the Northern Territory.

The regeneration program involved fencing the area into large paddocks, cattle destocking and donkey eradication, and cultivation and seeding of degraded areas accessible to machinery. Cultivation was carried out using tractor-mounted implements, and all cultivations were carried out on the contour in discontinuous parallel strips about 3 m wide, usually separated from each other by 5-10 m of uncultivated ground. The introduced species kapok bush (*Aerva javanica*), buffel grass (*Cenchrus ciliaris*) and Birdwood grass (*C. setigerus*) were seeded together.

Cultivation works and seeding continued at various levels of intensity until the late-1980s. Many areas were treated more than once, some three or four times. Repeat work involved strip cultivation, sometimes without seeding, between the lines of the original cultivations to encourage spread of the introduced species, particularly the grasses.

Recovery within the project area was described by Fitzgerald (1968), Ryan (1981), and de Salis (1993). Since the late 1990s, observational evidence had suggested that vegetative cover had continued to improve considerably throughout the project area, dominated in many areas by the introduced Cenchrus species, but with native grasses common and increasing (Figs. 26.3a and 26.3b), but there was no quantitative information concerning gully stabilisation. Good or very good seasonal conditions during most of the 1990s, combined with the success of the cattle destocking program (which was essentially completed in the early 1990s apart from on-going control of incursions), drove this recovery. In 2002, a full review of the status of the ORRR scheme was conducted (Payne et al. 2004). This confirmed the success of the rehabilitation program in achieving the initial objectives, although perennial vegetation cover could still increase substantially over time in some areas, with gully stabilisation also continuing over time as run-off is reduced. In 2006, the Reserve became part of the Western Australian conservation estate, and is now managed by the Department of Environment and Conservation, Western Australia.

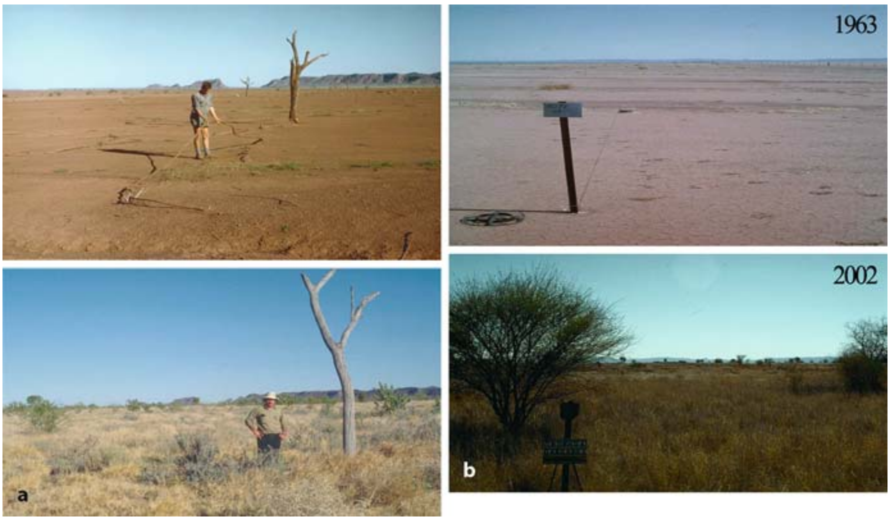


Fig 26.3. a,b **a** Ord River Regeneration Project site Nelson land system, Turner Plains with the Hardman Range in the background, 1962 (above) and similar area in August 2002 (below). **b** Kelly paddock, Headley land system, Ord River Regeneration Reserve, September 1963 (above) and August 2002 (below)

26.4.1
Why was the Regeneration so Successful?

The regeneration of the ORRR was extremely successful but this success appears to have been unique. As mentioned above (see Introduction), the success of regeneration programs has been extremely variable, as has been the willingness of governments and other bodies to attempt large scale rangeland rehabilitation programs. Given the success of the ORRR scheme, it is useful to assess why it was successful, the extent to which factors important in regeneration may be unique to the ORRR scheme, and the extent to which lessons of benefit in other situations may be drawn.

26.4.1.1
There was a "catalyst" for action

From the early 1960s, there was a significant change in the land use in the lower Ord River floodplain, from low output extensive cattle production to an irrigation program promising a significant increase in financial return per unit area. Preliminary studies by Dumas (1944) had revealed the existence of suitable dam sites on the Ord River, and studies by the Western Australian Government and the Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO) suggested that approximately 40,000 ha of the alluvial plains north of Kununurra (well outside the ORRR) were considered suitable for irrigation. Research into the potential for irrigated farming was undertaken jointly by DAF and CSIRO from 1947 (Anon 1960), with water for irrigation to be provided by damming the Ord River and creating Lake Argyle (approximately 1,000 km^2 in area) as the reservoir. Irrigated agriculture began in the early 1960s with water from a diversion dam built to regulate the flow of water for irrigation. Following completion of the main dam, Lake Argyle reached spillway capacity for the first time in the 1973/1974 wet season.

During the early assessment of irrigation potential, serious soil erosion was noted on the red soils of the Nelson and Elder land systems, and the potential for sedimentation to reduce the life of the storage reservoir was identified as early as 1944. During the period of dam construction that led to the formation of Lake Argyle, several studies assessed sediment movement through the catchment. Sadler's (1970) estimate of average sediment load for the Ord River was 24×10^6 t yr^{-1}, suggesting that there would be approximately a 30% reduction in storage volume in Lake Argyle after 100 years. Therefore, sedimentation was recognized as a serious threat to irrigation security, potentially putting at risk the water resource for the irrigation area.

The income generated from grazing rangeland is low compared with the costs of rehabilitation. Moreover, the capacity of many rangeland users to fund any form of rehabilitation is often non-existent, requiring significant government or other agency input. In the Ord River catchment, without the potential financial returns from the irrigation proposal, there would have been limited capacity (or perhaps even will) from the Western Australian Government to initiate the rehabilitation program, and there is no doubt that this change of land use was instrumental in initiating the regeneration program. MacLeod and Johnston (1990) and Lindner (1990) clearly outline the issues in regard to funding rangeland rehabilitation, and the limits if a proposal is to be assessed on purely economic grounds. This leads to the conclusion that there are few supporters for the concept of actually investing in reversing degradation (as opposed to rhetoric) when the rationale is based solely on the premise that degradation itself is unacceptable. Perhaps to expect such support, given the social, cultural and economic difficulties (without even considering the technical ones) confronting those attempting to gain control of land for the purposes of rehabilitation, is naïve. Perhaps the correct focus, given the difficulties in rehabilitation, appears to be on reducing the further spread of degradation. But, reducing spread will have limited effect on reversing the impacts on those areas and communities already affected by degradation, and the economic and social effects of such a situation.

26.4.1.2 Legislation and Government action

Initial regeneration work in the ORRR was done in conjunction with the existing lessees. The lessees of the Western Australian stations were to remove cattle from areas to be reseeded, to contribute to the cost of fencing and assist in ensuring seeded areas remained stock free. But this arrangement proved unworkable, and in 1967 the most severely eroded areas of the catchment (around 15,000 km^2) were resumed by the Western Australian Government as a Water Catchment Reserve under Section 109 of the Land Act (1939-1965). This resumption was strengthened by the Ord River Dam Catchment Area (Straying Cattle) Act, gazetted in 1967 and amended in 1969, which vested ownership of all cattle found within the Reserve with the Crown. The Reserve still (in 2007) remains subject to the provisions of this Act.

This degree of control over both land management and animal numbers (i.e. grazing pressure) provided the authority to develop a 'workable' program and to deal with issues as they arose. This contrasted significantly with the situation prior to resumption when cattle 'invaded' regenerating areas and restricted rehabilitation. Without the authority provided by this legislation, it is doubtful that the control necessary for complete success in the ORRR would have been possible. But, such changes in Government policy through legislation generally cause a disruption in the *status quo*, and can result in significant opposition. Consequently, such changes need to be carefully considered and support and compensation provided to those negatively affected by the change. Ideally, such changes should be worked out in collaboration with those who have a direct stake in the outcomes (see, for example, Brinkerhoff 1995).

While programs such as the ORRR rehabilitation are often the function of only one government agency or department, this 'whole of Government' approach also provided additional support beyond that which could be achieved by only one agency with a specific charter of operations. While DAF was responsible for the management of the program for the entire period, the input and support provided by this ‘whole of Government’ approach assisted in maintaining budget requirements, control etc. This was particularly the case in the first decades of the program, although the focus did shift towards DAF being the major ‘champion’ in later years.

26.4.1.3
Removal of cattle

The most common feature of rangeland degradation is the carrying of far too many animals and an excessive grazing pressure on the landscape. Whether or not ‘drought’ plays a part, ultimately degradation is caused by too many herbivores for the forage available. Often, in fact, ‘drought’ is simply the time when non-sustainable grazing management practices become evident. Thus, the major management issue in extensive grazing systems is managing the number of animals, both domestic and feral. Of significant importance in the ORRR scheme was the clear realization that rehabilitation would not be successful without control of cattle and feral donkeys. Moreover, Government was prepared not only to invest in removal of existing cattle on the ORRR, but to take seriously ingress of cattle from surrounding leases and remove these cattle and their impact by whatever means was necessary, including the shooting of animals from helicopters.

Initial mustering to destock paddocks was undertaken by station lessees. However, after resumption of the leases, subsequent mustering and destocking was facilitated by the Ord River Dam Catchment Area (Straying Cattle) Act. Contract musterers and DAF staff turned off cattle in most years, until the mid-1990s. Between 1961 and 1990, 143,000 cattle were recorded as being removed from the area, while from 1979 to 1981, 15,138 donkeys were shot from helicopters, and recorded numbers were by no means all of those removed (Fig. 26.4).

From 1994 to 2000, a further 2,503 donkeys and 1,148 cattle were removed. Because of the large area and the rough terrain, animal control was not fully achieved until the early 1990s. Rehabilitation success reflected this, with rehabilitation even during extended periods of favourable seasonal conditions in the 1970s severely restricted by continued grazing impact. The ORRR is currently stock free, with an on-going program of surveillance and removal of any cattle found entering the Regeneration Reserve.

The ability and willingness to address the issue of grazing pressure through legislation (it was after all excessive grazing pressure that was the cause of degradation in the ORRR) was of major importance in the success of this scheme. Degradation was the symptom of a deeper problem, that of excessive, prolonged and uncontrolled grazing pressure. If the cause of the problem had not been addressed, and continued to be addressed throughout the life of the program, it is unlikely the outcome would have been favourable. Recent interest to re-open the ORRR area to grazing has also been resisted, because of the inherent fragility of the rangelands, and the potential for the degradation process to begin anew.

Such an option was possible in the extensively managed rangelands of northern Australia, but may not be possible in other countries where alternative sources of income may not be available to communities who depend on the grazing animals

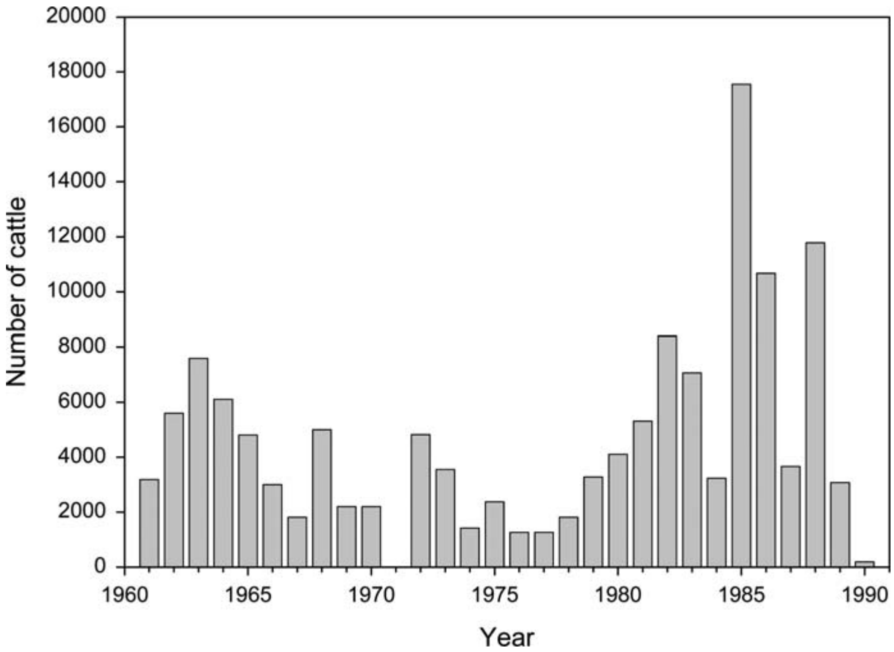


Fig 26.4. Cattle removed from the Ord River Regeneration Reserve, 1961 to 1990

for their livelihoods. Induced destocking requires significant investment in logistics and technical support, and is only possible in certain situations. Traditional herders suffer high losses from destocking programs and are faced with difficult circumstances during the subsequent years of very slow herd reconstitution. Most pastoralists, especially smallholders, have no options other than selling animals at very low prices in order to purchase food grains at very high prices. Once the situation improves, the smallholders cannot return to herding without external support. These factors cannot be ignored. Equally, other factors defining a differing "pressure" or driver towards degradation such as excessive fuel wood collection and the encroachment of non-sustainable cultivation into rangeland require similar consideration and assessment as to being both a cause of degradation and a barrier to its reversal. Whatever the cause (or causes), rehabilitation attempts will be severely restricted if the focus remains on the symptoms rather than the cause. This highlights the interrelationship of the social/economic factors with the ecological, and the need for a broadly based view in assessing both the potential success of schemes being considered for implementation as well as in assessing schemes as they near completion. Examples such as the United Nations Convention to Combat Desertification (United Nations 1995) endorse the requirement for community involvement and acceptance of the problem, and advocate participatory development and the rights of local communities to manage their natural resources. Its strong emphasis on the need for community participation in development initiatives and the necessity for government to delegate decision making authority to the local level is fundamental to sustainable community development. But this is not meant to merely to allow communities to have a 'say' in the initiatives. It is necessary to encourage communities to 'own' the problem (in this case rangeland degradation), its causes (such as excessive grazing pressure) and the solution (such a adhering to restrictions on grazing pressure). This must not be ignored, and if the community cannot implement the solution (or one or more of the various steps in that path), then an alternative solution must be found if success is to be at all possible.

26.4.1.4
Rainfall

Rainfall, the major driver for success of the ORRR regeneration program, was beyond management control. Yet, the Ord River catchment, and north-west Australia in general, is characterized by an unpredictable and highly variable rainfall environment. Significant and extended periods of poor rainfall were recorded during the program, with rehabilitation stagnating during such periods.

Annual deviations from the mean rainfall at ORRR depot are substantial (Fig. 26.5). In general, the early years of the project were characterised by below average seasons. A run of very good seasons occurred from the mid-1970s to the ear-

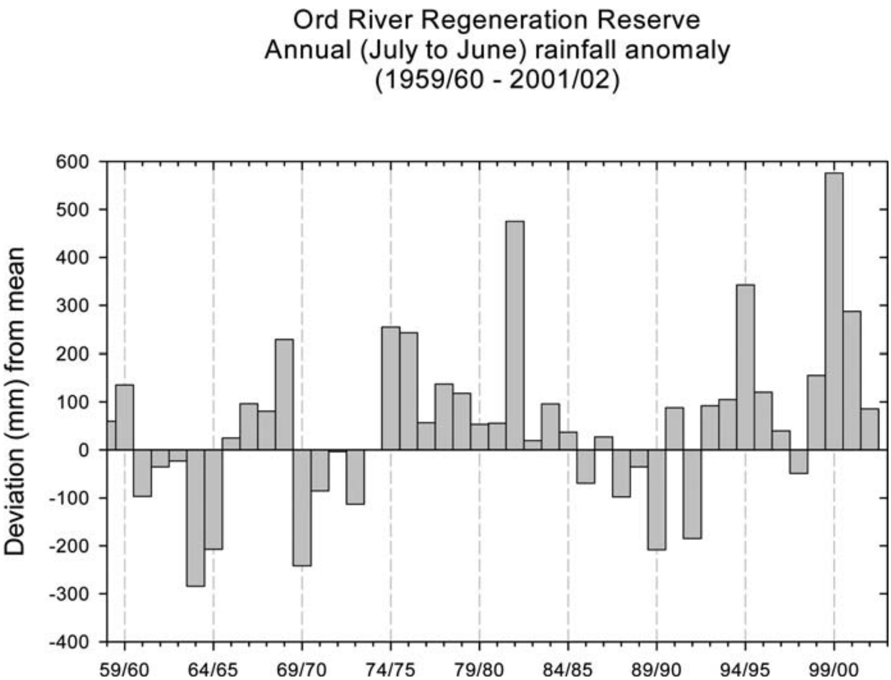


Fig. 26.5. Annual (July to June) rainfall deviation from long term mean at Ord River Regeneration Reserve depot (1959/60-2001/02)

ly 1980s, with another run of good seasons during the 1990s from 1992/93 onwards.

Of importance is the concurrency of extended periods of satisfactory rainfall and the occurrence of other factors necessary for success (in particular control of grazing pressure). While rainfall appeared satisfactory for establishment of seeded species in the 1970s, animal control was minimal at that time, and the grazing pressure in the areas defined for rehabilitation remained high. As a consequence, the program was unable to take advantage of this run of good seasons and assessments suggested minimal rehabilitation. Subsequently, when grazing pressure had been controlled in many areas, this coincided with the extended dry period from the late 1980s to the early 1990s. Again rehabilitation stagnated. It was only from the 1992/1993 wet season onwards that a succession of good seasons coincided with effective and sustained grazing pressure control with the virtual elimination of all cattle and donkeys from the ORRR. This highlights the importance of long-term commitment to such programs (see next section), particularly considering that rainfall management is impossible and that climates such as those of north-west Australia are characterized by substantial inter-annual variability. It also highlights the interaction of many of the factors important in the success of the regeneration program, and the need to consider such interactions when framing a rehabilitation program.

26.4.1.5
Extended timeframes

Government commitment to the rehabilitation program continued beyond the time when the sediment load entering Lake Argyle fell to acceptable levels, and continues still (2007). Apart from assessments and reviews conducted in the first decades of the program (Kata 1978; Ryan and Payne 1976; Ryan 1981; de Salis 1993), internal reviews by DAF in the mid-1980s and in 1990 highlighted concerns that sediment loads of the Ord River were still unacceptably high. With successful regeneration evident on the upper slopes, it was thought that the majority of sediment entering the dam may have originated from gully extension, widening and deepening. Gully control measures were tested on a small number of gullies with reasonable success but were not applied as a broad scale treatment because the cost was considered prohibitive. A further multi-agency major review was conducted from 1990 to 1992, a review of the then management program conducted in 2000, and further testing of sediment levels entering Lake Argyle carried out as late as November 2006.

Such long timeframes and focus on objectives are uncommon in Government programs, where timeframes for projects can be as short as two years. The ORRR regeneration program continued for over 45 years, and while actual seeding/land management activities were completed after approximately 30 years, on-going assessment and specific management (surveillance and removal of cattle entering the Reserve, wildfire management, maintenance of fences and tracks) continues, with the costs borne by Government. In fact, it is fair to say that until the mid-1990s there was no real surety that the aims of the program (sediment reduction) would be achieved. Yet Government continued with the commitment.

Commitment to extended timeframes is not only a requirement of Government. Most certainly, in many parts of the world, a long term commitment from the community would also be required. The aim increasingly must be to encourage the communities themselves, through on-going and long term support and training, to introduce land improvement measures, and to accept a stake in the outcomes, even if desired outcomes may be a long time coming (see, for example, Ramberg 1993). Concurrently, the commitment of the community requires that the technologies introduced are both relevant to the situation and available to the community (in both a financial and logistical sense) for the full duration of the rehabilitation program. Too often, support made available to the community diminishes as time passes, and the community is limited in its capacity to continue with the steps necessary for full rehabilitation or manage during an extended period of limited income. Rangeland rehabilitation often requires a decadal timeframe. Programs initiated without clear recognition being given to this reality risk failure from the outset.

26.4.1.6
Focus on the single objective

The ORRR regeneration program was established with one purpose in mind – the ‘single-minded’ purpose of reducing the sediment load in the Ord River and so the sediment deposition in Lake Argyle, the source of water for the Ord River Irrigation Area. The decisions made, such as that to use exotic rather than indigenous plant species for regeneration, were taken in the context of this focus.

The ORRR project began in 1960, when a less ‘holistic’ view was taken of natural resource management by both government and the community. Issues such as the use of exotic species for regeneration rather than native species, and the impact that exotic species may have on factors such as biodiversity, were either not considered at all or were discounted. However, what could be defined as ‘community values’ are now changing. For example, in 2007, the issue of the use of exotic pasture plants is far more contentious. While many ‘producers’ regard the establishment of exotic pasture plants as a necessary component for either land reclamation or economic viability (or both), many regard exotic species as a threat, particularly to biodiversity values, both within the area in which they are planted and in the context of the broader landscape values as a whole. Similar situations occur with other issues, social and economic as well as the more ‘agronomic’ and ecological.

It is now recognized that the problems that arise on rangelands are complex and multidimensional, and are not amenable to quick and easy fixes. Consequently, the extent to which the focus on this single objective was important in the success of the ORRR scheme will always be debateable. There is no doubt that once the decision had been made to dam the Ord River for irrigation, the objective of reducing sediment flow into Lake Argyle became paramount, and other factors were not permitted to deflect the focus. This is not to minimize the need to fully consider the complex environment or context within which such programs are generally set. This context can, and should, include a range of factors, including the 'human nature' issues, and the context within which governments, organizations and agencies operate must be kept firmly in view. Equally important is the link between environmental degradation and poverty and the need to address broader socio-economic causes of a natural resource management problem (although the relationship between poverty and environmental degradation has been questioned (Broad 1994). But, there is no doubt that as the focus of a program broadens, the impediments increase, reducing the capacity to achieve the fundamental goal. Consequently, the 'purpose' of any rehabilitation scheme must be clearly defined, and the requirements to achieve the goals must be adhered to.

26.6 Discussion and Conclusions

The rehabilitation of degraded rangelands is a contentious issue (see, for example, Blaikie 1989; Lindner 1990). Seeding degraded landscapes is a speculative procedure, with the prospect of successfully establishing perennial species being critically dependent on seasonal conditions and on issues such as grazing pressure in the years following initial establishment. The limited return per unit area of much of the world's rangelands makes the economic rationalists argue that rehabilitation is simply not cost effective (MacLeod and Johnston 1990).

In situations where rehabilitation has been carried out, assessment of the program often concentrates on more "technical" issues associated with the activities – the species planted, their ecology and agronomy and other such factors. These factors are certainly important – a poor choice of species or seed quality, not addressing soil chemical limitations, and inappropriate planting techniques must all be addressed and 'work' appropriately for the plants to thrive and the regeneration to be a success. In the case of the ORRR program, the combination of a 'colonising species' (*Aerva javanica*) and two adapted perennial bunch grasses (*Cenchrus* species) proved excellent for initial soil stabilisation, while allowing the native grass and forb species to also develop.

However, this assessment also clearly illustrates that 'success' in rehabilitation generally requires more than technical expertise. The 'whole of government' approach and the insistence on and commitment to removal of all grazing pressure (the cause of the degradation), the acceptance of a long time frame and a commitment to seeing the project through were equally important. In fact, it could be argued that given the interaction between grazing pressure and favourable seasonal conditions, these factors were more important than the species chosen for seeding.

Although the individual non-technical factors may vary in other situations, the ORRR program is not atypical. There are numerous non-technical factors that will potentially influence each regeneration scheme, many of which are hotly debated. For example, there is debate about the role of factors such as 'excessive carrying capacity' as drivers for degradation and the need to reduce carrying capacities to achieve rehabilitation (see, for example, Abel 1993). Most of the factors important to the success of a rehabilitation program will be unique and peculiar to that scheme; other factors are perhaps part of the socioeconomic and political forces of a more global nature (for example, prices or market access) that affect a stockowner's capacity, and willingness, to reduce stock numbers early in a 'degradation cycle' and so reduce grazing pressure to more manageable levels. There is no attempt in this analysis to suggest that the factors identified as important in the ORRR scheme will be equally important, if important at all, in other schemes. However, in the case of the ORRR, these non-technical factors were perhaps more important than the technical ones, and what this assessment highlights is the importance of looking beyond the mere technical aspects when planning such a scheme and identifying and assessing the reasons behind success or failure of an on-going rehabilitation program.

While it would be wrong to draw too much relevance from this assessment for other schemes, there is no doubt that several points do stand out. There are commonalities between what was important in the ORRR and what is going to be important in most rehabilitation schemes. These include a need for strong commitment from Government, a willingness to make "hard" decisions focussing on the objective of the scheme, dealing with the cause of the problem (excessive grazing pressure in this case) concurrently with addressing the symptoms, and a clear initial acceptance that timeframes will be long. In addition, the required support for a long time frame within a subsistence community can only come with a whole of government approach because the communities themselves and individual agencies within governments do not have the necessary resources to complete projects that have timeframes that stretch over decades.

The factors important in the success of the ORRR scheme have been discussed individually for the purposes of this paper, but, as discussed with respect to the interactions of rainfall and grazing pressure, it was the interrelationship of these factors and their overall impact that was as important as their individual contributions.

References

Abel N (1993) Challenging the notion of Carrying Capacity: how can the debate inform development programs in Botswana? Overseas Development Network, Pastoral Development Network, Network Paper No. 35.

Anon (1960) Kimberley Research Station – A Progress Report. J Agric West Aust 1:3-14

Blaikie P (1989) Explanation and Policy in Land Degradation and Rehabilitation for Developing Countries. Land Degrad Rehabil 1:23-37

Brinkerhoff DW (1995) Enhancing capacity for strategic management of policy implementation in developing countries. IPC Monographs No. 1, USAID Project #936-5470, Washington DC, USA

Broad R (1994) The poor and the environment: friends or foes? World Dev 22:811-822.

Bureau of Meteorology (1996) Kimberley Western Australia climatic survey. Australian Government Publishing Service, Canberra.

de Salis J (1993) Resource inventory and condition survey of the Ord River Regeneration Reserve. Department of Agriculture, Western Australia, Miscellaneous Publication 14/93.

Dumas RJ (1944) Development of the north-west of Australia – East Kimberleys – Ord Irrigation Scheme. J Inst Eng (Aust) 16:65-70

Fitzgerald K (1968) The Ord River Catchment Regeneration Project. Department of Agriculture, Western Australia, Bulletin 3599.

Jeffrey SJ, Carter JO, Moodie KM, Beswick AR (2001) Using spatial interpolation to construct a comprehensive archive of Australian climate data. Environ Model Softw 16:309-330

Kata P (1978) Ord River sediment study. Water Resources Section, Western Australian Public Works Department, internal report.

Lindner RK (1990) Should range rehabilitation be paid for from the public purse? Aust Rangel J 12: 61-68

MacLeod ND, Johnston BG (1990) An economic framework for evaluating rangeland restoration options. 34th Annual Conference, Australian Agricultural Economics Society, University of Queensland, Brisbane.

McKeon GM, Hall W, Henry BH, Stone G, Watson IW (Eds) (2004). Pasture degradation and recovery in Australia's rangelands. Learning from history. Queensland Department of Natural Resources, Mines and Energy, Brisbane, Australia, 256 pp.

Medcalf FG (1944) Soil erosion reconnaissance of the Ord River valley and watershed. Western Australian Lands and Survey Report.

Narjisse H (2000) Rangelands issues and trends in developing countries. In: Arnalds O, Archer S (eds) Rangeland Desertification, Kluwer Academic Publishers, Dordrecht, pp. 181–195

Payne AL, Watson IW, Novelly PE (2004) Spectacular recovery in the Ord River catchment. Misc. Publ. 17/2004, Department of Agriculture, Western Australia.

Pickard J (2002) Assessing vegetation change over a century using repeat photography. Aust J Bot 50: 409-414.

Ramberg L (1993) African communities in conservation: a humanistic perspective. J Afr Zool 107:5-18.

Ryan WJ (1981) An assessment of recovery and land capability of part of the Ord River Catchment Regeneration Project. Department of Agriculture, Western Australia Technical Bulletin 53.

Ryan WJ, Payne AL (1976) A measure of recovery on the Ord River Catchment Regeneration Project. Working papers of the Australian Arid Zone Research Conference, July 1976, Kalgoorlie, Western Australia, 4:43-47

Sadler BS (1970) The hydrologic investigations for the Ord River dam. Public Works Department, Perth, Western Australia.

Stewart GA, Perry RA, Paterson SJ, Traves DM, Slatyer RO, Dunne PR, Jones PJ, Sleeman JR (1970) Lands of the Ord-Victoria Area, Western Australia and Northern Territory. CSIRO Land Research Series 28.

Teakle LJH (1944) Soil erosion and its relationship to soil type and geological formations of the Upper Ord Basin. From File 23/44, Vol. 1 Kimberley Investigations Soil Survey, pp 174-182

United Nations (1995) United Nations Convention to Combat Desertification in those countries experiencing serious drought and/or desertification, particularly Africa. Text with annexes, UNEP/CCD, Geneva.

CHAPTER 27

Land Degradation Management in Southern Africa

Josephine Philip Msangi

Abstract. In all eight out of the ten countries constituting Southern Africa region most people live in rural areas and depend on subsistence agriculture for their livelihoods. In the region land degradation occurs mostly from soil erosion, chemical degradation (loss of nutrients, depletion of organic matter and acidification) and biological depletion. Other factors which contribute to land degradation in the region include compaction from overgrazing of rangelands, uncontrolled burning and improper cultivation of steep slopes, alternating flooding and crusting, salinization and pollution which all combine to cause degeneration of the fragile ecosystems covering large expanses of the region. Landscapes devoid of vegetative cover deeply incised by gullies that are difficult to reclaim, characterize large land expanses in the region classified as drylands. The portions classified as sub-humid or humid (highlands and wetlands) are prone to rapid soil loss from flash floods or periodic flooding. With a cycle of 2-3 and sometimes 5-6 years, droughts that have occurred in the region for over a century, worsen the land degradation problem making land management a formidable task particularly during the critical moisture deficient periods. Differing land tenure systems combined with high poverty and low literacy levels common among the rural population complicate land management process. Low technological capacity, poor governance, poorly conceived management policies and their implementation further complicate land management issues. Technology development, technology transfer and low adoption rates further exacerbate the situation. Pressure on the land and competition for land is of main concern throughout the region. Governments in the region as well as private organizations (including the numerous NGOs operating in the region), some communities and individuals (including researchers and academicians) have all identified the need to conserve land and reverse degradation to restore its productivity and improve the quality of life for those who depend on it for their livelihoods. The chapter examines the nature and causes of land degradation in the region, linking it to population characteristics, land ownership, low technological capacity, poverty, poor governance, low literacy and inappropriate land management practices. The chapter points out that numerous interventions targeted at reducing poverty and improvement in land resource management have not achieved their targets due to lack of coordination, rigidity and imposition which culminated in failure of the interveners to recognize and incorporate indigenous knowledge and peoples' preferences and/or indigenous age-old land management strategies. Linkages to trade and unequal market access that encourages poverty and unwise use of the land resources are discussed. Adopting "people centered" interventions is recommended together with smart partnerships between the participating partners both

from the north and those from the south. Solutions will largely depend on willingness to change and sharing information that will guide appropriate regional action. The region faces an enormous challenge part of which is to come up with viable solutions that will reverse the degradation of land and manage it sustainably.

27.1 Introduction

In Southern Africa, land tenure determines sustainability in agriculture and rural livelihoods (Bond et al. 2004). With the exception of Mozambique, Lesotho and Swaziland, vast areas of Southern Africa are arid or semi-arid receiving 500 mm of average annual rainfall. Most parts in Namibia, South Africa and Botswana receive less than 250 mm with extremely high evapotranspiration rates of over 2500 mm yr^{-1}. The soils are generally poor with low organic matter content and have low water retention. They are vulnerable to water and wind erosion, leaching and salinization if put under irrigation. For example, in South Africa over 30% of the soils are sandy with less than 10% clay content; 60% of the soils have a low soil organic matter and hence conducive to low productivity and degradation (Villiers et al. 2005). In Namibia 95% of the soils have clay content of less than 5% and thus have very low water holding capacity (Liebenberg 2005). In Botswana, 70% of the soils are sandy, geologically old and highly leached, poorly structured, infertile and characterized by hard setting upon wetting (Moroke 2005). In Lesotho, more than 70% of the soils are acidic, have low organic matter, low pH and are infertile (Ranthamane 2005). Elsewhere in the region, varying soils with varying fertilities are found depending on physiography, land use and land management techniques.

In Southern Africa, most of the land is used for agriculture (crop production and/or livestock production); most farmers who live in the rural areas are poor and practice small-scale rainfed agriculture and/or agro-pastoralism. In South Africa for example, out of 46 million total population with a density of 88 persons ha^{-1}, 3 million small-scale farmers occupy 13% of the total agricultural land from which they meet their subsistence needs while 87% of the arable land is used for commercial farming by about 46,000 commercial farmers who produce about 95% of the market output (Villiers et al. 2005). There is pressure on land and high competition for land by different land users (such as urbanization). In South Africa, land degradation is attributed to land use change, drought severity, frequency, duration and numerous land use changes. Like wise, in Lesotho most of the population is rural; about 82% reside in rural areas and out of these, 55% depend on agriculture for their livelihoods. Decline in agricultural land productivity over the years is attributed to declining soil fertility; poor land management, soil erosion and land degradation (Ranthamane 2005).

All over the Southern Africa region, expansive areas are owned by commercial farmers cultivating crops for export particularly in South Africa, Swaziland and to a lesser extent Zimbabwe (pre-land reforms). Large commercial ranches exist in most of the countries but predominantly in South Africa, Namibia and Botswana where most of the land is not suitable for rainfed agriculture. However, irrigated agriculture and/or dryland farming is practiced by a few commercial farmers in the three countries. Elsewhere, small-scale producers struggle to use the land to meet their subsistence needs as well as produce for the world market economy including materials needed by a wide range of industries located in the developed countries. This includes tobacco in Malawi; fruits and cut flowers in South Africa and Zimbabwe and to a lesser extent Namibia; beef in Namibia and Botswana; and minerals in South Africa, Namibia, Botswana and Zambia. In so doing, land gets degraded either from over-use/misuse, erosion (steep slopes cultivation, monocropping and overgrazing), pollution (especially from mining) and acidification/leaching (irrigation and flooding).

Land degradation varies from country to country with the type of physical environment and the type of usage. In Lesotho for example, degradation includes severe soil erosion on the steep slopes and chemical degradation (depletion of organic matter, leaching, loss of nutrients and acidification) on the lesser steep slopes and the lowlands. Alluvial erosion has led to the formation of gullies or "dongas" while sheet erosion removes tons and tons of surface soil every year.

In South Africa on the other hand, major forms of degradation are soil acidity and alkalinity, nutrient and biological depletion, erosion, compaction, crusting and pollution. The soils are characterized by high water loss and high runoff rates with high evapotranspiration which make most of land unproductive without irrigation and addition of fertilizers. High stocking rates in the traditional lands have resulted in serious soil erosion and rangeland degradation.

In Namibia, where the mainstays of the economy include agriculture, mining and fishing, agriculture supports 70-75% of the population. About 45% of the land is commercial farmland with freehold tenure, 41% is communal farmland and 15% is state land including conservation areas. Out of the total area, only 1% of the land area is suitable for crop production with or without irrigation. This is found mostly in the north and northeast part of the country. The bulk of the agricultural land is thus suitable for livestock production (Liebenberg 2005).

Similarly, in Zimbabwe, about 70% of the population live in the rural areas and depend on agriculture. They live in communal areas with marginal productivity, infertile soils, medium rainfall (600 mm yr^{-1}) and high population densities that have over the years put unimaginable pressure on land and bio-resources (Mharapara 2005). Land degradation has its roots in the socio-economic and political history of the country as well as climatic anomalies (excessive periodic high rainfall). Dependence on common property resources by the majority (70%) of the population has led to overgrazing, deforestation, soil erosion, over-cultivation, inappropriate agricultural practices and resultant poverty.

In Zambia on the other hand, there is ample agricultural land and 60% of the population depends on small-scale agriculture both for subsistence and for income generation. The smallholder sector (85%) that is dependent on rainfed agriculture employs 67% of the labour force while commercial farming employs 14% (Phiri 2005). The soils are fragile and infertile due to misuse and a long period of weathering of old mineral rich rocks. Degradation is thus attributed to prolonged use of the land without appropriate tillage methods and the age of the parent material.

In Swaziland, only a small area (10% of total land area) is suitable for crop cultivation and the majority of the land (67%) is devoted to cattle grazing. An additional 14.4% used for crop production gets converted to grazing land during summer.

About 77% of the total population lives in the rural areas and is dependent on 54% of the land that is held in trust by the King for the Swazi people. The rest of the land is privately owned and is used for the production of sugarcane and fruits (Manyatsi 2005). Land degradation is severe in the hilly and undulating middle grasslands which constitute the most important agricultural lands and are heavily populated. Here intensive farming and livestock grazing have caused soil erosion, particularly in the communal lands held in trust by the King for the people. Elsewhere the rangelands are said to be in good condition.

In Malawi, about 86% of the population lives in the rural areas and depend on agriculture for their livelihoods while in Mozambique agriculture absorbs about 84% of the population (both subsistence small-scale and commercial farmers). In Malawi, ever declining land productivity is a problem attributed to recurring droughts, excessive soil erosion, depletion of soil nutrients, reduced soil water retention capacity and soil low organic matter content (Mulenga 2005). In Mozambique the small-scale farmers depending on rainfed agriculture cultivate 95% of the total land devoted to agriculture. Although important to the national economy, irrigated agriculture occupies only 1% of the total cultivated land. Due to the vagaries of war, not much literature exists on land degradation in Mozambique (Brito et al. 2005).

27.2 Land Degradation Management

Land ownership and land tenure partly determines the success rate of technology adoption as well as willingness to invest in land management initiatives (Fisher et al. 2005). In Southern Africa, a range of technologies have been developed over time in order to cope with land degradation in general and these include resource conservation, better water harvesting methodologies, development of the most suitable crop varieties and development of most suitable tillage and cropping systems. Governments, Non-Governmental Organizations (NGOs) and in some instances, the private sector have made efforts to address the issue of land degradation with the sole aim of finding solutions. SADC as a regional organization has also put in place specific units to address the land degradation and land management issues in the region.

Throughout Southern Africa, with the exception of Swaziland where it is reported that there is a lack of focus on land management, relevant and interesting technology development has been addressed over time focusing mainly on the small-scale farmers. Despite the availability of these technologies, the rate of adoption by the majority of the small-scale farmers has been low. The reasons advanced include poverty, inability to afford the required inputs such as fertilizers and necessary machinery, and low-level education inhibiting an understanding and appreciation of these technologies (Msangi 2004). Other reasons include non-involvement of indigenous people during project formulation and ignoring their land management practices. Some of the introduced technologies are so general that they do not address the problems facing a specific area and hence lack in relevance and applicability to different micro-environments (Molapong 2005).

Individually, most countries have made notable efforts in promoting land management in their countries. Botswana for example, has introduced and implemented a number of programs to promote management of dry land farming and irrigated agriculture. These include Arable Lands Development Program (ALDEP), Accelerated Rainfed Arable Program (ARAP), Irrigation and Water Development Project, Development of Extension Services and Pandamatenga Development Project (Moroke 2005). However, success has been minimal due to low technology adoption, water shortage, infertile soils and poor infrastructure that discourage private sector investment in the agricultural sector.

Meanwhile, the Botswana Government has introduced The National Master Plan for Arable Agriculture and Dairy Development (NAMPAADD), a new program to improve land productivity by reforming the small-scale farming sector. It is geared towards transforming traditional/subsistence farming and its operations to a commercial level and also to enable commercial farmers to upgrade their management and technological application. Incentives including subsidies are made available to those who adopt practices that would lead to increased production such as mechanization. Countless research projects to improve tillage practices (such as Dry Land Farming Research Scheme (DLFRS)) and pasture and land resources management are being undertaken.

It is obvious that over the years, Botswana has heavily invested in land management for improved land productivity; technologies aimed at improving both crop and livestock outputs are in place but the adoption has been poor/slow partly due to inadequate private investment and partly due to inadequate human capacity (HIV/AIDS has hugely affected the man-power availability).

In Lesotho, the budgetary allocation for land management programs is not equivalent to the serious soil erosion and soil declining fertility problems being experienced in the country. Budgetary allocations have been declining in the last 10 years and there has been a huge loss of experienced and qualified staff in the land management sectors as the senior members leave the sector for higher positions in other sectors (Ranthamane 2005).

However legislation for land conservation (rangelands and wetlands mostly) exists and plays a vital role in the management efforts being made by both the Government and other players including NGOs and training institutions. There also exists a National Environmental Action Plan that addresses, in very general terms, the overall management and conservation of biodiversity and natural resources. Government Ministries have put in place various programs and projects aimed at the management of soil and water and the promotion of agroforestry projects. Also in place are training programs for farmers and the youth on conservation farming systems. Included in this training are activities on grass seeding for marginal and degraded lands.

Soil erosion is controlled on the marginal lands by the construction of grade stabilization structures and stone lines on the rangelands. Check dams have been built and progressive soil survey and mapping is carried out to determine land suitability for different land use purposes. Courses on soil and water management are taught at the National University in an effort to build capacity for land management in Lesotho. The University also provides extension services to farmers and herders during which the farmers and herders are trained on land and water conservation methods, conservation farming systems and how to combat soil erosion. Field trips to conservation sites are also conducted for both groups.

Lesotho has numerous other programs managed by different organizations such as SERUMULA, an NGO concentrating on natural resources management and Katleho-Moho Association, another NGO concentrating on among other things rehabilitation of degraded lands and soil fertility management techniques for small-scale farmers. Despite the presence of a legal framework which guides the activities on land and water management in Lesotho, there is a lack of proper coordination and communication among the various players. There is thus need to improve on communication and sharing of information.

In Malawi, there are various policy documents to guide management of land and other natural resources that are held by different Government Ministries and departments. For instance, the National Environmental Action Plan (NEAP) identified soil erosion as the biggest threat to agricultural production and called for urgent action to arrest land degradation and restore soil resources (Mulenga 2005). Also available is the National Land Resources Management Policy and Strategy aimed at improving land productivity. In an effort to rectify the situation and foster sustainable management of land and other natural resources, earlier policies have been revised and new ones have been formulated. Good examples include the revision of the National Environmental Policy (NEP) to incorporate issues on Community Based Natural Resources Management (CBNRM) and the launching of Malawi's National Strategy for Sustainable Development (MSSD) in compliance with the recommendations of the 2002 World Summit on Sustainable Development (WSSD).

While policies provide a basic foundation for managing land degradation, it is stipulated that their implementation remains the greatest challenge in achieving sustainability in the management of land and other natural resources in Malawi. There is neither coordination in the implementation of these policies nor well articulated regulations for their implementation. Where some regulations exist, there is weak enforcement. Recent increase in the frequency of drought has compounded the problem of ineffective land management and associated decline in land productivity (Mulenga 2005).

Other projects undertaken to promote land degradation management by small-scale farmers in Malawi include the Promotion of Soil Conservation and Rural Production Project (PROSCARP) and a follow up Bridging Project on Sustainable Livelihoods supported by the European Union (EU). Another project in this category is that on rehabilitation of heavily degraded areas supported by NATURE. Regular training and materials to facilitate the implementation of activities is provided. Other efforts made to improve land management include the formulation of Malawi Better Land Husbandry Concept, New Agricultural Extension Policy and Contract Research and Core Function Analysis where the Ministry of Agriculture was reorganized so as to empower and give responsibility to the local communities in the management of their land. Good success has been recorded apparently because introduced technologies were centered on the farmers' desire to increase food supplies.

The challenges which are likely to undermine isolated cases of success in Malawi include inadequate budgetary allocations, fragmentation of implementation among the Government departments, lack of integrated human expertise and most importantly lack of coordination. Another challenge affecting land management in Malawi is the impact of HIV/AIDS, which has caused loss of experts and created labour constraints at the implementation level. There have not been enough efforts to incorporate indigenous knowledge for scientific investigations and recommendations on land management. Poverty has aggravated the situation as poor farmers tend to respond to their daily or immediate needs rather than long term needs. As such they do not invest their time into long-term land management practices (Mulenga 2005).

While a clear policy on land use and management is lacking in Swaziland and there seems to be little or no research on land management, in Namibia, land management is of great concern to the Governments and private landowners. Rangeland reclamation and management, land carrying capacity and agro-forestry promotion has been accorded high priority through several projects including those on pasture rehabilitation, bush encroachment control, and expansion of irrigated land. Both the Government and NGOs are involved in land management through the promotion and support of appropriate projects. Ongoing projects include Veld Reclamation on Denuded Communal Areas; Evaluation of Saline Tolerant Vegetation as a source of fodder for livestock and the Effect of Bush Control Measures and Grazing on Species Composition and Bush Densities. The Desert Research Foundation of Namibia (DRFN), an NGO that concentrates on sustainable use of land and natural resources in the country, collaborates with the Ministry of Environment and Tourism to administer the NAPCORD program which concentrates on combating land degradation (Liebenberg 2005).

A flagship initiative by the Government to manage land and water resources in Namibia is the Green Scheme Policy, which aims at encouraging investment into land management to stimulate increased productivity and encourage the development of small-scale irrigation farmer settlements. The scheme aims to enhance socio-economic development and promote the uplift of Namibia's rural communities by creating an enabling, commercially viable environment through an effective public-private partnership to stimulate increased private sector investment in the irrigation sector. The scheme aims to stabilize the agricultural sector and overcome drought effects and thus stabilize land output and small-scale farmers' income through the growing of high value crops including horticultural products.

The Green Scheme is one of Namibia Government's initiatives to sustainably manage land in order to increase its productivity. A few projects have been started under the umbrella of the scheme, all guided by the existing legal framework in the country. The Communal Land Reform Act, Act No.5 of 2002, the Traditional Authorities Act No. 25 of 2000 and the Namibian Environmental Assessment Policy support the scheme. The scheme requires that large private landholders work hand in hand with small-scale farmers so as to build capacity, ensure technology and skills transfer to promote proper land management and add value to produce before marketing.

Other initiatives on land management are closely linked with the conservation activities such as the setting up of conservancies that aim to conserve land and other natural resources to empower the rural communities and increase their livelihoods. The aim of the conservancies is to empower the communities so that they can manage land and the resources therein with little or no assistance from the Government. Currently 14% of Namibia's land constitutes communal conservancies created under the Community-Based Natural Resources Management (CBNRM) program which give rural people rights to benefit from the natural resources in their areas (Garoes 2006). Given the country's poor soils and limited rainfall, this is a viable method of conserving land and at the same time bring benefits to the rural communities.

Mozambique has extensive wetlands subject to periodic flooding, mountainous lands and low-lying dry areas frequently affected by droughts. Nevertheless, good quality land is plentiful. The land management policy described in the Government 2000-2004 program stipulates that land use rights must be guaranteed to all singular and collective entities to ensure accruing of benefits to all Mozambique people.

Mozambique has different land tenure systems ranging from state-owned to private and communal and open access. Due to this fact, there is competition for and subsequent pressure on the better lands by numerous interested groups who wish to acquire and develop land. At independence in 1975, all land became state land. In 1977 a new Land Bill was passed which recognized the different land tenure systems and 1979 the Government enacted a new Land Law, which governs land ownership under different systems (Brito et al. 2005).

Land management in Mozambique is affected by climatic, technical and institutional factors. These include periodic severe floods and drought, presence of land mines, low level of technological development; absence of credit facilities for would be investors and underdeveloped infrastructure and communication system. The effects of the prolonged war ravaged the rural areas leaving them poor and without necessary investment resources. Therefore the government strategy is to stimulate production of both food and cash crops and conduct research on the different production systems and land management technologies including irrigated agriculture.

In Zambia approximately 90% of the land falls under traditional/customary tenure arrangements and 10% is under lease tenure arrangements. Both tenure systems are recognized through the Lands Act. Thus landowners have land security and can invest in land without fear of loosing their investments. However, land resources management has not been adequately integrated into the overall social and economic policies and strategies for economic development. Coordination is disjointed; the policy on land management is said to date back to the Structural Adjustment Program days (1992) during when the focus was on liberalizing the agricultural land usage to attain food security for the country and produce raw materials for the agro-based industries. During early 2002 the newly elected President emphasized on science and technology agriculture and the need to adopt farming practices that are both economically and environmentally sustainable (Phiri 2005).

During the last decade, several projects were undertaken in Zambia to ensure sustainable land management which include those on conservation farming technologies advocated by the Conservation Farming Unit (CFU) funded by NORAD, SIDA and the Royal Netherlands Government. The objective was to enable small-scale farmers to adopt more productive and environmentally friendly sustainable conservational farming systems. By 2005, CFU had undertaken 300 farmer-managed trials at the Golden Valley Agricultural Research Trust sites. Training and farmer support was provided by CFU on land management techniques such as terracing, ridging, range management and green manure. Further support in land management was provided through research supported by World Agroforestry Center (ICRAF) project funded by CIDA and IDRC of Canada. Through partnerships, agroforestry technologies (improved fallows, mixed cropping, relay cropping and biomass transfer for fertility improvement) were tested and adopted by farmers.

In Zimbabwe on the other hand, the Government, individual institutions, organizations and some communities have identified the need to conserve natural resources, reverse land degradation, restore productivity and promote wise use of land resources on a sustainable basis. Land degradation in the country is rooted in both its socio-economic and political history as well as climatic vagaries. The Government instituted the Land and Water Management Applied Research Program aimed at enhancing capacities to generate and facilitate the availability of appropriate technologies for use by communities inhabiting the marginal lands where more than 70% of the population lives. Very high population densities characterizing these areas have over the years put enormous pressure on the land and other natural resources. The program attracted a large number of organizations and institutions interested in sustainable land productivity.

Although the Government has developed other policies that influence conservation, management and utilization of land, the implementation of these policies is not well supported with resources, there is inadequate capacity to enforce these policies as well as lack of commitment and political will (Mharapara, 2005). It is also documented that there has not been deliberate and specific policies to support research and development on land management; rather there has been experimentation by numerous organizations on different aspects of land management including conservation farming, gullies ("dambo") management system, soil fertility improvement and mapping, micro-irrigation techniques development, rangeland management strategies and policy development on natural resources management (including land and water). Several challenges including poor knowledge of the environment and necessary linkages in the management of resources in a given ecosystem, poor strategy formulation and implementation without full appreciation of time frame and high investments required to realize benefits have deterred success. Many investors dropped/abandoned projects after a few years because the short term results were not encouraging.

Current changes in land ownership in Zimbabwe have baffled many, both landowners and land management advisors. Resettled farmers (new land owners) suddenly find themselves at a loss given the many challenges present in managing large chunks of land and in meeting expectation (conservation, reclamation, commercialization and intensification vs. subsistence, etc). Service providers are equally as overwhelmed by the sudden change and demands placed upon them by the change of land ownership. Facilities existing on some of the farms where relocation has taken place are old or obsolete; the new owners do not have the resources with which to operate them or replace them neither does the Government have enough credit to advance to these farmers. Land is either being mismanaged and/

or under-utilized because of the sudden change. Brain drain has rendered many Government departments ineffective and many organizations activities have been paralyzed or heavily scaled down. Because of disjointed activities, the many institutions and organizations active in Zimbabwe are said to be ignorant of each other and what each is doing in their respective enclaves. There is thus failure to share vision, increased duplication of efforts, increased inefficiency and failure to create a critical mass of expertise around land management issues. Networking is lacking; lacking also is a national land strategic management master plan forcing individuals, institutions and organizations to come up with their own plans that may have little relevance to the whole picture (Mharapara 2005).

27.3 Conclusions and Recommendations

This short chapter has reviewed land usage and land degradation in eight of the ten countries in Southern Africa discussing various land degradation management efforts pinpointing the partial successes that have been recorded by the various actors and players. One of the contributing factors to lack of full success is lack of capacity, both financial and human as well as lack of universal coordination and information sharing. Land degradation and restoration issues take time to yield results; investors have displayed impatience and disappointment when expected results were not forthcoming within the short plan periods. Ambitious programs and projects were either left unfinished or conclusions drawn prematurely. The varying situations existing in the different areas in all the countries were not clearly understood by foreign investors who sometimes came up with much generalized projects lacking in specificity. Governments who followed advice given by foreign institutions including the World Bank and International Monetary Fund created false illusions that disappointed many when results fell short of expectations. Failure was further compounded by weak follow-ups because of limited capacity, lack of political will, non-involvement of local people in setting up the projects and/or the inability of the national governments to continue with the projects or activities in the plans and programs after donor assistance has come to an end (Msangi 2004). Other factors contributing to the partial success in land degradation management strategies include ineffective land tenure policies. For example by fencing off large tracts of land to create commercial farms, parks and game reserves, large numbers of people were either displaced or constrained in smaller areas where old-age land management mechanisms are jeopardized. Civil strife and prolonged wars in Mozambique and Angola plundered resources, introduced land mines, destroyed infrastructure and rendered large areas unusable. Land management in such areas poses insurmountable challenges for the affected areas both in and outside the boundaries of the two countries.

Inappropriate donor and land management policies as well as rigidity on the part of developed countries and investors greatly constrains most of Southern Africa countries and deprives them of room to maneuver, which has in turn led to the accumulation of large debts whose repayment has/is siphoning savings from the national coffers. This is limiting investment into land management and other development issues. Unfavorable terms of world trade force these countries to overexploit their land and other natural resources in the quest of meeting set demands or in generating enough incomes, which accelerate the rate of land degradation.

Over the years, it became apparent that the magnitude of land degradation related problems facing the countries in Southern Africa is so high that national governments alone cannot exhaustively manage them. National Governments and other players such as regional bodies (e.g. SADC) and numerous NGOs have made it their responsibility to address the management of land degradation issue with the intention of coming up with viable recommendations to restore productivity and attain sustainability. It is now accepted that the indigenous people particularly those in the rural areas, whose survival is at stake, have to be involved at all levels. Efforts are being made to reduce the vulnerability of the affected populations by securing their environments, increasing food security and creating new opportunities for alternative livelihoods to reduce pressure on land. Earlier copping strategies that were weakened through inappropriate interventions and policies are now being researched into with the view of incorporating them into plans and programs for land degradation management. In some instances, the efforts are geared towards fostering cooperation with the private sector in land degradation management activities.

SADC, which was formed to promote development efforts of its member countries, has been very instrumental in various developmental issues affecting land degradation management and the welfare of the people in the region. It addresses resource related issues including those on soil and environmental degradation and those touching on impacts of climatic vagaries particularly drought. Through cooperation and smart partnerships, the countries offer assistance to each other in mitigating land degradation issues that indiscriminately spill over political boundaries drawn in complete disregard of physical and ecosystem boundaries. SADC has embarked on formulating and working out mechanisms of implementing a Regional Action Program to combat land degradation including the challenge of assisting individual countries in coming up with national action programs. Sadly, implementation of interventions continues to be effected at country level contrained by the financial and human capacity of individual countries. This practice is a great shortcoming in attempts to holistically integrate the management of land degradation in Southern Africa.

The impacts of climatic vagaries (droughts and floods) on people, their domesticated animals, wildlife, rangelands and cropped lands have been enormous. Empowering the people so that they can participate and take the lead in land degradation management means increasing awareness and training. Needed short courses and seminars/workshops could include understanding of the role of climate in land management including overcoming and/or adjustment to climatic hazards, land use planning, land management, soil fertility and soil fertility management, tillage practices, farming systems and their management, cropping systems and their impacts on soil fertility and land degradation and integrated farming systems. Where appropriate, irrigated farming for small-scale farmers and management of wetlands should be emphasized. Other issues to be included in the training programs should include, regeneration of over-grazed areas, reforestation of bare areas and management of lands for growing high value crops and their marketing.

To be able to take control in the management of their land and other resources, the impact, control and management of the HIV/AIDS pandemic should form part of any training program.

One other way of empowering the people and alleviating poverty through better management of land is fair distribution of land and generated incomes. The conservancies' mode of land and resources management is one good example. The concept of Community-Based Natural Resource Management should be strengthened and embraced by all countries when addressing land degradation management. People-centered development should be a priority in Southern Africa taking into account access to land, ownership, development and management.

References

Bond I, Child B, de la Harpe D, Jones B, Barnes J, Anderson H (2004) Private Land Contribution to Conservation in South Africa. In: Child B (ed) Biodiversity, Rural Development and the Bottom Line: Parks in Transition. IUCN, South Africa

Brian TB, Murphee MW (2004) Community-Based Natural Resource Management as a Conservation Mechanism: Lessons and Directions. In: Child B (ed) Biodiversity, Rural Development and the Bottom Line: Parks in Transition. IUCN, South Africa

Brito R, Chilundo M, Munguambe P (2005) Land and Water Management: Mozambique Situational Analysis. In: Nhira C, Mapiki A (Ed.) Proceedings of the Workshop on Regional Situational Analysis: Land and Water Management in the SADC Region.

Cumming, DHM and Bond, I (1991) Animal Production in Southern Africa: Present Practice and Opportunities for Peasant Farmers in Arid Lands. Report prepared for IDRC Regional Office for Eastern and Southern Africa. WWF (MAPS), Harare

Economic Commission for Africa-Southern Africa Office (2005) Report of the Workshop on Interventions to Mitigate the Impacts of HIV/AIDS on Smallholder Agriculture, Food Security and Rural Livelihoods in Southern Africa, 17-19 October 2005, Lusaka, Zambia

Esler KJ, Milton SJ, Dean WRJ (eds.) (2006) Karoo Veld: Ecology and Management. Briza Publications, Pretoria, South Africa.

Fisher RJ, Maginnis S, Jackson WJ, Barrow E, Jeanrenaud S (2005) Poverty and Conservation: Landscapes, People and Power. IUCN, Gland, Switzerland

Garoes T (2006) Ministry of Environment and Tourism, Namibia. The Namibian

Liebenberg P (2005) Land and Water Management: Namibia Situational Analysis. In: Nhira C, Mapiki A.(eds.) Proceedings of the Workshop on Regional Situational Analysis: Land and Water Management in the SADC Region. Southern African Development Community.

Manyatsi AM (2005) Land and Water Management: Swaziland Situational Analysis In: Nhira C, Mapiki A.(eds.) Proceedings of the Workshop on Regional Situational Analysis: Land and Water Management in the SADC Region. Southern African Development Community.

Mharapara J (2005) Land and Water Management: Zimbabwe Situational Analysis. In: Nhira C, Mapiki A.(eds.) Proceedings of the Workshop on Regional Situational Analysis: Land and Water Management in the SADC Region. Southern African Development Community.

Nhira C, Mapiki A.(eds.) Proceedings of the Workshop on Regional Situational Analysis: Land and Water Management in the SADC Region

Moroke TS (2005) Land and Water Management: Botswana Situational Analysis. In: Nhira C, Mapiki A.(eds.) Proceedings of the Workshop on Regional Situational Analysis: Land and Water Management in the SADC Region. Southern African Development Community.

Msangi JP (2004) Drought Hazard and Desertification Management in the Drylands of Southern Africa. Environ Monit Assess 99:75-87

Mulenga NJ (2005) Land and Water Management: Malawi Situational Analysis In: Nhira C, Mapiki A.(eds.) Proceedings of the Workshop on Regional Situational Analysis: Land and Water Management in the SADC Region. Southern African Development Community.

Phiri E (2005) Land and Water Management: Zambia Situational Analysis In: Nhira C, Mapiki A.(eds.) Proceedings of the Workshop on Regional Situational Analysis: Land and Water Management in the SADC Region. Southern African Development Community.

Ranthamane, M (2005) Land and Water Management: Lethoso Country Situational Analysis. In: Nhira C, Mapiki A (eds) Proceedings of the Workshop on Regional Situational Analysis: Land and Water Management in the SADC Region. Southern African Development Community.

UNDP (2004) Sharing Innovative Experiences Volume 9: Examples of the Successful Conservation and Sustainable Use of Dryland Biodiversity. Special Unit for South-South Cooperation, UNDP, New York.

Villiers MC (2005) Land and Water Management: South Africa Situational Analysis In: Nhira C, Mapiki A.(eds.) Proceedings of the Workshop on Regional Situational Analysis: Land and Water Management in the SADC Region

Successful Experiences of Sustainable Land Use in Hyperarid, Arid and Semiarid Zones from Peru

Juan Torres Guevara and Dora Velásquez Milla

Abstract. Three case studies of successful measures of sustainable use of arid coastal and semiarid Andean mountain ecosystems from Peru are presented. The first case study is on agroforestry and silvo-herding systems located in the northern arid coast (Piura), where El Niño events, especially the 97/98 (December to May) one, had impacted the productivity of these systems. The second case study focused on *in situ* conservation of Andean crops and their wild parents in northern (Piura and Cajamarca) and central (Huanuco and Huancavelica) Andean mountain ecosystems of Peru. In this case study, not only the crop areas and the conservancy culture of the traditional farmers were addressed, but also their natural environment ie., the soils, fauna and plant communities (pastures, bushes and forests) that surround them. This guarantees the continuity of the conservancy activity of the Andean cultures and, therefore, of the northern and central Andean mountain semiarid ecosystems of Peru. The third case study is located in the southern coastal desert from Peru, on an oases ecosystem locally called as: "Lomas", which is inhabited by the Atiquipa peasant community. During the winter seasons (June-October), the Atiquipa Lomas support a strong presence of fog water, which is being "harvested" through "atrapanieblas" ("fog catcher") that permit fog water to precipitate with a noticeable increase in volume. This harvested water is used for reforestation of the community high zones for livestock and human consumption, as well as for food crops that contribute to the food security of the community. So, the bases for a sustainable use of the desert resources of the southern coast from Peru are being established. These three case studies show the successful measures for the sustainable land use in the arid coast and semiarid Andean mountains of Peru.

28.1 Introduction

World deserts (Fig. 28.1) constitute a quarter of the terrestrial surface of the planet and within their borders, approximately 500 million people live accounting for 8% of the world population (UNEP 2006).

At a world level, United Nations specialists and organizations related with the theme (UNEP 2006) indicate that 40% of the arable lands of the planet are considered drylands and that 70% of them are affected by desertification processes.

Latin America and the Caribbean surface cover approximately 20 million km^2 and occupy 15% of the total area of the planet. Some 320 million ha of this area is affected by some of the processes that lead to desertification (Urquiza 2003). These

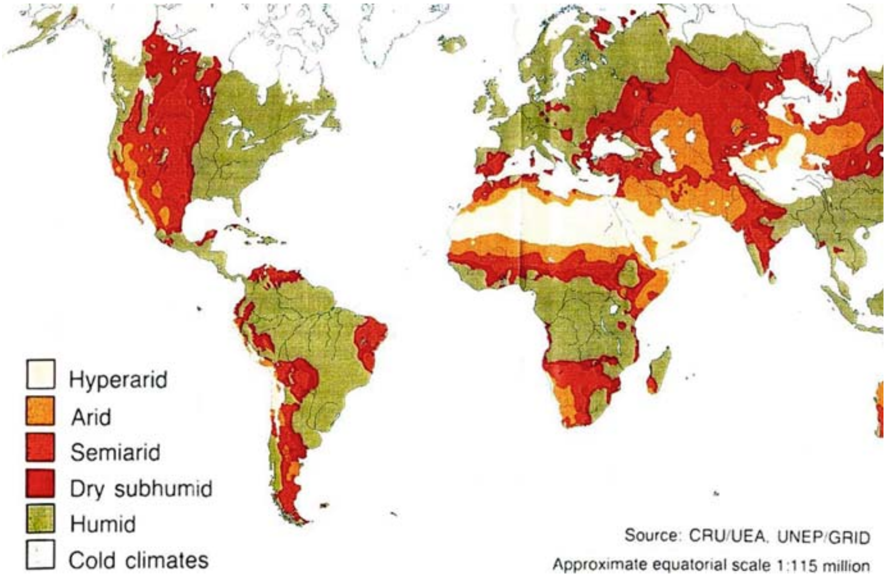


Fig. 28.1. World deserts

drylands are inhabited by 28% of the population, which in a majority of cases, is affected by poverty.

The major problems that these Latin American and the Caribbean arid and semiarid lands (Fig. 28.2) face include: deforestation, change in land use, inadequate farm practices and overgrazing. All these activities, besides the climate change processes or natural events such as El Niño and droughts, as well as frosts, hail and floods in the mountain ecosystems such as the "Cordillera de los Andes", lead to soil loss, salinization, compaction, fertility loss, biodiversity loss and, therefore, lead to a decline in the quality of life, mainly for the most vulnerable population sectors. The historic exclusion of the local traditional cultures plays an important role in this situation.

Peruvian drylands, including the hyperarid, arid and semiarid regions, cover 40% of Peru's total area, and are home to 90% of the Peruvian population.

28.2 The Desertification Problem in Peru

28.2.1 Some important features of the Peruvian ecology

Peru is a country with a very singular ecology, with a surface of 1.2 millions km^2 occupied by 28 millions of inhabitants. It is characterized by one the most arid deserts

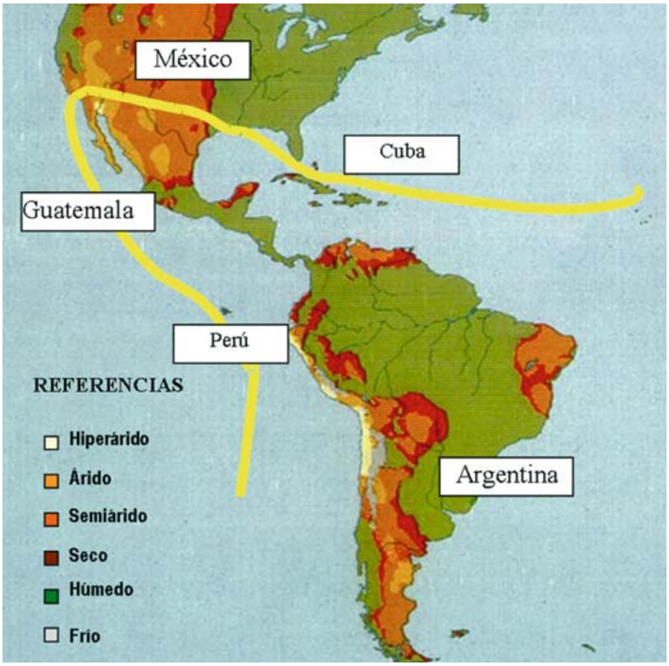


Fig. 28.2. Latin American and the Caribbean Arid Lands

of the world -the South Pacific desert, with a mean annual rainfall of less than 100 mm, by one of the biggest and most inhabited ridge of mountains of the world - with 7 250 km in length, and by one of the most diverse and greatest forests of the planet, that cover more than the half of the country's surface (58.8%).

This complex nature is being modified for more than 10,000 years by man, converting the region into one of the world's original centers of agriculture, Peru being the center of origin for many important cultivated plants for humanity such as potatoes, maize, pumpkins, tomatoes, and beans among others.

The complex nature of Peru has in the "Cordillera de los Andes" its principal component. All the landscape diversity, including climate, lands, plants, animals and microorganisms, and the uncountable ways of relationship with nature are closely related with the Andes.

This mosaic of ecosystems has some basic features that can be summarized under three main features:

- Climatic instability
- Biological diversity
- Fragility

These features are closely related to each other; certainly, climatic instability forms part of the diversity of habitats, where the existing great diversity of forms of life occurred, all of which constituting a very delicate and fragile system.

Fig. 28.3. The desertification in Peru is a major problem

28.2.2 Desertification Situation

Desertification is the principal environmental problem of Peru (Fig. 28.3). Certainly, desertification is a process affected by natural factors, but in the case of Peru human factors are a special component, that are basically related with the lack of coherence between the development models encouraged up to date and the particular ecological characteristics of the country. Natural factors are mainly represented by the vulnerability of the arid lands, that cover a third of the total area of Peru, including the arid coast, and the semiarid and subhumid Sierra (covering 36% of the total surface), the mountainous character of the country and the tropical rain forest. In addition, there is a tremendous asymmetry in water resources, with a western slope that receives only 1.7% of the total water in the country, but supporting 90% of the Peruvian population.

These mountainous arid and semiarid lands are home to most of the farming, industrial and mining activities of the country. Today, problems like the coastal soil salinization affect the 40% of the cultivated surface of this region. The "Sierra" (mountainous) region, in turn, presents strong degradation problems of its fragile ecosystems, especially in the eastern slope ("Selva Alta"), because of desertification processes like the natural geological gradual waste on one hand, and the human factors on the other. It is estimated that the degradation is basically caused by the human factors, through farming and forestry activities (salinization, water erosion, soil erosion, genetic erosion, indiscriminate cutting of trees etc.,), as well as mining.

The economic consequences of the degradation have not been quantified yet, but are visible at first sight. In the Sierra region, the lack of lands plus the violent phenomena of the 80s′ have generated strong migration processes, and, in the Coastal region, the northern dry forests had to face a strong pressure.

28.2.3
Identification of affected and vulnerable groups

As was mentioned before, 90% of population is settled in areas where the water resources are barely 2% of the total water availability in the country and in ecosystems facing a high risk of desertification (mountainous arid and semiarid lands).

The people mainly settled in the mountainous ("serranas") regions, are strongly rural, with the highest levels of poverty: Cajamarca, Huancavelica, Ayacucho, Apurimac, Cusco and Puno. In these regions, the drought and frost frequency is high and the vegetative cover is sparse with relative isolation.

28.3
Case studies

Three case studies were conducted on implementing measures for sustainable land use in arid and semiarid lands from Peru (Fig. 28.4): these include the northern coastal arid lands (Dry Forests of Piura), southern coastal hyperarid lands (Atiquipa Fog Oases-"Lomas"-, Arequipa) and Andean mountainous semiarid lands from the northern and central Andes of Peru (Piura, Cajamarca, Huanuco and Huancavelica).

28.3.1
Seasonally Dry Forests

This case study is carried out by various governmental institutions (INRENA) and Non Governmental Organizations (NGOs) during over more than 15 years throughout Lambayeque, Piura and Tumbes regions, situated in the northern coast of Peru. The experience carried on at Piura Region is presented here.

28.3.1.1
General Characteristics

Technically, the name of the plant formations in this region is "Seasonal Dry Tropical Forests in the Neotropic", but culturally the name used by the local people is: "Montes de Algarrobo".

The seasonal dry tropical forests in Peru (Fig. 28.5) are distributed in its northern coast, along the Tumbes, Piura and Lambayeque regions. These northern coastal seasonal dry forests are considered fragile ecosystems and occupy approximately a total area of 3,230,263 ha (after the El Niño 97–98 event), with 67% of it in the Piura region (Casaretto 2003).

Moreover, these seasonally dry forests of the northern coast of Peru have been historically occupied by cultures since 10 thousand years ago. Today, a vigorous cultural life with multiple and popular religious ceremonies exists in these desert ecosystems.

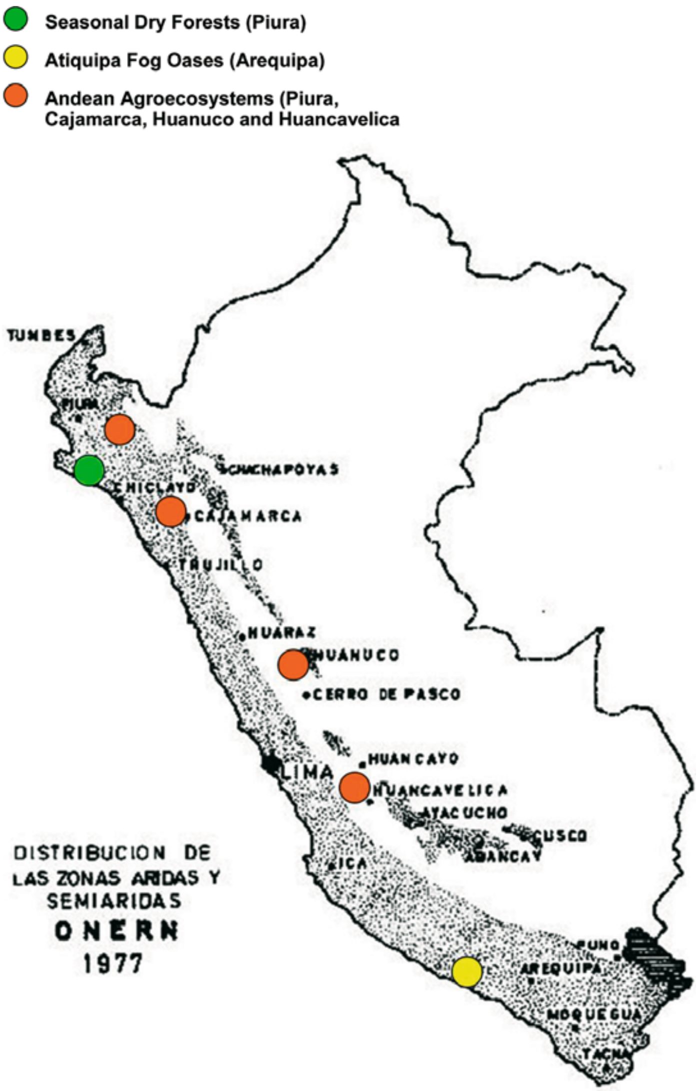


Fig. 28.4. Location of the case studies of successful measures in sustain-able land use in Peru

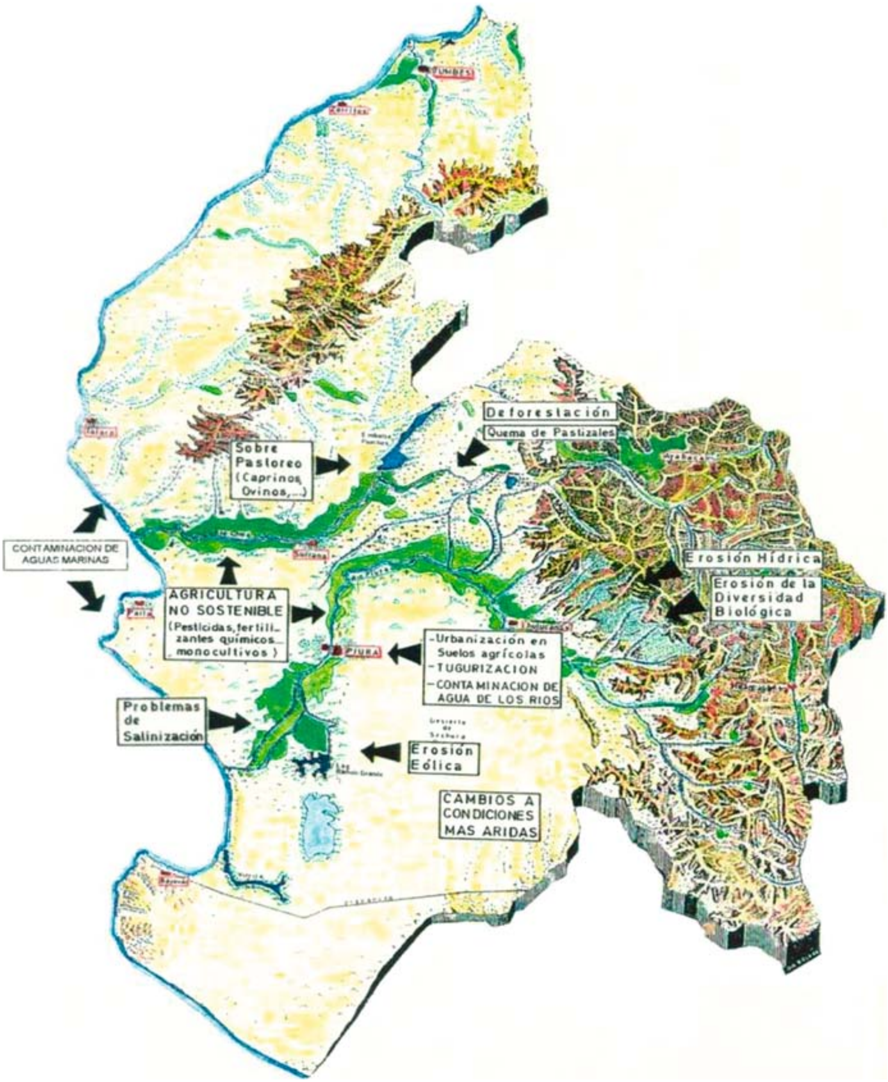


Fig. 28.5. Seasonally Dry Forests in Piura Region

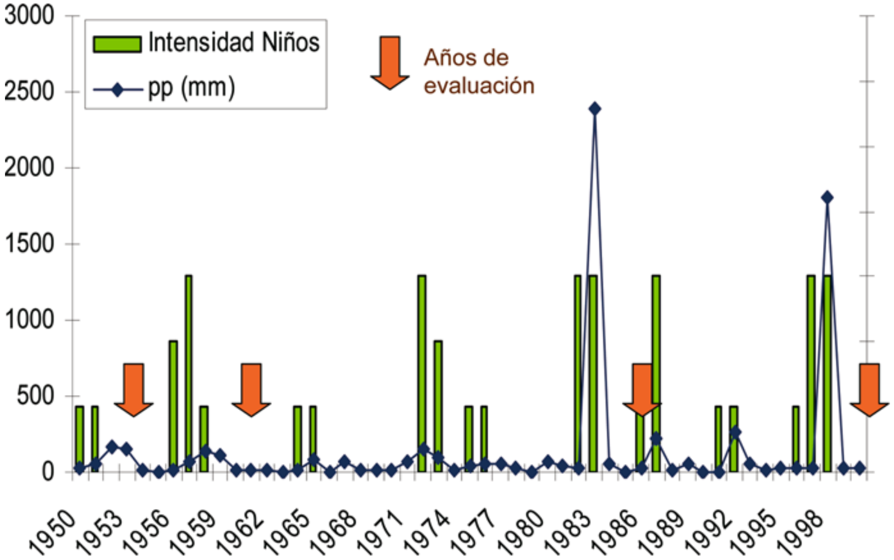


Fig. 28.6. Occurrence of El Niño Southern Oscillation (ENSO) Events between 1950 and 1998 (Source: Woodman 1998)

Fig. 28.7. Forest cover (**a**) before El Niño 1997-1998 and (**b**) during El Niño 1997-1998

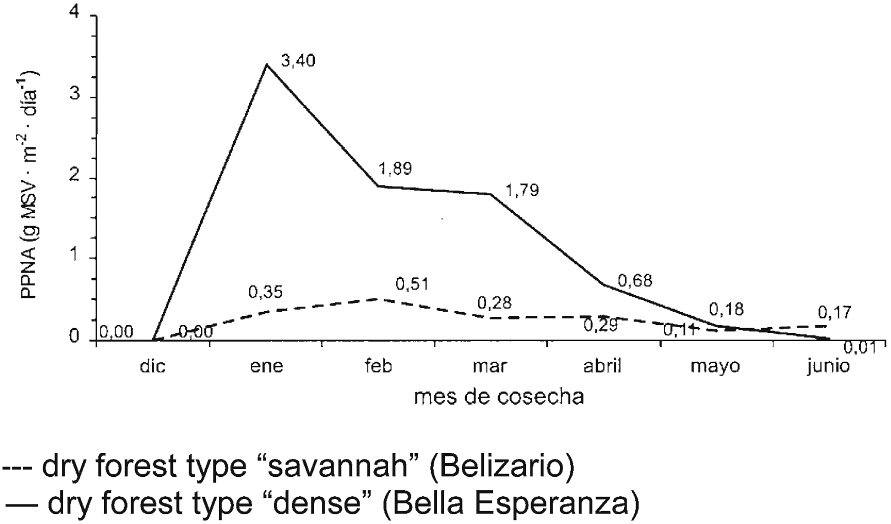


Fig. 28.8. Monthly change of Aerial Net Primary Productivity of Herbaceous Plants from December 1997 to June 1998 in Piura, Peru

The climate of these dry forests is characterized by periodic occurrences of the El Niño events (Fig. 28.6)

28.3.1.2
Measures of Successful in Northern Coast Dry Forest

28.3.1.2.1
Conservancy of the forest natural regeneration

El Niño events change the dry forest scenario. During 1997-1998, the warm episode El Niño generated a new scenario in the Peruvian northern coast dry forest when rainfall increased from an average of 150 mm yr^{-1} to 3198 mm only in 6 months (December 97 and May 98), i.e. an increment of 5070% (Mendoza Vila 1998).

As a result, the two El Niño mega events which occurred during 82-83 and 97-98 generated a forest surface of 3.1 million ha, while before 82 the forest cover was less than 320,000 ha (Fig. 28.7)

Likewise, the El Niño 97-98 event generated a noticeable increment of the herbaceous primary production both in “savannah” and in “dense” dry forests (Fig. 28.8)

Currently it is important to ensure that the areas naturally reforested with the “help” of these two El Niño 82-83 and 97-98 natural megaevents, could be maintained over time. This is the main challenge in the ongoing work, a concrete successful experience of sustainable land use in an arid zone from Peru.

Fig. 28.9. A view of the semiarid ecosystems of the northern coast of Peru

28.3.1.2.2
Storage strategies for food production of temporary agriculture

With El Niño appears the so called "temporary agriculture", which means a change in the production system:

- New crop seeds, that the peasants have kept for years, appear.
- New crop varieties also appear.
- Increase in crop production, generating high yields (e.g. 6 ha of hybrid maize, was planted to produce "chicha", a traditional drink, in a familiar temporary agriculture farm during El Niño 97-98).

Therefore, there is a total change in agricultural strategy; these are periods of abundance that must become useful, mainly, recovering food storage strategies in order to cross over the hard drought years. To take advantage of this opportunity, products of the two last El Niño megaevents (82-83 and 97-98), are other successful experiences of sustainable land use in arid zone from Peru.

28.3.1.2.3
Agroforestry, silviculture and honey beekeeping

Some proposals of ecological agriculture strategies have been developed for the semiarid ecosystems of the northern coast (Fig. 28.9). The focus is to promote diversified production systems in order to make progress of the arid ecosystem with plant and animals adapted to hydric stress.

Today, in the seasonally dry forests of the northern coast of Peru some agroforestry experiences are carrying on, so the tree and shrub strata generate by the El Niño megaevents are conserved and, at the same time, both an annual plant species agriculture and a livestock activity that contribute with food security of the seasonally dry forests communities, are developed. This is another successful experience of sustainable land use in arid zone from Peru.

Fig. 28.10. Location of Atiquipa Fog Oases (Lomas)

28.3.2
Atiquipa Fog Oases ("LOMAS")

This experience is carrying on by the Atiquipa Peasant Community ("Comunidad Campesina") with the support of the "Instituto Regional de Ciencias Ambientales de la Universidad Nacional de San Agustín de Arequipa" (IRECA-UNSA), which has more than 10 years of presence in the zone.

28.3.2.1
General Characteristics

- *Location.* Atiquipa fog oases (Fig. 28.10) are situated in the southern coast of Peru, between 15°47′ S.L. and 74°20′ W.L. (Caravelí Province of Arequipa Region).

- *Landscape*. The Atiquipa fog oases are displayed from the sea level to a height of 1200 m (Fig. 28.11), reaching more or less 30,000 hectares: it is the biggest fog oases (Loma) of Peru. They present three morphological clusters: marine terraces, alluvial plains and mountains (ONERN, 1989).

During the pre-Columbian time (c.XVI), the Atiquipa fog oases presented a landscape and a dynamics (Fig. 28.12) very different as it looks up to date (Canziani, 1998).

- *Climate*. This area corresponds to the semi-warm and very dry climate type, with a relative humidity over 75% (according to Thornwaite classification).

They present a period of arid months, with temperatures that oscillate between 16 to 20°C (Santa Cruz, 1999), and a fog period, with a maximum occurrence during May to November, with a rainfall that can account for as much as 120 mm, thanks to the rainfalls generated by fog condensation (CONCYTEC, 1989).

Todate, the annual precipitation (one of the main factors of "Lomas" presence), has dramatically diminished, registering approximately 40 mm a year, almost 40 mm less than was registered 10 years ago (from 59.1 to 76.4 mm by year).

- *Vegetation*. The Atiquipa "Lomas" are covered by various plant communities distributed along an altitudinal profile: "tara" forest (*Caesalpinea spinosa)*, semi-dense bushy formation, thin bushy formation and "arrayan" forest (*Myrcianthes ferreyrae*). Some plant species function as natural catchers of fogs humidity.
- *Wild animals*. The wild animal community is mainly constituted by birds, as doves, and foxes "zorro" (*Dusicyon culpaeus*).

Around 40 years ago partridges, the "condor" (*Vultur gryphus*), the "Andean puma" (*Puma concolor*), the deer (*Odocoileus virginianus*) and the "guanaco" (*Lama guanicoide*), were common.

- *Culture and economy*. The Peasant Community of Atiquipa, Jaqui and Yauca is owner of the Atiquipa "Lomas", being its principal city Atiquipa, capital of the Atiquipa District.

Atiquipa District has approximately 750 inhabitants, mainly dedicated to agriculture, livestock and artisan fishing, activities oriented to local consumption and to marketing of products and sub-products in close cities as Chala.

- *Organization*. The Atiquipa community has a communal organization constituted by a Communal Assembly that takes decisions about the local resource management. Also, the Atiquipa Municipality exists as the local government authorized to take political decisions.

Fig. 28.11. Landscape of Atiquipa Fog Oases (Lomas)

Fig. 28.12. Pre-Columbian Atiquipa (c.XVI)

Fig. 28.13. Fog catcher ("atrapanieblas"). Mesh rectangular panels of syn-thetic material that allow water condensation.

28.3.2.2 Success stories

- Proposals of forest management, based on studies about the "tara" (*Caesalpinea spinosa)* natural forests, main natural catchers of humidity.
- Vegetation management by the Atiquipa community with more knowledges about local plant use technology.
- Reforestation of "tara" and "arrayan" species.
- Extraction entrance regulation through a harvest and prohibition calendar.
- Establishment of regulatory measures determined by the communal organization for pods recollection.

28.3.2.3 Successful measures in Atiquipa Fog Oases

28.3.2.3.1 Fog Capture

- Establishment of a fog water catchers system ("atrapanieblas"), mainly aimed at irrigating "tara", "arrayan" and "huarango" plantations, under the responsibility of the communal organization and with UNSA support (Fig. 28.13).
- With the capture of fog, an average of 22 $l\ m^{-2}\ day^{-1}$ of water is collected, which is basically used in reforestation of 400 ha.

Fig. 28.14. Areas of greatest biological diversity in the world

28.3.2.3.2
Reforestation of "tara" forest

- The recovering of natural "tara" forests has had a very concrete and palpable effect on pod production for marketing.
- The trees have been recovering their natural regeneration capacity, as well as their productivity, which is reflected in a relative increase in the amount of pods collected.

28.3.3
Andean Agroecosystems

This experience was developed by CCTA (*Coordinadora de Ciencia y Tecnología en los Andes*), as part of the Project "*In Situ* Conservation of Native Crops and their Wild Parents in Peru", in traditional agroecosystems of Peruvian Andean mountains, and earlier through the Project "Microwatersheds Management", adding together 15 years of work at the Andean mountainous semiarid lands from Peru.

The mountains are one of the greatest centres of biological diversity in the world (Fig. 28.14)

28.3.3.1
General Characteristics of the Andean Agroecosystems Project

- *Location.* The experience was developed in 10 microwatersheds/watersheds located in 4 Sierra regions from Peru: Piura, Cajamarca, Huanuco and Huancavelica (Fig. 28.15).

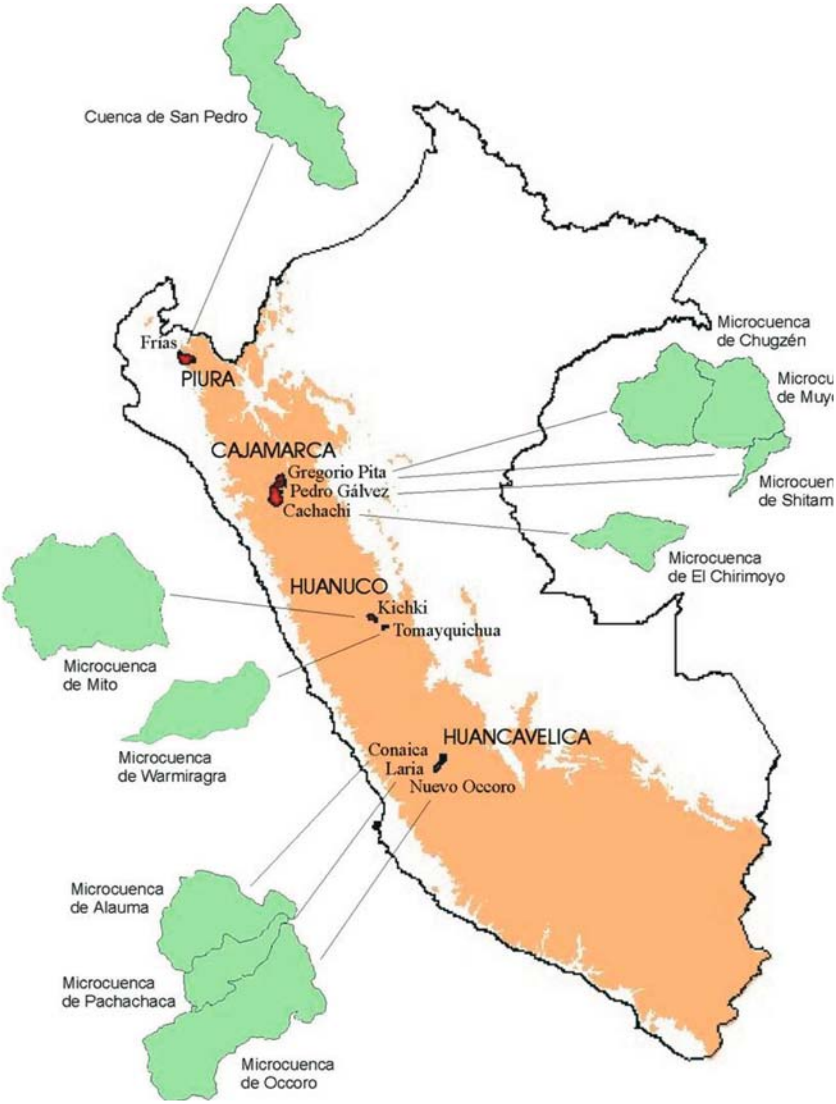


Fig. 28.15. Location of CCTA-In Situ Project Work Area

San Pedro watershed, located in Piura, in northern Sierra of Peru, covers 13,900 ha with altitudes ranging from 2,900 to 3,700 m.

Chugzen, Muyoc, Shitamalca and Chirimoyo watersheds, located in Cajamarca, in northern Sierra of Peru, cover 33,856 ha with altitudes ranging from 2,100 to 4,150 m.

Mito and Warmiragra watersheds, located in Huanuco, in central Sierra of Peru, cover 20,364 ha with altitudes ranging from 2,100 to 4,400 m.

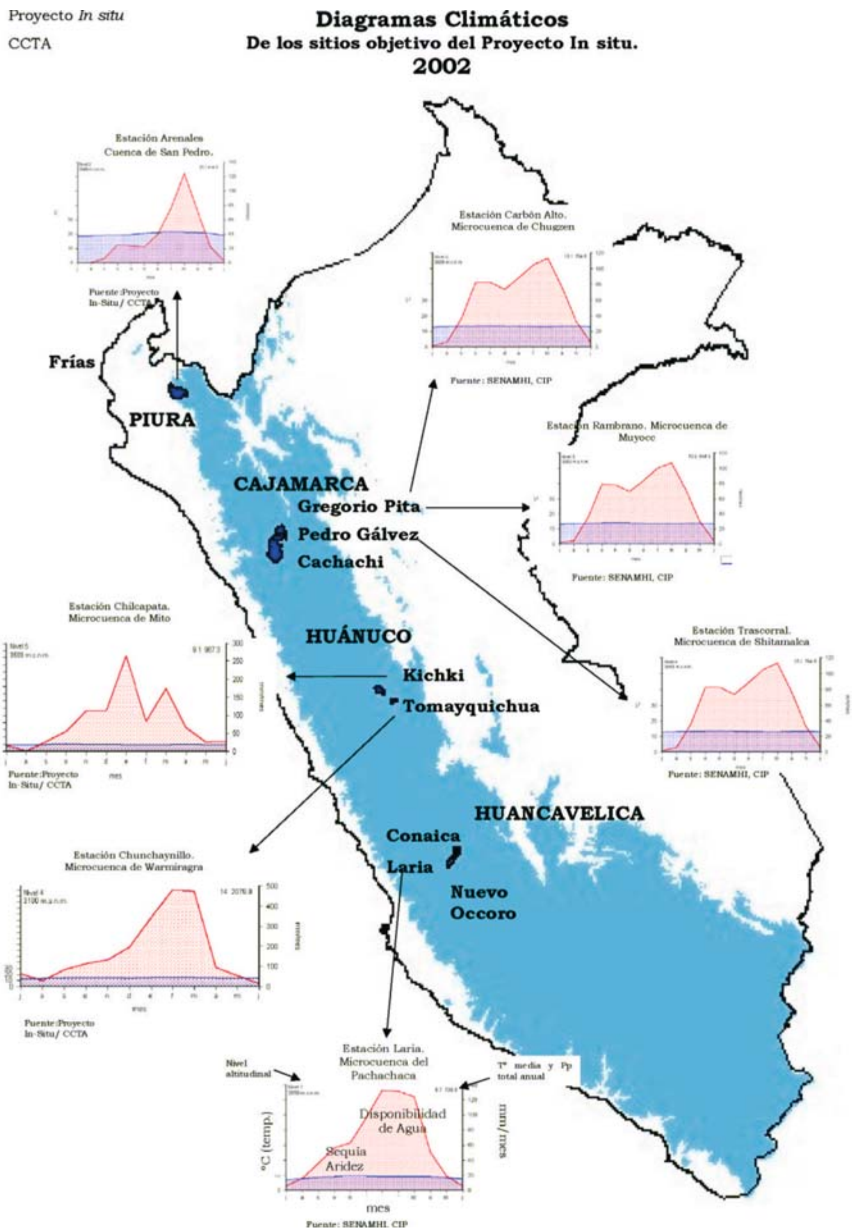


Fig. 28.16. Rainfall patterns at different locations in the project area

Alauma, Pachachaca and Occoro watersheds, located in Huancavelica, in central Sierra of Peru, 221,435 ha with altitudes ranging from 3,350 to 4,700 m.

- *Climate*. The climate of the area where the Project was implemented is mainly semiarid, with annual rainfall varying between 400 and 700 mm, with the possibility of only 200 mm during drought years or 900 mm during years with abundant rains (Fig. 28.16). Furthermore, the rainfall is concentrated in only 3 or 4 months during the year with no rain during the rest of the months.
- *Culture*. The Project involved directly 526 rural families of Andean peasant communities whose main activity is traditional agriculture of native crops.
- *Agriculture*. The most important characteristics of traditional agriculture is the high diversity of crops and of varieties within crops.
- *Natural Areas*. The natural areas that surround the agricultural zones reach 61,043 ha and there are numerous habitats for the wild parents of native crops.

28.3.3.2
Successful measures in the Andean Agroecosystems Project

In accordance with the concept of the *In Situ* Project, the central emphasis is on *in situ* conservation of native crops (and their wild parents). Hence it deals with domesticated plants with the peasants as the conservators; hence, emphasis is placed on cultural components.

Table 28.1. Successful measures implemented in the three different case studies

Case Studies	Measures implemented		
	Management of Land Use	Protection of Land	Mitigation of Land Degradation
Seasonally Dry Forest Piura (INRENA and NGOs)	Zones of protection (natural regeneration areas)	Zones of soil protection in areas of natural forest regeneration	After 1998, 3.1 million ha of seasonally dry forest with ENOS help
Fog Oases (Lomas) Atiquipa, Arequipa (Atiquipa Peasant Community and IRECA/UNSA)	Zones of protection (Caesalpinea forest on highland watersheds)	Protection of slope eroded soil with 400 ha of Caesalpinea (“tara”) reforestation	Recovery of 400 ha of soil protected with Caesalpinea (“tara”) reforestation
In Situ Conservation Piura, Cajamarca, Huanuco and Huancavelica (CCTA: CEPESER, IDEAS,IDMA and TALPUY)	Special Areas of Crop Management	Protection of natural areas around crop fields	Recovery of natural areas of highland forests and marshes.

The Project encourages an intercultural approach in all the project activities, working specially with the young people.

The successful measures accomplished by the project include:

- Recognition by the own indigenous farmers as protagonists of the in situ conservation
- Enforcement of the indigenous organizations
- Recognition of traditional knowledge and practices
- Maintenance of the diversity of native crops
- Maintenance of traditional management of native field crops ("chacras")
- Transformation of the productive space with appropriate technologies
- Conservation of the environment and the wild parents
- Appraisal of the native crops agriculture in rural schools
- AMECAs: Landscapes reserves as an option for conservation of native crops and soils.

28.4 Conclusions

Three case studies of land use and the successful experiences in protection are presented (Table 28.1). These experiences were focused on protection against the erosion taking advantage of natural phenomena like the El Niño (83-83 and 97-98) mega events or the coastal marine fog, as well as of the native agrobiodiversity to ensure soil conservation and food security of the peasant communities that inhabit the Andean mountainous semiarid ecosystems.

All the experiences just presented, are synthesized in the following measures of successes related with the land use, protection of land and mitigation of the soil degradation.

References

Apéstegui J (1992) Análisis de la vegetación en las partes altas de las lomas de Atiquipa. Tesis para optar por el título de Ingeniero Forestal. Facultad de Ciencias Forestales. Universidad Nacional Agraria La Molina. Lima, Peru

Arias C (1990) Productividad primaria, estacionalidad y uso de la vegetación de las lomas de Atiquipa – departamento de Arequipa. Tesis para optar por el titulo de Biólogo. Universidad Nacional Agraria La Molina, Facultad de Ciencias. Lima, Peru

Cárdenas C (1998) El impacto del evento "El Niño" en la productividad primaria de los bosques secos de algarrobo de Sechura y Tambogrande. Piura. Diciembre 1997 –Junio 1998. Tesis de Bióloga. Universidad Nacional Agraria La Molina, Lima, Perú

Canziani J (1998) Las lomas de Atiquipa, un caso de paisaje cultural en la costa desértica del sur del Perú. In: P*aisajes culturales en los Andes*. Memoria Narrativa, Casos de Estudio, Conclusiones y Recomendaciones de la Reunión de Expertos. UNESCO. Arequipa y Chivay, Peru

Canziani J, Mujica E (1995) Atiquipa, un caso prehispánico de manejo sustentable en ecología de Lomas. In: P*erú: el problema agrario en debate*. Seminario Permanente de Investigación Agraria Sepia VI. Lima, Peru

Casareto C (2003) Secuencia histórica de la cobertura vegetal y uso del suelo de los bosques secos de Piura durante los 50 últimos años. Tesis para optar el título de Bióloga. Universidad Nacional Agraria La Molina. Lima, Perú

CCTA – Coordinadora de Ciencia y Tecnología en los Andes (Coordinator for Andean Science and Technology). Camilo Carrillo 300 A, Jesús María – Lima, Perú.

CIZA UNALM – Centro de Investigaciones de Zonas Áridas de la Universidad Nacional Agraria La Molina (Centre for Arid Zones Research from the National Agrarian University La Molina), Camilo Carrillo 300 A, Jesús María – Lima, Perú.

Claros D (2000) Composición florística y fenología de los bosques secos de la costa norte del Perú, Caso Piura: (Sechura – Tambogrande) en la etapa del post Niño 97-98 (Feb-Oct 2000). Tesis para optar el título de Bióloga. UNSA. Arequipa, Perú

CONAM (1999) Perú: vulnerabilidad frente al cambio climático: aproximaciones a la experiencia con el fenómeno El Niño. Consejo Nacional del Ambiente. Lima, Perú

Consejo Nacional de Ciencia y Tecnología (CONCYTEC) (1989) Aprovechamiento de nieblas costeras en las zonas aridas de la costa. Las Lomas de Atiquipa (Provincia de Caravelí. Departamento de Arequipa). CIZA,ONERN,SENAMHI,CONCYTEC. Lima, Perú

Coordinadora de Ciencia y Tecnología en los Andes (CCTA) (1999) La gestión de microcuencas: una estrategia para el desarrollo sostenible en las montañas del Perú. Lima, Perú

Dora Velásquez M. – Researcher associated to CIZA-UNALM and CCTA's consultant. doravelasquez@yahoo.com

Gushiken S (1994) Estructura y análisis de los algarrobales de Sechura y Tambogrande (Piura –Perú). Tesis de Bióloga. Universidad Nacional Agraria La Molina. Lima, Perú

INRENA (1996) Programa de acción nacional de lucha contra la desertificación Perú. Instituto Nacional de Recursos Naturales, Lima, Perú

INRENA (1998) Bosques secos y desertificación. Memorias del Seminario Internacional. INRENA-Proyecto Algarrobo. Lima, Perú

Mabres A (1988) lluvias en la zona costera norte del Perú: Analisis del contraste entre años de Niño y no Niño (avance de resultados). Trabajo presentado al congreso de la Sociedad Geologica de Lima, 22-27 febrero 1988.

Mendoza Y (1997) El microclima en el bosque seco de algarrobos de la costa norte del Perú: Piura. durante el periodo 1991 –1995. In: Seminario internacional bosque seco y desertificación . 5-8 noviembre de 1997. INRENA – Proyecto Algarrobo.

Mendoza Y (2001) Condiciones microclimáticas de los bosques secos de algarrobo de la costa norte del Perú – Piura: caso Sechura y Tambogrande 1996. Tesis de Ingeniero Meteorólogo (por publicar). Universidad Nacional Agraria La Molina. Lima, Perú

Mendoza Y, Vila M (1998) Condiciones meteorológicas durante episodios cálidos "El Niño" en los algarrobales de la costa norte del Perú, Caso: Caserío Bella Esperanza, Tambogrande, Piura. Periodo 1991 –1998. CONCYTEC. Lima, Peru

Naciones Unidas Asamblea General (1994) Convención de las naciones unidas de lucha contra la desertificación en los países afectados por sequía grave o desertificación, en particular en Africa. Bonn: UNCCD Secretariat. 36 p. + anexos 1 al 5 (texto español en formato pdf tomado de la página web: http://www.unccd.int).

Ojeda R (2004) Evaluación de la vegetación de las lomas con predominio de herbáceas (200 a 400msnm), de Atiquipa, durante la ocurrencia del evento "El Niño 1997-1998". Tesis para optar por el titulo de Biólogo. Facultad de Ciencias Biológicas y Agropecuarias. Escuela Profesional y Académica de Biología. Universidad Nacional San Agustín. Arequipa, Perú

Rodas J (1997) Productividad primaria neta y sus principales factores ecológicos en los bosques secos de algarrobo (*prosopis sp.*) de la costa norte del Perú. Tambogrande Piura – Región Grau (enero 92 – marzo 93). Tesis de Biólogo. Universidad Nacional Agraria La Molina. Lima, Peru

Santa Cruz W (1999) Flora y estructura de la vegetación estrato arbóreo de Atiquipa, durante el fenómeno de el niño 1997-1998. Tesis Biólogo. Facultad Ciencias Biológicas y

Agopecuarias. Escuela Profesional y Académica de Biología . Universidad Nacional San Agustín de Arequipa, Peru
Juan Torres G. – Chairman from CIZA-UNALM and Executive Director from CCTA. amotape@yahoo.com
Torres GJ (1998a) La desertificación en Piura. Fundación F Ebert. Lima, Peru
Torres GJ (1998b) La desertificación en el Perú. Lima, Peru
Torres GJ (2000) Los desencuentros con la naturaleza en América Latina tienen un nuevo nombre: desertificación. Leisa 16:9-10
Torres GJ, Millones J, Tapia M, Monroe J, Gallardo M (1994) La desertificación en el Perú. En Seminario latinoamericano de desertificación. 9 – 11 marzo 1994, Fortaleza, Brasil
UNEP (2006) Desiertos del Mundo: perspectivas. UNEP, Nairobi, Kenya.
Urquiza MN (2003) Desertificación, un flagelo de la humanidad. In: Revista Zonas Aridas nº7. Centro de Investigaciones de Zonas Aridas de la Universidad Nacional Agraria La Molina, Peru
Velásquez D (1993) Aves de importancia económica en los algarrobales de Sechura y Tambogrande (Piura – Perú) Tesis de Bióloga. Universidad Nacional Agraria La Molina. Lima, Perú
Woodman R (1997) El Niño 1997-98 en el contexto de Niños anteriores. In: Informe preliminar del Taller Regional “El Niño” nuevas oportunidades! cómo aprovecharlas? Agosto 1997, Piura
Woodman R (1985) Recurrencia del fenómeno El Niño con intensidad comparable a la del Niño 1982-83. In: C*iencia,Tecnología y Agresión Ambiental:ElFenómenoÊl Niño*. CONCYTEC. Lima, Peru

CHAPTER 29

Role of Organic Agriculture in Preventing and Reversing Land Degradation

Sue Edwards

Abstract. Soil erosion and desertification are the physical expressions of land degradation, while the social and economic impacts are degraded lifestyles and pernicious poverty. An understanding of how to maintain healthy soil is essential to reverse and prevent land degradation.

Organic agriculture is a whole system approach based upon a set of processes resulting in sustainable ecosystems, safe food, good nutrition, animal welfare and social justice. It is more than just a system of production that includes or excludes certain inputs, particularly agro-chemicals, because it builds on and enhances the ecological management skills of farmers, fisher folk and pastoralists. Practicing organic or agro-ecological agriculture requires ecological knowledge, planning and commitment to work with natural systems, rather than trying to change them.

IFOAM (International Federation of Organic Agriculture Movements) is an organization that promotes such sustainable agricultural systems. The application and upholding of the principles of organic agriculture can help ensure that agriculture can be continued throughout the world while contributing to the prevention and reversal of land degradation, combating poverty and building a fairer world order for all people. In 2004, IFOAM published a scoping study on "The Role of Organic Agriculture in Mitigating Climate Change". The study looked at how organic agriculture could contribute to reducing green house gas (GHG) emissions and mitigate the impacts of climate change.

Organic agriculture minimizes carbon dioxide emissions from agricultural ecosystems, and can also contribute to carbon sequestration because of the systematic application of manure and compost from animal and crop residues, crop-legume rotations, green manuring with legumes, and agroforestry with multipurpose leguminous trees. Soil is the most important sink for methane where high bacterial activity oxidizes it. Controlled anaerobic digestion of animal manure can contribute significantly to reducing methane emissions. Nitrous oxide emissions are minimized in an organic system.

In 1996, the Institute for Sustainable Development started to work with local farming communities and local development agents and experts in Tigray, northern Ethiopia, to rehabilitate their environment and raise crop yields through using compost. Since 1998, ISD has monitored the impact of compost on crop yields in farmers' fields. Overall, compost generally doubles the yield from fields that have not had any input. In most cases it also gives a higher yield than the use of chemical fertilizer. Other benefits from using compost include increased moisture retention capacity of the soil and reduced crop pest problems.

The principles behind organic agriculture are also used in programs and projects focused on overcoming food insecurity, rural poverty and environmental degradation. In 2003, IFOAM reported that over 40,000 farms covering 235,000 ha of land were growing certified organic products in Africa.

29.1 Introduction

Loss of vegetation cover and biodiversity leading to soil erosion, disruption of the hydrological cycle and consequent desertification are the biological and physical expressions of land degradation, while the social and economic impacts are equally degraded and degrading lifestyles resulting from and contributing to pernicious poverty. An understanding of how to maintain a healthy soil is essential for reversing and preventing land degradation, and for helping local communities to get out of poverty. A healthy soil carries a good plant cover that enables rain water to infiltrate and recharge both soil water and underlying aquifers. A healthy plant cover regulates the local microclimate and plays a significant role in regulating macroclimate by sequestrating carbon for the biosphere as a whole, and by maintaining air humidity at local ecosystem and landscape levels. An agricultural system that is based on maintaining such a self-sustaining productive ecosystem is referred to as organic.

IFOAM (International Federation of Organic Agriculture Movements) is an organization that promotes such sustainable agricultural systems, be they in crop and animal production, forestry or fisheries. Its mission is leading, uniting and assisting the organic movement in its full diversity. The goal is the worldwide adoption of ecologically, socially and economically sound agricultural systems that are based on the Principles of Organic Agriculture (IFOAM undated).

Agriculture is a basic activity because all people need food on a daily basis. History, culture and community values are embedded in agriculture. The Principles of Organic Agriculture concern agriculture in the broadest sense: how people tend the soil and interact with the landscape, the surrounding plants and animals; what they eat and wear; how food and other vital goods are obtained, handled, prepared, and distributed; and the quality of the global environmental legacy that will be left for future generations.

IFOAM recognizes four principles:

- The principle of health
- The principle of ecology
- The principle of fairness
- The principle of care [of people and the environment through the precautionary principle]

The application and upholding of these principles can help ensure that agriculture can be continued throughout the world while contributing to the prevention and reversal of land degradation, combating poverty and building a fairer world order for all people.

29.2
What is organic agriculture?

Organic agriculture uses a whole system approach based upon a set of processes resulting in sustainable ecosystems, safe food, good nutrition, animal welfare and social justice. It is more than just a system of production that includes or excludes certain inputs, particularly agro-chemicals, because it builds on and enhances the ecological management skills of farmers, fisher folk and pastoralists. Practicing organic or agro-ecological agriculture requires ecological knowledge, planning and commitment to work with natural systems, rather than trying to change them. Industrial agriculture uses an opposite approach: it provides inputs and technologies to substitute and thus reduce or destroy the inherent diversity of natural systems. It contributes to both land degradation and climate change. This is vividly portrayed in the books 'The Fatal Harvest: the tragedy of industrial agriculture' and 'The Fatal Harvest Reader: the tragedy of industrial agriculture' (Kimbrell 2002).

In 2004, IFOAM published a scoping study on "The Role of Organic Agriculture in Mitigating Climate Change" (Kotschi and Müller-Sämann 2004). The study looked at how organic agriculture could contribute to reducing green house gas (GHG) emissions and mitigate the impacts of climate change. Specifically, organic agriculture:

- Encourages and enhances biological cycles within the farming system;
- Maintains and increases long-term fertility in soils;
- Uses, as far as possible, locally available renewable resources in locally organized production systems; and
- Minimizes all forms of pollution (IFOAM 1998).

29.3
Mitigating climate change through organic agriculture

Climate change is manifesting itself as global warming with many adverse local, regional and global impacts. Africa is already the driest continent, and global warming is exacerbating desertification due to erratic rainfall and droughts resulting in famines. Even when rainfall improves, the soil is often too degraded to absorb it and the water runs off in torrents taking much of the important top soil with it. Building and maintaining a healthy soil contributes substantially to offsetting some of these negative impacts, as shown in the following case study from Tigray, northern Ethiopia.

It is generally recognized that the most important environmental factor that is causing climate change is the production of green house gases (GHG), particularly carbon dioxide, methane and nitrous oxide. Agriculture is the main contributor of methane and nitrous oxide, and to a lesser extent of carbon dioxide. However, because of its relatively high concentration in the atmosphere, carbon dioxide contributes most to global warming, although the proportion of this carbon in the atmosphere is only a small part (1.6%) of the overall global carbon budget (International Geosphere Biosphere Program 1998).

29.3.1 Carbon dioxide

Organic agriculture minimizes carbon dioxide emissions from agricultural ecosystems because it:

1. Avoids the need for farmers to use shifting cultivation to restore soil fertility since it increases yield per unit area through organic intensification integrated with animal production. In the past, the burning of natural vegetation in shifting cultivation was a major contributor to atmospheric carbon dioxide. Now industrial agriculture is a more important source of GHG;
2. Maintains soil fertility through enhancing the natural nutrient cycles and combats pests and weeds through ecological techniques and thus reduces fossil fuel consumption. Fossil fuel is the major source of agro-chemicals, which require much energy to produce. In Germany, organic farms were found to have 48-66 percent lower carbon dioxide emissions per ha (Burdick, Haas & Köpke, Stolze, and DFG-Forschergruppe Klimarelevante Gase, cited in Kotschi & Müller-Sämann 2004);
3. Reduces fossil fuel consumption through promoting fresh, locally produced food, thus minimizing the distance that food has to be transported before it is consumed, and provides raw materials for local food processing.
4. Provides animals with locally produced feed and/or allows them to forage for their feed and thus avoid using feed that has often traveled thousands of kilometers, as is the case with the soyabean grown in South America that is used to feed animals in Europe.

29.3.2 Methane

According to Bockish (cited in Kotschi & Müller-Sämann 2004), methane contributes about 15% to global warming, more than half of it coming from agriculture. The biggest contributors are livestock (85-130 Mt yr^{-1}) and rice paddies (20-100 Mt yr^{-1}). Wetlands are the largest natural source of methane, producing 55-150 Mt yr^{-1} (IPCC 2001).

The most important natural sink for methane is the soil where high bacterial activity oxidizes it. Therefore, maintaining soil fertility with good humus content and high biological activity also contributes to reducing methane emissions. It is because of this that undisturbed soils under grassland and forests have higher oxidation rates than cropland. The natural oxidation process is inhibited by chemical nitrogenous fertilizers (Hütch 2001).

Using compost is not significant in reducing methane emissions from animal manure because the shift from anaerobic to aerobic digestion increases nitrous oxide emissions (Bates 2001). However, the production and use of methane in the form of biogas from controlled anaerobic digestion of animal manure as well as many other forms of organic waste can contribute significantly to reducing methane emissions into the atmosphere. Changes in diet for domestic animals can also reduce methane emissions.

There has not been much research into technologies to reduce methane production from rice paddy fields. However, introducing two 'aeration' periods before the crop matures, as well as using compost with a low C/N ratio[1] seems promising (Kotschi and Müller-Sämann 2004).

29.3.3
Nitrous oxide

Nitrous oxide is produced in the soil during the microbial transformation of ammonia to nitrate (nitrification) and nitrate to gaseous nitrogen (denitrification). For this reason, all sources of soil nitrogen – chemical fertilizer, organic manure, nitrogen fixing legumes – enhance nitrous oxide emissions. However, it is not just the total amount of nitrogen but how efficiently it can be used by plants that determines its release into the atmosphere. Extreme overdoses and unbalanced application, i.e. without other nutrients, often result in more of the nitrogen being lost as nitrous oxide than is taken up by plants.

Therefore, applying the principles of organic agriculture is an effective contribution to minimizing nitrous oxide emissions. Specifically:

- No synthetic nitrogenous fertilizer is used so that nitrogen comes from within the system thus avoiding overdoses and high losses;
- Animal stocking rates are linked to the available land with the nitrogenous compounds being recycled back into the system through compost and biogas slurry, thus limiting excess production of animal manure; and
- Diets for dairy cows are lower in protein and higher in fiber, resulting in the lower emission of nitrogenous gases (Kotschi and Müller-Sämann 2004)

29.3.4
Organic agriculture's contribution to carbon sequestration

The emphasis on strengthening the internal nutrient and energy cycles inherent in organic agriculture offers a means to sequester carbon dioxide in the soil and in the vegetation. Table 29.1 summarizes data on carbon sequestration by organic and conventional agricultural systems. Organic agriculture shows a clear advantage with an efficiency of 41.5% compared to 21.3% for conventional farming. The data in the table also show the much higher contribution to sequestration of root biomass as compared with above ground biomass. It should also be noted that root biomass is not removed at harvesting.

Organic agriculture is often equated with the use of organic fertilization techniques – systematic application of manure and compost from animal and crop residues, crop-legume rotations, green manuring with legumes, and agroforestry with multipurpose leguminous trees. Much expertise has been developed in these techniques and the use of these practices has produced outstanding improvements to

[1] The author considers the ratio of N to C should be low, not as stated in the reference.

Table 29.1. Carbon sequestration by organic and conventional farming systems. (Source: Haas & Köpke (cited in Kotschi and Müller-Sämann 2004))

Source	Organic systems [t CO_2 ha^{-1}]	Conventional systems [t CO_2 ha^{-1}]	Difference [t CO_2 ha^{-1}]
Cash crops			
• Above ground biomass	3.76	4.95	–1.18
• Root biomass	1.44	0.89	0.55
Catch crops[a]			
• Above ground biomass	0.55	0.22	0.33
• Root biomass	0.22	0.09	0.13
Weeds			
• Above ground biomass	0.22	0.04	0.17
• Root biomass	0.04	0.01	0.03
Gross output (sequestration)	6.23	6.19	0.04
Energy input (emission)	0.15	0.29	–0.14
Net output (sequestration)	6.08	5.91	0.18
Carbon sequestration efficiency %	41.4	21.3	

productivity and environmental health, as the case study from Tigray, northern Ethiopia, demonstrates. In Switzerland, a long-term comparison between organic and conventional agricultural systems was carried out. After 18 years, soils treated with organic manures were found to contain 3-8 t ha^{-1} more carbon than those that had had chemical fertilizer treatment [Raupp, cited in Kotschi and Müller-Sämann 2004].

29.4 Can organic agriculture combat poverty?

Despite the fact that Ethiopia is also known as the 'water tower' of the Horn of Africa, it is better known for the images of emaciated children and the high rate of soil erosion. The popular image is a 'desert' – dry, with very little vegetation, and very large numbers of emaciated free-ranging livestock.

Since 1996, the Institute for Sustainable Development (ISD) has been working on a project with the local farmers and agricultural experts of Tigray Regional State, northern Ethiopia, to help them build up soil fertility and reverse environmental degradation. This project is generally referred to as the 'Sustainable Agriculture Project' (Hailu and Edwards 2006).

29.4.1
Why the land degradation?

Efforts at building the administratively centralized state of Ethiopia started in the second half of the 19th century. In the process of centralization much of the local community organization, including its natural resource management, was undermined or destroyed. The feudal landlord system was maintained with the bulk of the population existing as peasant farmers. Modern development efforts started only in the 1960s. In the centralized state, smallholder (peasant) farmers were ordered about or ignored altogether despite the fact that virtually all of the food was and still is produced by them. As a consequence, they lost their traditional community organization that had enabled them to manage the land, which thus ended up being 'mined'. There were no inputs in technologies or ideas to help them improve their productivity. They had to continue to rely for their survival on their indigenous knowledge and the rich agrobiodiversity that they had developed, but were unable to continue effectively developing.

Then, in 1974, Emperor Haile Selassie and the feudal system of control over farmers and their land was removed in a 'revolution' that organized the whole population into local, nominally self-governing, organizations with their own elected officials. Under the military government, called the 'Derg', there were massive efforts at land rehabilitation through mass mobilization for soil and water conservation and the provision of external inputs through cooperatives. However, administration remained centralized and overall productivity did not increase. The peasants continued to be ordered about and exploited as had been done under the over-centralized feudal regime. There were also frequent and disruptive redistributions of land. The farmers had no possibility for collective decision taking on management and no interest or incentives to invest in improving their land.

In 1991, the military government was replaced by the present government. In 1993, the Sasakawa-Global 2000 approach was launched to provide high external inputs – principally chemical fertilizer – to farmers. As from 1995, this program was taken up by the National Extension Program of the Ministry of Agriculture and Rural Development. At the beginning, fertilizer cost was subsidized, but as from 1998, the subsidy has been removed and the local price of diammonium phosphate (DAP) and urea has doubled. Overall grain production has increased each year since 1998. However, this has not benefited the people living in the drought prone areas of the northeast and east, who continue to depend on aid. These people have become chronically food insecure requiring annual inputs of aid as food. Whilst this food may save lives, it does not and cannot replenish productive assets that would enable people to reduce their poverty (Alemu undated). It was against this background that the ISD suggested, in 1995, a project to work with local farming communities in Tigray using an ecological, low external input approach. This is now recognized as an uncertified organic system of agricultural production.

29.4.2 The sustainable agriculture project

The project builds on the existing strengths of the local farmers – they control their own seeds and they still have a wealth of agrobiodiversity and traditional knowledge. There still are community-based methods for managing and using common land resources, e.g. grazing land and water that have survived in spite of the disruptive impacts of the uninformed centralized state of the previous one and a half centuries. This community management has been extended to preventing access to hillsides for free range grazing and fuel wood collection so that the natural vegetation can recover. Local community control over land resources is being strengthened through the present government's policy of decentralization to the 'woreda' – the lowest level of official administration in Ethiopia.

The components of the Project were developed from a combination of initiatives from the Institute for Sustainable Development, the Bureau of Agriculture and Rural Development (BoARD) of Tigray and the local farmers.

These are:

- Making and using compost.
- Building trench bunds for catching both soil and water.
- Planting small multipurpose trees – particularly *Sesbania sesban*– and local grasses.
- Halting gullies.
- Making communal ponds.
- Formulating and enforcing bylaws to enable community action, including controlling access to and use of local biological resources, and the stopping of free range grazing.

Four communities were identified to start the project. In one growing season, the farmers saw the impact of compost on crop yields and the improved water holding capacity of their soils. In May 1998, representatives of the farmers and their development agents from the four original communities made exchange visits to one another's areas ending up with a two-day discussion and general evaluation of what they had seen of the project's activities. This encouraged most of the communities to take up all the components of the project. In October 1998, one community was the focus of the annual farmers' field day for the Region, and this encouraged the senior members of the BoARD to promote the 'sustainable agriculture package' as part of the extension program to improve food security for the Region. This was the start of the scaling up of the project's activities. By 2005, ISD and BoARD were working together implementing the project in 42 communities while the BoARD on its own was promoting the 'sustainable agriculture package' of compost-making together with trench bunding and planting multipurpose trees, particularly *Sesbania sesban,* throughout the Region.

29.4.3 Impact of compost on crop yields

The Project's activities have increased the biomass in the farms and their surroundings. Therefore, policy makers have come to realize that the answer to the question "Is there sufficient biomass to make adequate compost?" is "if farmers want they can make enough compost, especially at the end of the growing season".

In 1998, ISD started to monitor the impact of compost on crop yields in farmers' fields. The method used to obtain the yield data is based on the crop sampling system of FAO. Three one-metre square plots are cut from the field. These plots are placed in the field to reflect the range of crop conditions, i.e. well grown and not so well grown areas are sampled from the centre and towards the edge of the field. The cut crop is then threshed and the grain and straw are weighed separately. The plot data are recorded along with the name of the farmer, the crop and the treatment as well as the location and the date. The farmer keeps the straw and grain. The straw is important because it is the main source of animal feed during the dry season, and thus also the raw material for obtaining animal manure for making compost.

Tables 29.2 and 29.3 give the crop yields in kg ha^{-1} from 2003 in two communities. The farmers of Adi Nefas had been using compost for seven years, and had almost completely stopped using chemical fertilizer, while 2003 was the first year farmers of Adi Gua`edad had made and used compost. They, therefore, had also continued to use chemical fertilizer. The 'check' is a field without either compost or chemical fertilizer being applied to it. It should be remembered that most farmers' fields are half a hectare or less in extent.

The data in the tables show that using compost usually doubles the yield when compared to the check. Except for wheat in Adi Gua`edad, yields from fields treated with compost also exceeded the yields from fields treated with chemical fertilizer.

These results from the two communities are a reflection of what has happened in all the areas where the farmers have learnt how to make and apply compost. In the first year or two, they continue to use chemical fertilizer, but as they gain confidence in making compost and also see its residual effects in restoring soil fertility, they stop using chemical fertilizer. It is interesting to note that after farmers stop using chemical fertilizer, no reduction in yields has been recorded as they 'convert' to using only compost. This is probably because the use of chemical fertilizer is relatively recent, i.e. only since 1995 or even later.

Table 29.4 gives the total use of Urea and DAP in Tigray Region since 1995. The total production of all crops for the last 4 years is also given. This shows that while the demand from farmers for chemical fertilizer has decreased, the total production has increased. This is a reflection of the widespread uptake of making and using compost throughout the Region.

Finger millet, faba bean and field pea are usually not given much attention by farmers who apply chemical fertilizer, but they decided to find out if compost could improve their yields. Figure 29.1 shows the results of using compost on these crops. It also compares the yields in Adi Abo Mossa for 1998, when compost had only been used for two years, with the yields for 2002, when compost had been being used for six years.

Table 29.2. Grain yields, expenses and returns for Adi Nefas in 2003. [a] In 2003, Birr 10 = 1 Euro, or Birr 8.5 = US $ 1. Source: Data collected by ISD

Crop	Input	Yield [kg ha^{-1}]	Gross income [birr][a]	Fertilizer cost [birr]	Net income [birr]
Faba bean	Compost	4,391	13,173	–	13,173
	Check	2,287	6,861	–	6,861
Finger millet	Compost	2,650	4,505	–	4,505
	Check	833	1,416	–	1,416
Maize	Compost	5,480	8,768	–	8,768
	Check	708	1,133	–	1,133
Teff	Compost	1,384	3,875	–	3,875
	Chemical fertilizer	1,033	2,892	377	2,515
	Check	739	2,069	–	2,069
Wheat	Compost	2,250	5,625	–	5,625
	Chemical fertilizer	1,480	3,700	377	3,323
	Check	842	2,105	–	2,105
Barley	Compost	1,633	3,266	–	3,266
	Check	859	1,718	–	1,718

It is interesting to see that the ‘checks’ for faba bean and field pea in Adibo Mossa in 2002 were nearly the same as the compost treatment. The crops were growing on fields that had had compost applied to them in previous years, and were thus benefiting from the residual effect of the compost. The results in Tables 29.2 and 29.3 and Figure 29.1 show that applying compost to farmers’ fields can raise yields of all types of crop.

Other benefits from the use of compost have been noted by the farmers. These include:

1. Reduced pest problems – weed seeds, pathogens and insect pests are killed by the high temperature in the compost pits, but earthworms and other useful soil organisms establish well;
2. Disease and pest resistance – as seen through the problem of shoot fly on teff and root borer on faba bean; crops grown on composted soil are more disease and pest resistant;

Table 29.3. Grain yields, expenses and returns for Adi Gua'edad in 2003. [a] In 2003, Birr 10 = 1 Euro, or Birr 8.5 = US $ 1. Source: Data collected by ISD

Crop	Input	Yield [kg ha^{-1}]	Gross income [birr]	Fertilizer cost [birr][a]	Net income [birr]
Faba bean	Compost	2,900	8,700	–	8,700
	Chemical fertilizer	1,100	3,300	377	2,923
	Check	766	2,298	–	2,298
Finger millet	Compost	2,000	3,400	–	3,400
	Chemical fertilizer	1,433	2,436	377	2,059
	Check	500	850	–	850
Maize	Compost	2,000	3,200	–	3,200
	Chemical fertilizer	1,133	1,813	377	1,436
	Check	680	1,088	–	1,088
Barley	Compost	2,193	4,386	–	4,386
	Chemical fertilizer	1,283	2,566	377	2,189
	Check	900	1,800	–	1,800
Wheat	Compost	1,020	2,550	–	2,550
	Chemical fertilizer	1,617	4,043	377	3,666
	Check	590	1,475	–	1,475
Teff	Compost	1,650	4,620	–	4,620
	Chemical fertilizer	1,150	3,220	377	2,843
	Check	390	1,092	–	1,092

3. Increased moisture retention capacity of the soil – if rain stops early, crops grown on soil treated with compost resist wilting for about two weeks longer than those grown on soil treated with chemical fertilizer;
4. Residual effect – farmers who have used compost for one or two years can obtain high yields from their crops the next year without applying compost afresh;
5. Economic returns – farmers have been able to stop buying chemical fertilizer, but they still get even higher yields; and
6. Flavor and satisfaction – the food made from crops grown with compost is said to taste better and provide a more satisfying meal.

Tabel 29.4 Yearly consumption of Urea and DAP and total yields, Tigray. Source: Bureau of Agriculture and Rural Development, Tigray

Year	Urea/DAP ['000 tonnes]	Crop yield ['000 tonnes]
1998	13.71	
1999	12.43	
2000	11.54	
2001	11.32	
2002	10.09	
2003	10.17	713.95
2004	8.90	716.96
2005	8.17	1,162.20
2006		1,353.79

29.4.4 Ethiopia and organic production

In March 2006, the Ethiopian Government passed a law setting out a framework for organic agriculture (Federal Negarit Gazeta 2006). The experience of the farmers in Tigray in producing and using compost indicates that the aim for Ethiopia to have a substantial number of farmers producing organically could be realized. This would not only reduce poverty but also contribute to preventing and reversing land degradation not just in the semi-arid, drought prone parts of the country, but also in the better endowed areas.

The communities that have been part of the Sustainable Agriculture Project have developed bylaws for the management of their natural resources. There is thus a basis for introducing the participatory guarantee system being developed by IFOAM for communities to have their production certified as organic. The participatory guarantee system is based on IFOAM's Norms for Organic Production and Processing (IFOAM 2005).

29.5 Organic agriculture in Africa

In 2003, IFOAM commissioned a study to provide an overview of the status of the organic movement in Africa (IFOAM 2003). The survey covered both the formal (certified) and non-formal sectors for 22 of Africa's 54 countries. This represented 40% of the land area of the continent. Certified organic agriculture covers both

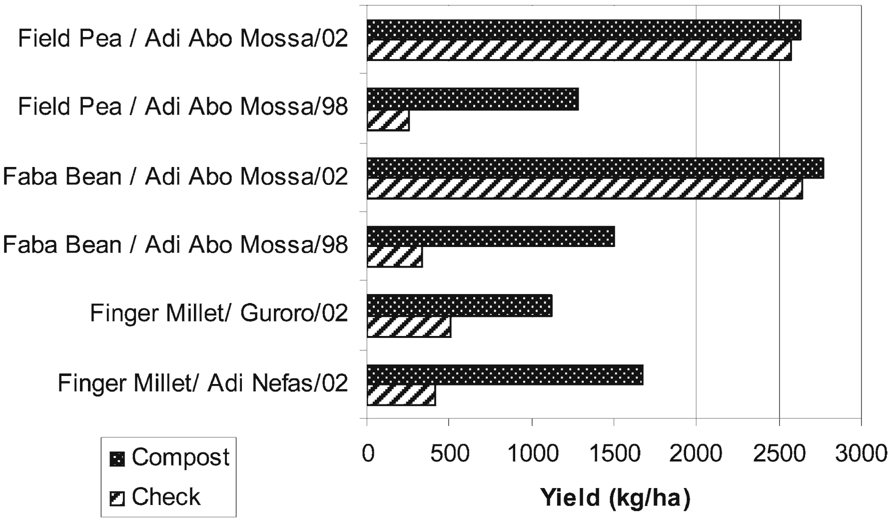


Fig. 29.1. Yields (kg/ha) for faba bean, field pea and finger millet in 4 sites with 1998 compared with 2002

large commercial and small-holder farmers. In global terms, only 1% of land under certified organic agriculture is found in Africa, but, because most of the farms are small (1-3 ha) the continent accounts for almost 10% of the farmers growing certified organic crops worldwide. The principles behind organic agriculture are also used in programs and projects focused on overcoming food insecurity, rural poverty and environmental degradation. In 2003, IFOAM reported that over 40,000 farms covering 235,000 ha of land were growing certified organic products in Africa (IFOAM 2003).

One of the biggest constraints to the expansion of certified organic agriculture in Africa has been the lack of domestic systems of certification. But this situation is changing fast. In 2004, both Egypt and South Africa established indigenous certification bodies. Expanding this to other African countries has been a major focus of the Export Promotion of Organic Products from Africa (EPOPA) project in Eastern Africa (Taylor 2006). An overview of the current state of organic agriculture in Kenya, Uganda and Tanzania was published in 2006 (Taylor 2006). One of the most successful activities of EPOPA has been the harmonization of organic standards for East Africa. The harmonized standards were finalized at a workshop in Nairobi in December 2006, and they will be officially launched at the East Africa Organic Conference to be held in Dar es Salaam, Tanzania, from 28 May to 1 June 2007. The launch of these East African Organic Standards will coincide with a campaign to increase consumer awareness in the region to promote the domestic market for organic products and build the capacity of producers to compete in the export market.

If the current momentum for expansion of the organic sector in agricultural production can be maintained, it will also bring environmental benefits and significantly contribute to reducing emissions of green house gases and to preventing further land degradation in the region.

References

Alemu Assefa (2002) Chronic food insecurity rather than availability is becoming the main issue in Ethiopia. Draft report prepared for USAID in Addis Ababa.

Bates J (2001) Economic evaluation of emission reductions of nitrous oxide and methane in agriculture in the EU. Contribution to a study for DG Environment, European Commission by Ecosys Energy and Environment, AEA Technology Environment and National Technical University of Athens.

Federal Negarit Gazeta (2006) Proclamation No. 488/2006. Ethiopian Organic Agriculture System Proclamation, dated 8 March 2006, Addis Ababa, Negarit Gazeta 12th year, No. 21. Federal Negarit Gazeta of the Federal Democratic Republic of Ethiopia, Addis Ababa.

Hailu Araya, Edwards S (2006) The Tigray Experience: a success story in sustainable agriculture. Environment & Development Series 4. TWN (Third World Network), Penang.

Hütch B (2001) Methane oxidation in non-flooded soils as affected by crop production. Eur J Agron 14:237-260

IFOAM (1998) Basic Standards for Organic Production and Processing. IFOAM General Assembly, Argentina.

IFOAM (2003) Organic and like-minded movements in Africa: development and status. Compiled by Nicholas Parrott and Bo van Elzakker of Agro Eco for IFOAM. IFOAM, Bonn.

IFOAM (2005) The IFOAM Norms for Organic Production and Processing – version 2005. IFOAM, Bonn.

IFOAM (undated) Principles of Organic Agriculture. IFOAM, Bonn.

International Geosphere Biosphere Program (1998) The terrestrian cycle: implications for the Kyoto protocol. Science 280:1393-1394

IPCC (2001) Climate Change 2001: The Scientific Basis. Houghton JT, Ding Y, Griggs DJ, Noguer M, van der Linden PJ, Dai X, Maskell K, Johnson CA (eds) Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change Cambridge University Press, Cambridge, UK and New York.

Kimbrell A (2002) The Fatal Harvest and The Fatal Harvest Reader: the tragedy of industrial agriculture. Foundation for Deep Ecology with the Island Press. Foundation for Deep Ecology, California.

Kotschi J, Müller-Sämann K (2004) The Role of Organic Agriculture in Mitigating Climate Change – a scoping study. IFOAM, Bonn.

Taylor A (2006) Overview of the current state of organic agriculture in Kenya, Uganda and the United Republic of Tanzania, and the opportunities for regional harmonization. Prepared under the UNEP-UNCTAD Capacity Building Task Force on Trade, Environment and Development Project 'Promoting Production and Trading Opportunities for Organic Agricultural Products in East Africa'. United Nations, New York and Geneva.

Using Better Climate Prediction in the Implementation of National Action Programmes – (Eastern) Europe

Vesselin Alexandrov

Abstract. According to the UNCCD (United Nation Convention to Combat Desertification) affected country Parties have to prepare, make public and implement National Action Programmes (NAPs) as the central element of the strategy to combat desertification and mitigate the effects of drought. NAPs could involve strengthening of drought preparedness and management, including drought contingency plans at the local, national, sub-regional and regional levels, which take into consideration seasonal to interannual climate predictions. In this paper the question on application of climate predictions in (Eastern) European countries is discussed. Results from a survey on CLIPS (Climate Information and Prediction Services) activities in the National Meteorological and Hydrological Services (NMHSs) from Eastern Europe are considered. Capabilities of certain Eastern European countries in the development of their own seasonal to interannual predictions or adaptation and interpretation of predictions issued by specialized climate prediction centers are also listed. A short overview on the contempoarary approaches towards better seasonal to interannual prediction and climate forecasting is done within the paper, as well. Seasonal forecasts can be developed using mathematical models of the climate system. A recent trend is to examine the potential use of regional climate models. In Europe the multi-model approach seems to be the most adequate to produce reliable probabilistic climate forecasts. EU-funded project such as ENSEMBLES, EUROCLIM, CECILIA evaluating the merits of the current approaches and methods in the field are mentioned, too.

30.1 Introduction

The United Nations Convention to Combat Desertification (UNCCD) was adopted in Paris on 17 June 1994 and opened for signature there on 14-15 October 1994. It entered into force on 26 December 1996, 90 days after the fiftieth ratification was received. Until present, more than 190 countries became Parties to the Convention by ratification or accession. Countries affected by desertification are implementing the Convention by developing and carrying out national, sub-regional, and regional action programmes. According to the UNCCD, affected country Parties shall "prepare, make public and implement national action programmes (NAPs) as the central element of the strategy to combat desertification and mitigate the effects of drought". NAPs shall "incorporate long-term strategies to combat desertification and mitigate the effects of drought" and "enhance national climatological, meteorological and hydrological capabilities and the means to provide for drought early warning". NAPs may include, inter alia, establishment and/or strengthening, as appropriate, of early warning systems as well as strengthening of drought preparedness and management, including drought contingency plans at the local, national, subregional and regional levels, which take into consideration seasonal to interannual climate predictions (UNCCD 2006)

It is considered that when discussing any issue related to climate predictions, the respective definitions of meteorological forecasting ranges should be clarified (Table 30.1)

According to the recommendations of the ad hoc ICCD/COP(4)/CST/4 Panel on Early Warning Systems (October 2000) it is necessary: to integrate early warning results with the results of other climate prediction systems such as the World Meteorological Organization (WMO) Climate Information and Prediction Services (CLIPS) and CLIVAR (CLImate VARiability and predictability); to encourage the further development and application of seasonal climate forecasting and long-range forecasting as tools for early warning systems; etc.

The specific objectives of CLIVAR (www.clivar.org) are:

- to describe and understand the physical processes responsible for climate variability and predictability on seasonal, interannual, decadal, and centennial time-scales, through the collection and analysis of observations and the development and application of models of the coupled climate system, in cooperation with other relevant climate-research and observing programmes;
- to extend the record of climate variability over the time-scales of interest through the assembly of quality-controlled paleoclimatic and instrumental data sets;
- to extend the range and accuracy of seasonal to interannual climate prediction through the development of global coupled predictive models;
- to understand and predict the response of the climate system to increases of radiatively active gases and aerosols and to compare these predictions to the observed climate record in order to detect the anthropogenic modification of the natural climate signal.

CLIPS (www.wmo.ch/web/wcp/clips2001/html/) is a WMO project that deals with the implementation of climate services around the globe. Climate services are any activity that employs and/or applies climate knowledge, climate information and climate predictions to the benefit of individuals, organizations and countries. Increasingly governments, international organizations, companies and individuals are recognizing the impacts that climate has on their activities, whether from long-term climate change or from climate variability on time scales of up to a few seasons or years.

30.2 CLIPS surveys

A survey undertaken during the year 2000 on behalf of the CLIPS project (Kimura 2001) revealed that about one-third of the WMO member countries already had,

Table 30.1. Definitions of meteorological forecasting ranges (source: www.wmo.int)

1.		Nowcasting	A description of current weather parameters and 0 -2 hours description of forecasted weather parameters
2.		Very short-range weather forecasting	Up to 12 hours description of weather parameters
3.		Short-range weather forecasting	Beyond 12 hours and up to 72 hours description of weather parameters
4.		Medium-range weather forecasting	Beyond 72 hours and up to 240 hours description of weather parameters
5.		Extended-range weather forecasting	Beyond 10 days and up to 30 days description of weather parameters, usually averaged and expressed as a departure from climate values for that period.
6.		Long-range forecasting*	From 30 days up to two years
	6.1	Monthly outlook	Description of averaged weather parameters expressed as a departure (deviation, variation, anomaly) from climate values for that month (not necessarily the coming month).
	6.2	Three month or 90 day outlook	Description of averaged weather parameters expressed as a departure from climate values for that 90 day period (not necessarily the coming 90 day period).
	6.3	Seasonal outlook	Description of averaged weather parameters expressed as a departure from climate values for that season.
Notes:	(1)	In some countries, long-range forecasts are considered to be climate products	
	(2)	Season has been loosely defined as Dec/Jan/Feb = Winter; Mar/Apr/May = Spring; etc...in the northern hemisphere. In the tropical areas seasons may have different durations. Outlooks spanning several months such as multi-seasonal outlooks or tropical rainy season outlooks may be provided.	
7.		Climate forecasting	Beyond two years
	7.1	Climate variability prediction	Description of the expected climate parameters associated with the variation of inter-annual, decadal and multi-decadal climate anomalies.
	7.2	Climate prediction	Description of expected future climate including the effects of both natural and human influences.

* – in the paper assumed as Seasonal to Interannual Prediction (SIP)

Table 30.2. Issuance of official climate forecasts (Kimura 2001)

	RA I	RA II	RA III	RA IV	RA V	RA VI	Global
Yes (class A)	15	9	4	4	7	10	49
Planned (Class B)	7	2	0	0	0	5	14
No (class C)	0	6	0	0	1	12	19
Total	22	17	4	4	8	27	82

or planned to obtain in the near future, the capability to provide some form of operational seasonal to interannual prediction (SIP). Most of the member countries do not have the necessary human and financial resources to develop and issue their own predictions (Kimura 2001, Sivakumar 2006). According to Kimura (2001) the total issuance of official climate forecasts in the WMO RA VI (Europe) was 27, which is higher than the totals of the other regional associations (Table 30.2).

In 2003 a comprehensive CLIPS questionnaire was created by Gocheva and Heckler (2004) and disseminated among WMO RA VI member countries. Here a summary of the respective answers from eastern European countries is given.

There is a wide range of answers to the question "Is SIP currently successful in specified regions and sectors only?" Countries such as Albania and Cyprus do not use SIP and have not any precise opinion about SIP. However, according Armenia, Moldova and Kazakhstan SIP is successful in wide geographical regions. Azerbaijan: it is difficult to say anything about successfulness of SIP; Latvia: it is difficult to point out any geographic region where SIP works better; Bulgaria; Estonia, Slovenia and Cyprus: SIP seems successful for specific regions and sectors; Croatia, Poland, Romania: successful in ENSO-related regions with insignificant predictability (NAO) in mid-latitudes (Gocheva and Heckler 2004)

In respect to the question "Does your NMHS (National Meteorological and Hydrological Service) provide official SIP?" the following countries replied negatively: Albania, Croatia, Cyprus, Estonia, Greece, Lithuania, Slovenia. Bulgaria, Latvia, Serbia & Montenegro provide monthly SIP; Belarus, Armenia, Azerbaijan, Poland – monthly and seasonal SIP; Russia -operational 1-3 month SIP containing both regional and global predictions. It is necessary to point out the Romanian information. The National Meteorological Administration in Romania provides, beyond the one-month weather forecasts, the following: prognostic estimates for the next two months, following the forecasting month; "seasonal supplement", containing the anomaly notification in the geophysical environment in past season and meteorological outlook for the next season; a bulletin with annual forecasting assessments, elaborated at the beginning of each season and containing estimates of the temperature and precipitation anomalies for the next four seasons (Gocheva and Heckler 2004).

Figure 30.1 shows the major global producers of long range forecasts. The next question from the survey of Gocheva and Heckler (2004) considers this topic: "Does your NMHS use SIP products from global producers?" The responses were

Fig. 30.1. Global producers of long range forecasts (source: www.wmo.int)

as follows: Croatia, Cyprus, Estonia – such products have been not applied yet; Armenia, Azerbaijan, Belarus, Latvia are using ROSHYDROMET products; Slovakia and Greece explore ECMWF (Figs. 30.2 and 30.3) products only; Bulgaria uses ECMWF, IRI (International Research Institute for Climate and Society), UK Met Office, Météo-France in the terms of development of monthly weather forecast involving local weather and climate archive data downscaling. For example, the National Institute of Meteorology and Hydrology in Sofia, Bulgaria shows on its web page (info.meteo.bg) UK Met Office and IRI products as well as their interpretation for the Balkan peninsula and especially Bulgaria (Fig. 30.4); Lithuania – products from IRI (Fig. 30.5 and 30.6), World Resource Institute and Swedish Regional Climate Modelling Programme; Poland – ECMWF, IRI, DWD (The German Weather Service); Romania – ECMWF, Met Office, IRI and Japan Meteorological Agency.

It is considered that the ability to predict climate fluctuations months in advance is improving to the point where there are good prospects for using such forecasts to modify, for example, the management of crops and livestock so as to ameliorate some of the negative impacts of climate variability in some environments (Mason 2001, Hansen 2002, O'Brien and Vogel 2003, Thornton, 2006). Gocheva and Heckler (2004) collected also the answers of the following question: "Do you apply SIP in the management of agricultural production, water resources, etc.?". Countries such as Armenia, Azerbaijan, Belarus, Bulgaria, Kazakhstan, Latvia, Poland, Romania have relatively widely SIP applications in the different sectors of economy (e.g. energy, agriculture, insurance, transport, water resources, tourism, human health, etc.). Russia, Croatia, Serbia and Montenegro, Slovakia apply SIP partially in some sectors, occasionally. Albania, Cyprus, Greece, Lithuania and Slovenia answered completely negatively. The eastern European countries were split into 50:50 in respect to the question "Has your NMHS contracts for regular SIP provision

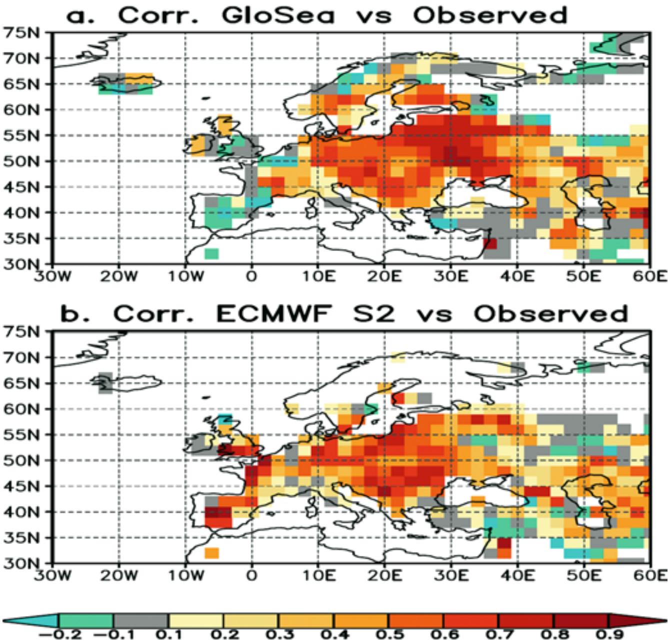


Fig. 30.2. Spatial pattern of correlation between modelled February-April snow cover and NCEP/NESDIS observations; a) shows the correla-tion for the GloSea model ;b) shows the correlation for the ECMWF S2 model (source: Shongwe et al. 2006)

with a specific sector for example, agriculture?". However, 90% of them confirmed availability of user's requests towards SIP products.

There were additional questions within the survey of Gocheva and Heckler (2004), such as: "Is your SIP officially issued by media?"; "Do you develop the theoretical basis of your SIP activities by own research efforts?"; "How do you maintain the theoretical basis of your operational SIP activities?"; "Do you apply downscaling methods for specific sectors/applications/locations?"; "What are the predicted meteorological elements and parameters in your national SIP practice?", etc. It is necessary to point out that the above summary could be slightly different from the current situations because of some positive changes in the terms of SIP applications during the last few years.

30.3 Towards better SIP and climate forecasting

The principal scientific basis of seasonal forecasting is founded on the premise (e.g. Palmer & Anderson 1994) that lower-boundary forcing, which evolves on a slower timescale than that of the weather systems themselves, can give rise to significant predictability of atmospheric developments. These boundary conditions in-

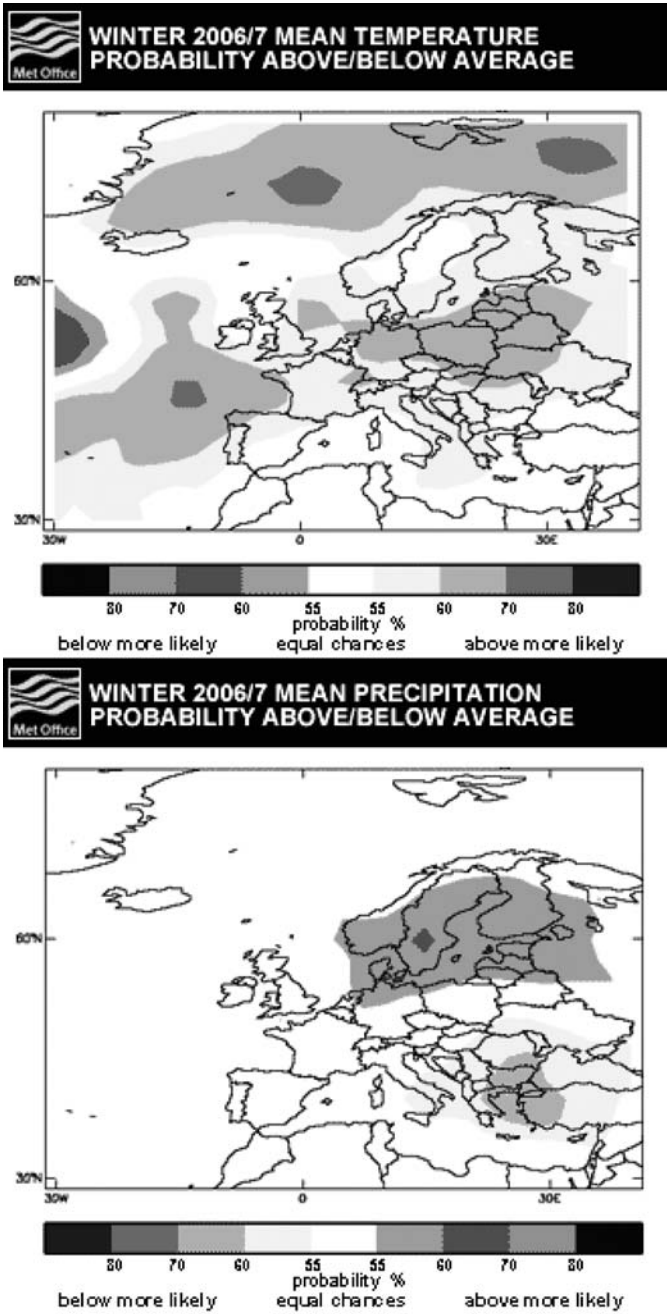


Fig. 30.3. ECMWF products for Europe (source: www.ecmwf.int)

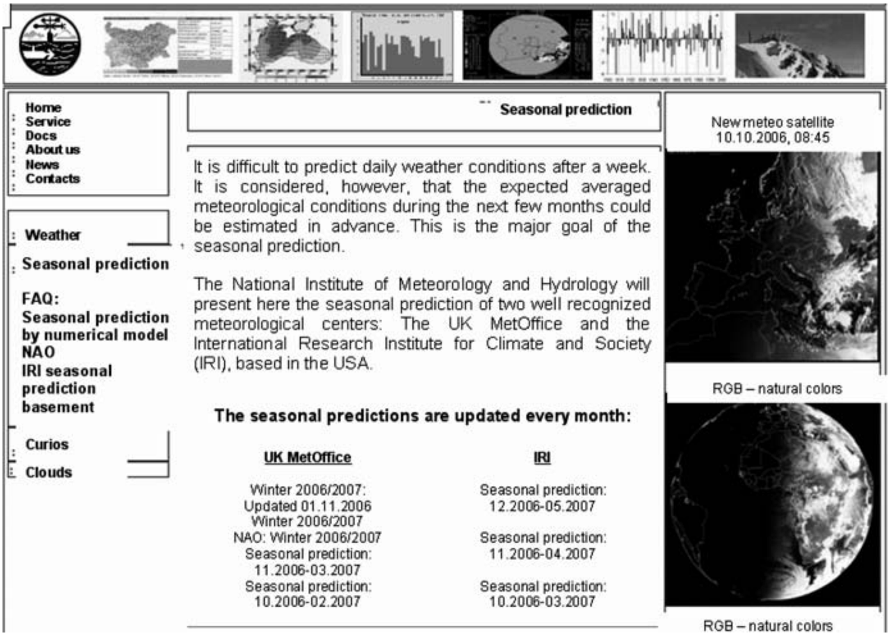
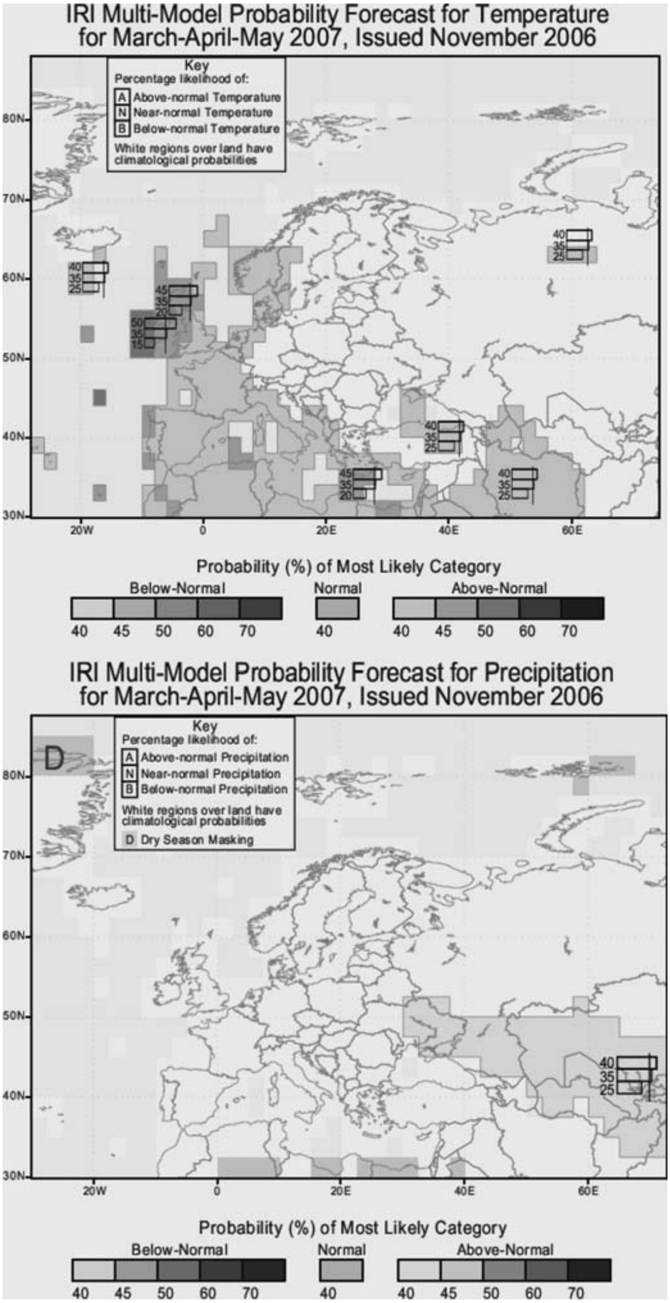


Fig. 30.4. The web page of the Information Center at the National Institute of Meteorology and Hydrology in Sofia, Bulgaria, where links to UK Met Office and IRI information on SIP are posted (source: info.meteo.bg)

clude sea surface temperature (SST), sea-ice cover and temperature, land-surface temperature and albedo, soil moisture and snow cover, although they are not all believed to be generally of equal importance (Sivakumar 2006). Seasonal climate forecasts are based also on the interactions between ocean and atmosphere as manifested in sea surface temperatures, which can offer some predictability in terms of future temperatures and rainfall amounts (Ziervogel et al. 2005). According to Hansen (2006) forecasts of climate fluctuations with a seasonal lead-time are possible because the atmosphere responds to the more slowly varying ocean and land surfaces, an example being climate fluctuations associated with the El Niño-Southern Oscillation (ENSO) in the tropical Pacific (Mason 2001). Regional forecasts for Europe are dependent on North Atlantic Oscillation events, as well (Fig. 30.7).

Seasonal forecasts can be developed using mathematical models of the climate system. Such dynamical seasonal forecasts are an extension of the numerical methods used to predict the weather a few days ahead. Dynamical models represent the climate system by a set of computer-solved equations, to predict its evolution several months in advance. Several climate prediction centers routinely issue probabilistic seasonal forecasts based on dynamic general circulation models (GCMs) that model the physical processes and dynamic interactions of the global climate system in response to sea and land surface boundary forcing. Probabilistic forecasts are obtained from ensembles of GCM integrations initialized with different atmo-

Fig. 30.5. IRI products for Europe (source: iri.columbia.edu)



The International Research Institute for Climate and Society

Back | Forecast Index

Climate Outlook
EUROPE November 2006 - April 2007

Issued: October 2006

The IRI has prepared this experimental Climate Outlook for Europe for November 2006 - April 2007. Of relevance in the preparation of this outlook is a quite strong likelihood that the present somewhat above average tropical Pacific SSTs will continue. Such weak El Nino tropical Pacific conditions are indicated in the SST predictions on which these climate forecasts are based. See the IRI's ENSO update for a discussion on the ENSO outlook (see IRI Probabilistic ENSO forecast). Somewhat warmer than average SSTs are now observed in the central and eastern tropical Pacific, while below normal SSTs are found in the western tropical Pacific. The eastern equatorial Indian Ocean has below normal SSTs, while the central and eastern Indian Ocean has above normal SSTs. Much of the northern tropical Atlantic Ocean shows above-average SSTs (SSTs). The Indian Ocean and tropical Atlantic SST anomalies are predicted to slowly weaken over the course of the forecast periods. (November-January 2007, December-February&2007, January-March 2007, February-April 2007).

METHODS -

This Outlook was prepared using the following procedures and information:

A) Coupled ocean-atmosphere model predictions of tropical Pacific SST covering the forecast period. Particularly heavy weighting has been given to predictions from the coupled model operated by the NOAA National Centers for Environmental Prediction, Climate Modeling Branch. This model suggests a continuation of near-average conditions during the first forecast season. The forecast for near-neutral conditions is consistent with some, but not all, numerical and statistical forecasts of central and eastern

Fig. 30.6. IRI climate outlook for Europe, November 2006 – April 2007 (source: iri.columbia.edu)

spheric conditions. In addition to dynamical predictions, empirical seasonal forecasts (Moura and Hastenrath 2004) can also be used in an attempt to find statistical links between current observations and general weather conditions some time in the future.

A recent trend is to examine the potential use of regional climate models. A sophisticated method of obtaining more localised estimates of climate is to apply numerical regional climate models at high resolution over the region of interest. Regional models have been used in several climate impact studies for many regions of the world, including parts of North America, Asia, Europe, Australia and Southern Africa (Giorgi and Mearns 1999, Mearns et al. 1997). The regional climate models obtain sub-grid scale estimates (sometimes down to 25 km resolution) and are able to account for important local forcing factors, such as surface type and elevation. Particularly, the regional climate model RegCM (Fig. 30.8) was originally developed at the National Center for Atmospheric Research (NCAR), USA and

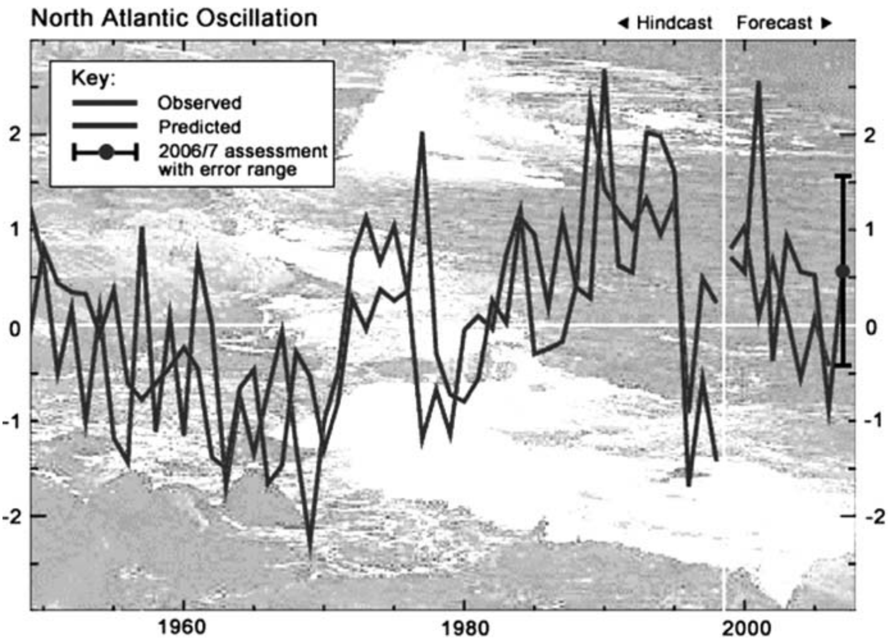


Fig. 30.7. Statistical forecast for the NAO index (www.metoffice.gov.uk)

has been mostly applied to studies of regional climate and seasonal predictability around the world. It is further developed by the Physics of Weather and Climate group at the Abdus Salam International Centre for Theoretical Physics (ICTP) in Trieste, Italy.

In Europe the multi-model approach seems to be the most adequate to produce reliable probabilistic climate forecasts (Doblas-Reyes 2006). The advantages of the multi-model approach have been illustrated in, among other research efforts, the DEMETER project. Briefly, the DEMETER system comprises 7 global coupled ocean–atmosphere models. Uncertainties in the initial state were represented through an ensemble of 9 different ocean initial conditions. Atmospheric and land-surface initial conditions are taken directly from the ERA-40 (ECMWF Re-analysis) atmospheric re-analysis (Uppala et al. 2005). The performance of the DEMETER system has been evaluated from a comprehensive set of predictions for past cases, or hindcasts, over a substantial part of the ERA-40 period (1958–2001). One of the main results of the experiment is that the DEMETER multi-model forecast system provides, on average, more skilful seasonal forecasts than is possible using a single-model ensemble system (Doblas-Reyes 2006)

The relative merits of the above methods (Fig. 30.9) are under evaluation within EU-funded project such as ENSEMBLES, EUROCLIM, CECILIA, etc. The ENSEMBLES objectives (www.ensembles-eu.org) are to: run ensembles of different climate models to sample uncertainties; measure variations in reliability between models; produce probabilistic predictions of climate change. The project will, for

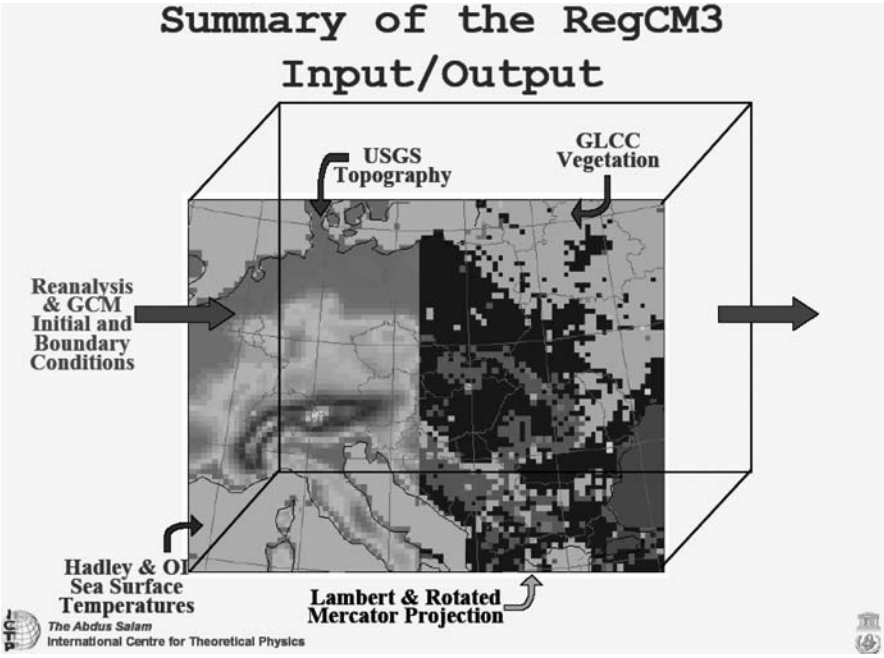


Fig. 30.8. RegCM3 inputs (source: Pal et al. 2005)

the first time, develop a common ensemble climate forecast system for use across a range of time (seasonal, decadal and longer) and spatial scales (global, regional, and local); link these projections to potential impacts: agriculture, health, energy, insurance, ecosystems, etc. One of the EUROCLIM project (euroclim.nr.no) targets is to improve climate models in order to better predict future climate conditions. The main CECILIA project (www.cecilia-eu.org) objectives are as following: producing high resolution (10 km) 30-year time slices over four target areas; comparing model responses with coarser results from existing simulations to assess the gain of a higher resolution; archiving daily data from the simulations in a common database; improving high resolution models for future scenarios (Fig. 30.10)

30.4 Conclusions

According to Hansen et al (2006) seasonal forecasts can be calibrated and evaluated at a local scale, although attempts to quantify the effect on prediction skill have so far been few. Incorporating understanding of fine-scale climatic influences – such as orography, land–water interfaces, or land cover – into either statistical downscaling models or highresolution, regional dynamic climate modeling is likely to further enhance prediction skill at the local scale that is relevant to farm im-

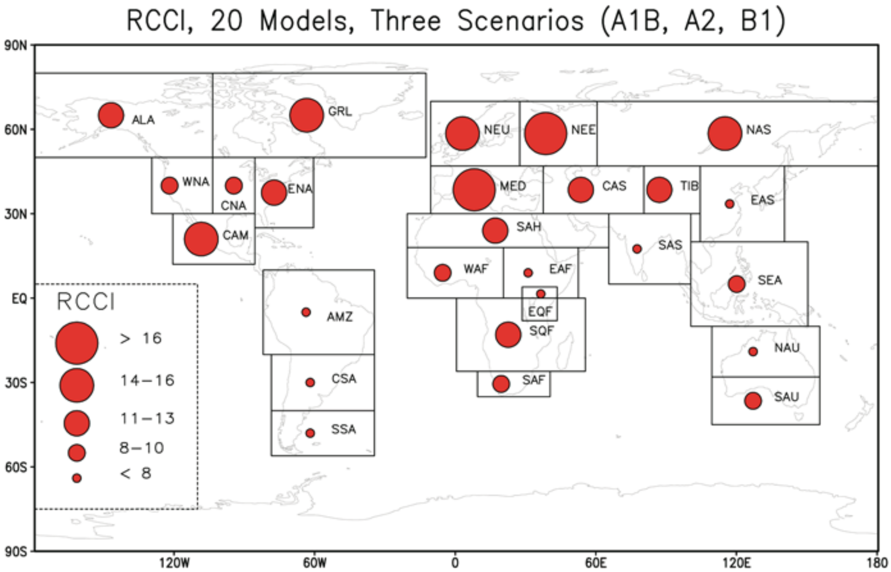


Fig. 30.9. Regional Climate Change Index, based on 20 models and 3 emission scenarios (source: Giorgi 2006)

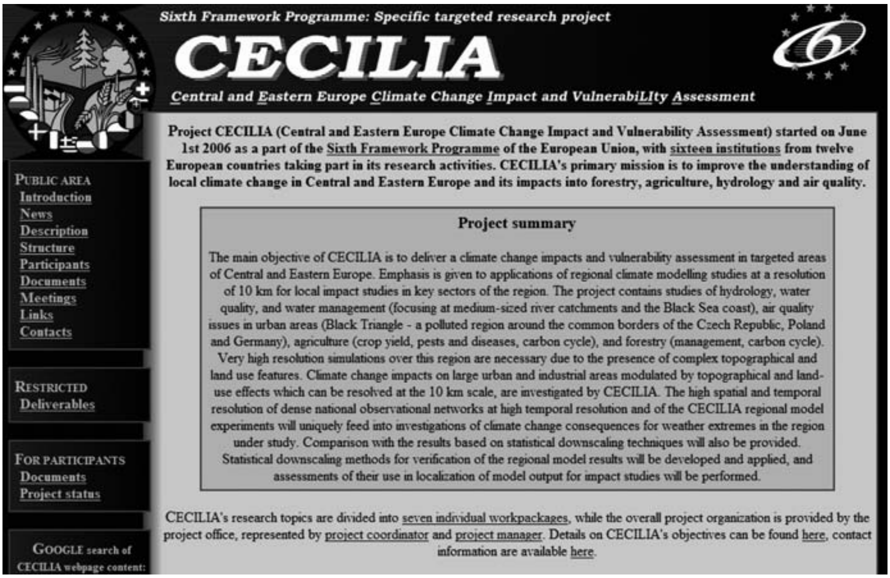


Fig. 30.10. CECILIA project web page (source: www.cecilia-eu.org)

pacts and decisions. Although it is impossible to predict the timing of daily weather events through a season, it is reasonable to assume that the large-scale ocean–atmosphere interactions that give rise to predicable shifts in seasonal means may also influence higher-order statistics of synoptic weather events that are important to agriculture, such as the frequency and persistence of rainfall events, the distribution of dry spell durations, the timing of season onset and the probabilities of intense rainfall events or temperature extremes. For now, the predictability of these higher-order statistics at a seasonal lead-time remains largely unquantified.

Climate variability and change contribute to the vulnerability of individuals, businesses, communities and regions. This influences decision makers at all levels (policy, businesses and farms), regardless of the level of economic development. When anticipating potential changes in climate such as possible changes in the frequency and/or magnitude of extreme events and other changes in the pattern of climate and system, there is a need for improved seasonal forecasts. It is considered that in the future there would be better characterization of predictability at finer spatial and temporal scales and perhaps challenge the convention of presenting operational forecasts only as seasonal climatic means at an aggregate spatial scale. If improved forecasting is to be harnessed effectively, however, various conditions will need to be met. Seasonal climate forecasts must address a real and perceived need, and they must have value (Hansen 2002). There are also clear needs for appropriate institutional structures that are adapted to manage such processes (Hudson and Vogel 2003, O'Brien and Vogel 2003).

References

Doblas-Reyes FJ, Hagedorn R, Palmer TN (2006) Developments in dynamical seasonal forecasting relevant to agricultural management. Clim Res 33:19-26

Giorgi F (2006) Climate change hot-spots. Geophys Res Lett 33

Giorgi F, Mearns LO (1999) Introduction to special section: Regional climate modeling revisited. J Geophys Res 14(D6):6335-6352

Gocheva A, Heckler P (2004) Questionnaire on CLIPS activities in the NMHSs of RA VI countries (www.wmo.int)

Hansen JW (2002) Realising the potential benefits of climate prediction to agriculture: issues, approaches, challenges. Agric Syst 74:309–330

Hansen JW, Challinor A, Ines A, Wheeler T, Moron V (2006) Translating climate forecasts into agricultural terms: advances and challenges. Clim Res 33:27-41

Hudson J, Vogel C (2003) The use of seasonal forecasts by livestock farmers in South Africa. In: O'Brien K, Vogel C (eds) Coping with climate variability: the use of seasonal climate forecasts in southern Africa. Ashgate, Aldershot

Kimura Y (2001) A survey on the present status of climate forecasting Thirteenth Session of the Commission for Climatology of World Meteorological Organisation, 21–30 November 2001, Geneva, Switzerland

Mason S (2001) El Niño, climate change, and Southern African climate. Environmetrics 12:327–345

Mearns LO, Rosenzweig C, Goldberg R (1997) Mean and variance change in climate scenarios: methods, agricultural applications and measures of uncertainty. Clim Chang 35:367-396

Moura AD, Hastenrath S (2004) Climate prediction for Brazil's Nordeste: performance of empirical and numerical modelling methods. J Clim 17:2667–2672

O'Brien K, Vogel C (2003) A future for forecasts? In: O'Brien K, Vogel C (eds), Coping with climate variability: the use of seasonal climate forecasts in Southern Africa. Ashgate Press, Aldershot

Pal JS, Giorgi F, Bi X, Elguindi N, Solmon F, Gao X (2005) Regional Climate Modeling and the ICTP Regional Climate Model (RegCM3). Presentation at the AGRIDEMA workshop, Vienna, Austria

Palmer TN, Anderson DLT (1994) The prospects for seasonal forecasting: a review paper. Q J R Meteorol Soc 120: 755–793

Thornton PK (2006) Ex ante impact assessment and seasonal climate forecasts: status and issues Clim Res 33: 55-65

Shongwe ME, Ferro CAT, Coelho CAS, van Oldenborgh GJ (2006) Predictability of cold spring seasons in Europe. J Clim (submitted)

Sivakumar MVK (2006) Climate prediction and agriculture: current status and future challenges. Clim Res 33:3-17

United Nations Convention to Combat Desertification (UNCCD) (2006) United Nations Convention to Combat Desertification in those countries experiencing serious drought and/or desertification, particularly in Africa: text with annexes. UNCCD Secretariat, Bonn, Germany

Uppala S, Kållberg PW, Simmons AJ, Andrae U and 42 others (2005) The ERA-40 reanalysis. Q J R Meteorol Soc 131:2961–3012

Ziervogel G, Bithell M, Washington R, Downing T (2005) Agent-based social simulation: a method for assessing the impact of seasonal climate forecast applications among smallholder farmers. Agric Syst 83:1–26

Improving NAP Implementation through Effective Use of Early Warning: Experiences in the IGAD Sub-Region

Reuben Sinange

Abstract. The principle purpose of an early warning system is to collect an appropriate set of data and information regularly, in a consistent manner so as to provide a sense of trends and enable prediction of future status of the environment and events on a timely basis. This is done with a view to have populations at risk to be in a state of preparedness to prevent and respond to disasters. It enables them improve response, save lives and property, reduce damage to property and reduce human suffering from the extreme events and processes.

The concepts and science and technology for early warning systems have been substantially improved and refined over the last 30 years. Broad institutional arrangements and networks at various levels have equally developed tremendously during the same period. Even if not always perfect, the systems have globally given results in terms of indications and trends that have often attracted interventions but unfortunately not in many countries. States are being urged to address the issue as apart of their national risk management responsibility.

However, it requires states to have conviction, commitments, laws and other instruments like development strategies and programmes that include National Action Programmes to Combat Desertification (NAPs) to implement interventions that ideally should be driven by an existing early warning system (EWS).

There are instances in the IGAD sub-region where early warnings were issued but "ignored" and regretfully governments and responsible institutions were blamed for not having done enough before, during and after the disastrous events and processes like desertification, droughts, famines and floods. Redressing the situation proves to be even more costly.

This paper endeavors to demonstrate that although the science and systems have been developed in the IGAD sub-region where extreme events abound, responses have not always been adequate. It is proposed that the solutions may lie in formulating strong pro-EWS policies, legal and institutional frameworks to enable effective utilization of the available science and technological capabilities. This will save our environment, reduce disastrous processes and events and promote the culture of risk assessments and management by the state. One of the appropriate vehicles to promote this can be the NAPs.

The emphasis is on placement of early warning systems in a legal and institutional framework. This is with a view to influencing decision and policy making on risk management of our environment. Some of the legal areas that can be targeted for repeal to accommodate EWS are those of national statistical services, disaster management laws, and environmental management laws.

31.1 Introduction

Desertification occurs in the dry-lands mainly due to deleterious activities of man and climatic factors including climate change and droughts. It is an insidious and continuous process of reduction of productivity of lands. Thus it negatively affects the provision of man's basic needs including food, wood, timber, fiber, medicine and water. Droughts and other extreme events exacerbate and dramatize the problem in terms of exposing the extent of environmental degradation; vulnerability of the poor; and fragility of national economies.

The processes that lead to reduction of land productivity include:

- *Climatic factors.* Climate change, droughts.
- *Over-cultivation.* Extensive, intensive, inappropriate conversion of land to cropland.
- *Overgrazing.* Overstocking, leading to lose of cover, topsoil and fertility.
- *Deforestation.* Removal of natural plant cover for crops, fuel, shelter, medicine.
- *Dehydration.* Water overuse, wastage, diversions, and interbasin transfers for urban centers and irrigation projects leading to severe surface and underground water shortages in certain areas.

Ideally these are the processes or whose indicators that should be monitored as part of an environmental information system (EIS) or environmental warning system (EWS). However, due to the immediate and adverse effects of these processes on food production that often lead to famines, there are more advances in food security early warning systems (FSEWS).

31.2 Food Security and Early Warning Systems (FSEWS) in the region

A number of monitoring and early warning systems evolved in East Africa mainly for ecological and wildlife monitoring. Initially they used ground level and aerial methodologies, and later with its advent, satellite remote sensing was incorporated (GEMS 1980; Clark 1986). Thus the UNEP global environmental monitoring system (GEMS) and other national and regional programmes were evolved. Recent reviews (SSO/UNSO, (1991); Sinange 1999) show that there exist many EW and monitoring systems in Western, Eastern, Central and Southern Africa sub-regions with different thematic and geographic scopes. Most are focused on food security and include among others:

- *Global systems.* FAO-FSEWS, WMO, UNEP.
- *Regional systems.* FEWS (USAID), ACMAD, AGRYMET.
- *Sub-regional systems.* SADC-DMC, ICPAC.
- *National systems.* most countries have their own.
- *Sub-national systems.* for example in Ethiopia and Kenya.

31.2.1
Case for improving FSEWS in the region

The reviews (SSO/UNSO (1991) and Sinange (1999) and recent reports from various systems including ICPAC, FSWS (USAID), FAO-FSEWS and SDAC-DMC indicate that these EWSs are working and are bound to improve for the following reasons:
- There is a need for EWSs at all levels as long as the hazards exist.
- Concepts, definitions, mandates and frameworks are clearer
- The science and technology tools continue to improve including:
  - *Remote sensing (RS)*, frequency of images, spatial and spectral resolutions and costs continue to improve;
  - *Geographic information systems (GIS)* for analysis, representation and communication are revolutionizing the EW science;
  - *Information and communication technology (ICT):* voice (telephone, conferencing); data (e-mail, internets, GIS); video; electronic media (television, radio); communication satellites are all improving by leaps and bounds;
- There is a marked reduction in blame games and controversies in relief and rehabilitation responses for example in the IGAD member states in recent years an indication that there is more effective use of information and improvements in governance.

A case in point is the recent (October to December 2006) mini El Niño rains in the Eastern Africa sub-region, which were predicted and the public was informed well in advance by ICPAC through its regular climate prediction forums. The rains caused floods, extensively damaged infrastructure (like roads, bridges, dykes and houses) and crops in various areas of Ethiopia, Kenya and Somalia. Many families were displaced and some lives lost. Compared to previous years, responses were relatively fast and adequate. Rehabilitation of the infrastructure was rapid. This saw very reduced criticism of the governments in the way they handle emergencies. These are indications that the systems have improved and are working.

31.2.2
Challenges to FSEWS in the Region

However, the reviews further showed that the EWS experience various challenges and constraints at all levels including:
- Data quality and reliability from certain sources, bring to the fore some source legitimacy and credibility issues of some stakeholders.
- Weak institutional set up and low capacity.
- Poor communication networking within and between countries.
- Inadequate co-ordination among the stakeholders involved in EW.
- The EW results and products most frequently not released in a timely manner.
- Frequent use of data and relief food for political expediency and profiteering.
- The inadequate use of EW data and information to develop strategic interventions that leads to ineffective risk management of the environmental hazards in

question. This is probably the biggest challenge when one considers the impacts of droughts to the national economies (Benson and Clay 1998; Benson 2000).

31.2.3 Kenyan case study

The drylands of Kenya which are vulnerable to desertification and the vulgaries of the weather and climate comprise over 80% of her land area (Fig. 31.1). They contain over 30% of the country's population and are very rich in biodiversity. The drylands contribute tremendously to the country's economy through tourism, livestock and agriculture. However it is an area that is affected by low and unpredictable rains and frequent severe drought, floods and famines. Desertification due to destruction of the vegetation cover and loss of soil fertility is an issue under intensive debate currently. This is despite the fact that the country has evolved ecological monitoring systems and FSEWS over the years.

The main participants of the FSEWS over the years in Kenya have included the following:

- *Meteorological Departmen*t: – weather and climatic information. It serves many clients that include agriculture and transport sectors.
- *Ministry of Agriculture (MOA).* Frontline extension staff performance reports, used for planning though not well calibrated for monitoring and EWS.
- *National cereals and produce board (NCPB).* National "granary", stocks and stock movement, business.
- *Central bureau of statistics (CBS).* National statistical office.
- *Department of resource surveys and remote sensing (DRSRS).* Gathers environmental data and information and has capabilities for rapid assessments
- *Districts Administration.* For ground level information and indicators for droughts and famines.
- *Office of the President (OoP).* Ultimate decision maker on response, relief and rehabilitation.
- *UN organizations.* Developmental and humanitarian affairs.
- *Non-governmental organizations (NGOs).* Humanitarian affairs.

The successes and failures of these stakeholders have been linked to legal and institutional frameworks. These have evolved over time taking the experiences and prevailing governance regimes. However Kenya still lacks a comprehensive legal and institutional framework to cater for the environmental hazards and disasters that the country frequently experiences. A draft disaster management bill has been under consideration for several years now. IGAD has concluded a disaster management strategy for the sub-region (IGAD 2004). This could form a framework for Kenya and other member states of IGAD to develop their own. Figures 31.2, 31.3 and 31.4 show the general evolution of Kenyan FSEWS models, before 1980, 1980-2000 and after 2000 respectively. The model was more rudimental before 1980 when the UN and intergovernmental organizations (IOs), NGOs and a number of governmental organizations (GOs) were largely non-participants and only critical

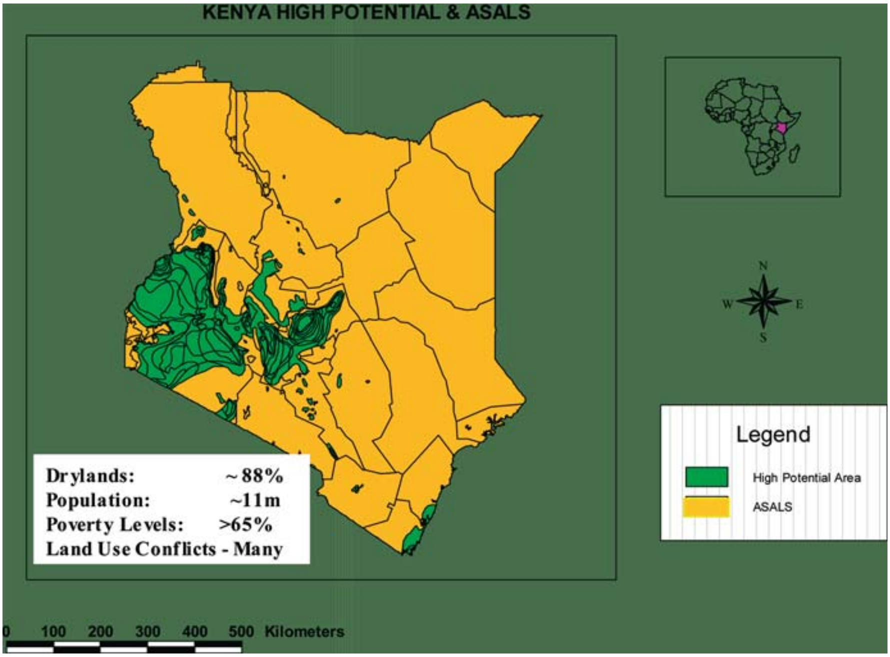


Fig. 31.1. Map showing the extent of the drylands of Kenya (Adopted from OoP 2006)

government institutions dominated the system. Lack of preparedness for drought related disasters and management by crisis often led to

In the next two decades (1980-2000) the UN organs, NGO and other stakeholders increasingly got involved with loose linkages to critical governance structures of the system (dotted lines). Concurrently, various EWS evolved at various levels and organizations. Response capacity was developed in terms of networking and institutional development but coordination was still a problem.

Since 2000, UN organizations and NGOs have been a substantial part of the system. Lessons have been learnt from Arid Lands Resource Management Project (ALRMP) and the Drought Preparedness, Intervention and Recovery Programme (DPIRP) in over ten districts. This has contributed to the development of the current system. The national disaster management center (NDMC) was also small before 2000. It is increasingly becoming strong and central to the system especially in response and rehabilitation. Equally central to the system are the cooperating structures including the all inclusive Kenya food security committee (KFSM), specialized thematic working groups (TWG), District steering committees (DSC) and community development committees (CDC). The system is responsible for the current favorable responses to disasters having built on lessons learnt in the previous management models (Halderman 2000; OoP 2006).

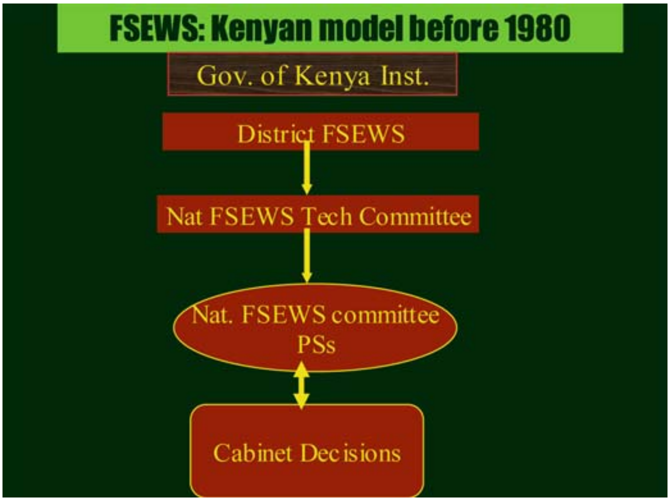


Fig. 31.2. FSEWS: Kenyan model before1980 (Adopted from GoK, 2002)

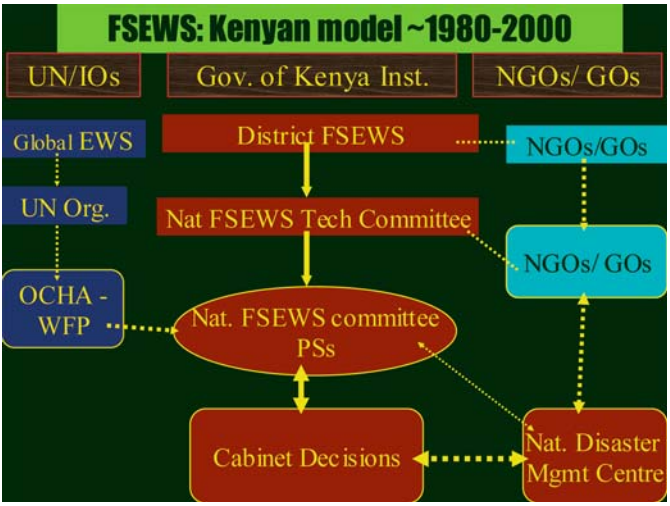


Fig. 31.3. FSEWS: Kenyan model between 1980 and 2000 (Adopted from GoK 2002)

The system is working and improving steadily but it does not have a comprehensive legal and institutional framework. Thus it frequently stumbles on hurdles which are resolved pragmatically as they come.

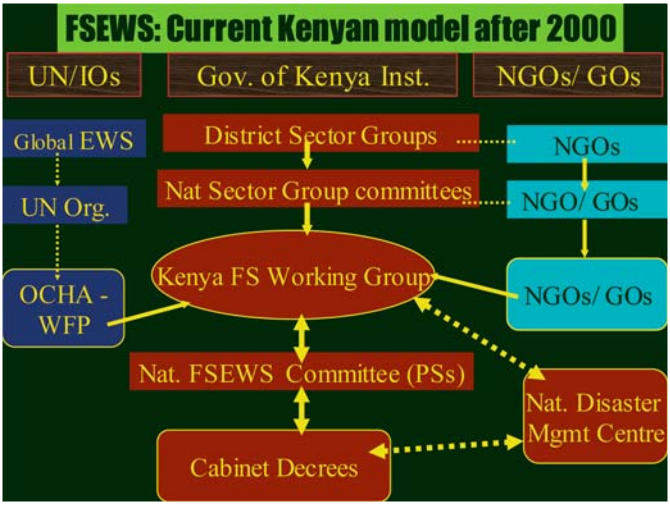


Fig. 31.4. FSEWS: Kenyan model after 2000 (Adopted from GoK, 2002)

31.3 Trends towards building a case for environmental early warning system (EEWS)

With the experiences gained in the many FSEWSs, why has it taken long for other environmental hazards like desertification to have a similar EWS setup? For example an environmental early warning system (EEWS) including one that can be named desertification early warning system (DEWS) would simply be an improvement or adaptation of existing environmental monitoring system. However an EEWS would have additional requirements of being regular, predictive and timely. All data and information required for FSEWS are part and parcel of an EEWS.

31.3.1 Objectives, principles and scope of an EEWS and FSEWS

An EEWS would essentially be an upgraded conventional environmental monitoring system, GEMS, 1980. It would only have the additional requirements of being regular, predictive and timely. An EEWS (eg Desertification EWS) would be a long-term programme of record taking on status and conditions of environmental resources, parameters or indicators for detecting trends and predicting environmental hazards.

The objectives of such EEWS would be to record, analyze, predict and indicate magnitude of deviations from the normal situation in order to help make judgments about possible impacts on environment, property, food and nutrition of the people. This will help all stakeholders to make informed decisions on interventions. On the other hand the objectives of a FSEW are to record, analyze, predict and indicate magnitude of a deviation from the normal situation on a timely basis in order to help make judgments about possible impacts on food and nutrition for the people in case of either deficits or surpluses.

The major principle of EEWS would be that the records must be taken regularly on same resources, parameters or indicators, using same approaches, methods and standards and predictions disseminated on a timely basis.. The same principles apply to FSEWS.

The scope of an EEWS would include a complete arrangement for the flow of data and information from collection to dissemination to end users. Ideally it should also include legal and institutional frameworks for the EW that link up strongly with those for mitigation, prevention, response and rehabilitation as well as general risk management or development interventions. Scope is same for FSEWS and ideally it should also include legal and institutional frameworks for the EW that link up strongly with those for mitigation, prevention, response and rehabilitation.

31.3.2 Parameters, indicators for a desertification early warning system (DEWS)

Were DEWS to be developed by any country or organization, possible parameters and indicators selected for the system could be from any of the following sets:

- *Primary causes:* population pressures; economic performance; changing lifestyles.
- *Processes:* cultivated areas; productivity; stocking rates; timber and fuelwood usage; water resources usage; sedimentation.
- *Manifestations:* rainfall and temperature changes; vegetation cover and composition; soil fertility, gullies & silt loads, sand dunes, dust storms; water levels; losses in biodiversity; fuelwood scarcity etc.
- *Impacts:* Soil desiccation; food security/ famines; prices of food/wood; health – (effect of inadequate nutrition, medicine and water); poverty levels; lose of livelihoods.

The choice must be made carefully in consideration of simplicity, representation, costs, measurability, and consistence. Above all the information derived from the system should enhance the formulation and implementation of NAPs for combating desertification.

31.4 National Action Programmes (NAPs): objectives and challenges

The main objectives of UNCCD/ NAPs are to prevent, reduce, rehabilitate, reclaim, conserve and sustainably manage drylands. As the convention emphasizes, the NAPs should ideally be based on research data and information. However, even after ten years of formulation and implementation of NAPs many challenges persist including limited knowledge base on the desertification phenomenon and resource scarcity (SADC/IGAD 2005). The main challenges identified in the SADC/IGAD (2005) workshop for preparing a report to the Committee for the Review of the Implementation of Convention (CRIC) after about ten years of UNCCD/NAPs implementation included:

- Inadequate institutional and legal frameworks.
- Inadequate awareness, advocacy and knowledge base.
- Inadequate transfer and use of technology.
- Inequity in international markets for drylands products.
- Inadequate resources for addressing the challenges.

The first three are relevant to the subject matter of this paper. The review showed how central these challenges are to combating desertification. Technology should be acquired to gather, analyze and disseminate data and information that enhance knowledge base on desertification for better decision making within a strong legal and institutional framework for national environmental risk management. As demonstrated above, technology and early warning systems are improving rapidly but out of step with legal and institutional developments. This might be the greatest bottleneck.

Despite all these challenges, there are many reasons for continuing to be optimistic although ten years have passed without very significant strides:

- Constitutional reform processes for better governance are being carried in many countries.
- Information and communication technology (ICT) continues to improve rapidly and soon no area will be too remote for observations.
- Willingness to decentralize decision making is evident in many countries.
- Medium-term expenditure framework (MTEF) planning system may provide resources at lower levels for EWS and interventions.
- Capable and active civil society organizations are emerging.

31.5 Conclusions and recommendations

The conclusions of the IDNDR (1999), UNCCD (2000) and the current conference provide the justification for endeavoring to improve on EEWS especially for desertification. These facts are that:

- Disasters are an expensive and growing problem – they should be nipped at the bud.
- Timely and accurate warnings empower people to take actions, reduce losses, respond and recover rapidly.
- Science continues to provide capability for more frequent and accurate warnings.
- Current warning delivery systems have inherent limitations but are improving rapidly.
- Technology can now deliver warnings that are well targeted at people at risk.
- Warnings are primarily issued by Government entities although information may be from other collaborating entities.

- Improvements of current systems depend on all stakeholders and governments working together effectively at all stages of disaster and risk management.
- Weather and climate data should be made available in a timely manner and be synthesized for use in the implementation of NAPs. Hence, it is important to strengthen the capacity of National Meteorological and Hydrological Services (NMHSs) in the acquisition, analysis and dissemination of data.
- A multi-disciplinary team (MDT) of data providers and data users for developing early warning systems for drought and desertification should be established at the national level to determine how information would be analyzed and packaged for the end users. MDTs should take into account local community knowledge to complement scientific expertise.
- Given the current technological advances and the availability of satellite data, greater efforts should be made for the use of these data in the implementation of NAPs.
- NMHSs, in collaboration with agricultural extension services and national coordinating bodies of UNCCD, should provide seminars on weather, climate and land use to farmers to promote implementation of NAPs.

To ensure that there are improvements in the governance of the disaster risk management and that legal and institutional frameworks develop along with technology and knowledge base it is recommended that attention be paid to the following:
- Policy change: There should be a policy shift from the current narrow FSEWS which are short-term famine disaster protection approaches to DEWS which will be part of wider long-term risk management strategies that embrace sustainable development and focused on disaster prevention. Notably, the UNCCD/NAPs aim at sustainable development and NAPs should be part of the national sustainable development frameworks. In order to ensure NAPs are effective then they should be served by DEWS and anchored in a comprehensive legal and institutional framework.
- Comprehensive legal and institutional framework: The DEWS should be seen as a result oriented process. National statistical bureaus serve countries in data and information collection, analysis dissemination and use with the central objective of using it for national economic planning and growth. The bureaus are anchored in acts of parliament. In the same breath, the gathering, analysis, dissemination and utilization of data and information of environmental (desertification) early warning systems should be crafted into a legal and institutional framework where they do not exist. This will be with a view to consolidating and strengthening policy and decision making on environmental risk management and sustainable development. This will be one alternative to ensuring effective implementation of NAPs.

- Roles and responsibilities of stakeholders: The present multitude of players and stakeholders will have specific legal roles and responsibilities to play in the comprehensive framework. This will improve coordination, standards and commitments by stakeholders to the one course of environmental protection and sustainable development. Some of the legal areas that can be targeted are those of national statistical services, disaster management laws, and environmental management laws.

References

Benson C (2000) The cost of Disasters Is Development at Risk? Natural Disasters and the third world, The UK National Coordination Committee for the IDNDR

Benson C, Clay E (1998) The Impact of Drought on Sub-Saharan African Economies: A preliminary Examination. World Bank

Clarke R (ed.) (1986) The handbook of Ecological Monitoring. A GEMS/UNEP Publication, UNEP, Nairobi

GEMS (1980) Selected works on ecological monitoring of arid areas. The Global Environment Monitoring System (GEMS) of the United Nations Environment Programme (UNEP), Nairobi

GoK (2002) National Action Programme : A framework for Combating Desertification in Kenya, in the context of UNCCD. Ministry of Environment and Natural Resources, Nairobi, Kenya.

Halderman M (2000) Drought preparedness intervention and recovery programme: Stakeholder review and analysis of issues. Acacia consultants Ltd and Royal Netherlands Embassy, Nairobi

IDNDR (1999) International Strategy for Disaster Reduction (ISDR) for a safer World in the 21st Century – International Decade for Natural Disaster Reduction 1990-1999, IDNDR, Geneva, Switzerland.

IGAD (2004) IGAD Sub-regional Disaster Preparedness Strategy. Intergovernmental Authority on Drought, Djibouti

OoP (2006) Arid Lands Resource Management Project: People-Driven Development. Office of the President, Kenya , Nairobi.

RSA (2000) Republic of South Africa (RSA) Green Paper on Disaster Management.

SADC/IGAD (2005) Report on the workshop of Eastern and Southern African countries on Lessons Learnt and Good Practices in the Context of National Reports on the Implementation of the United Nations Convention to Combat Desertification, held in Addis Ababa, Ethiopia.

Sinange RK (1999) Early Warning Systems in the Context of the Asia-African Cooperation to Combat Desertification. Paper presented at the UNCCD Regional meeting for Asia 22-27 July 1999, Beijing China.

SSO/UNSO (1991) Survey of Observation Structures. Sahara and Sahel observatory (SSO) and United Nations Sudano-Sahel Office (UNSO), New York, USA.

UNCCD (2000) Early Warning System. Report on ad hoc Panel. ICCD/Cop (4), CST4, United Nations Convention to Combat Desertification (UNCCD), Bonn, Germany.

Role of Drought Monitoring and Management in NAP Implementation

Hossein Badripour

Abstract. Land degradation is of great importance for sustainable livelihoods, hence the international community decided to develop a Convention that binds the countries to take measures to control land degradation process. Since, drought is a climatic feature that exacerbates land degradation, "mitigation of drought impact" was added to UNCCD.

Drought is a very common phenomenon all around the world especially in those countries located in the arid and semi arid areas. Like other countries in the arid zone, the Islamic Republic of Iran suffers from drought. Researches revealed that every 2.5 years, the country experiences drought with different severities. Apart from the impacts that drought imposes on natural resources and environment, huge economic losses impact the people i.e. the amount of losses caused by drought in just rainfed crops amounted to 6% of the GDP in 2000. Drought is also one of the causes of poverty and poverty causes land degradation. Thus, in NAP formulation, drought is one of the main subjects addressed.

In order to control the impacts of drought on land degradation, an integrated management model is needed. Since drought is a multi-faced phenomenon, the model should be quite comprehensive and cover hydrological, agricultural and socio-economic aspects.

In order to develop the strategies to manage drought, one should be aware of drought occurrence. In this regard, lots of indices such as PDSI and SPI have been developed and many countries are using such indices appropriate to their own circumstances to measure the drought severity and the area affected. As different sectors of the community and environment suffer from drought and since impacts are not always similar, each sector may also need its own indices to monitor drought impacts precisely.

Unfortunately, since drought is a slow and creeping disaster and since no clear and definite strategies to cope with drought have been developed, countries suffer a lot. Often, the approach is to go towards a fairly good crisis management system which is usually late and costly.

Some models to manage drought have been developed such as 3 phase management model (before, during and after drought), 10-step drought management model and recently a more comprehensive one has been developed for the disaster management. The latter consider both crisis management and risk management while the former models lack some components of this model.

Once, the model for each sector suffering from drought has been formulated, all stakeholders including managers and farmers can follow the strategies of the model leading to mitigate drought impacts and control land degradation.

32.1
Natural disasters in Asia

Most of the Asian countries are affected by many disasters including earthquakes, floods, droughts, volcanos, etc. According to the location, the kind and severity of disasters differ e.g., it is said that Iran is affected by 31 of the natural disasters. While earthquakes and floods are the most serious natural disasters affecting some countries like Iran, from the point of view of the number of fatalities, drought is the most serious one as shown in Figures 32.1 and 32.2.

Every disaster has its own losses. For example, the earthquake which occurred in Bam city resulted in more than 30,000 fatalities and collapse of all the buildings. In addition to the human fatalities and economic losses it inflicted, an ancient complex which is an UNESCO registered site, dating back to 2,500 years ago was totally destroyed. Since Iran is located in the arid zone, the country receives 246 mm of rainfall annually, which is less than a third of the world figure. The annual rainfall is not only low, but is erratic and fluctuates widely as shown in figure 32.3. main Mountain chains located in the north and west that create a "V" shape barrier, no wet cloud enters central Iran. While some parts of the country at the Caspian sea receive more than 1000 mm, there are some places with very little amount of rainfall (around 50 mm and less). Research data show that the country suffers from drought every 2.5 years with different severities as shown in Figure 32.4.

Drought also has its own losses. A report published by United Nations on 2001 drought situation in Iran showed that 90% of the country's population were af-

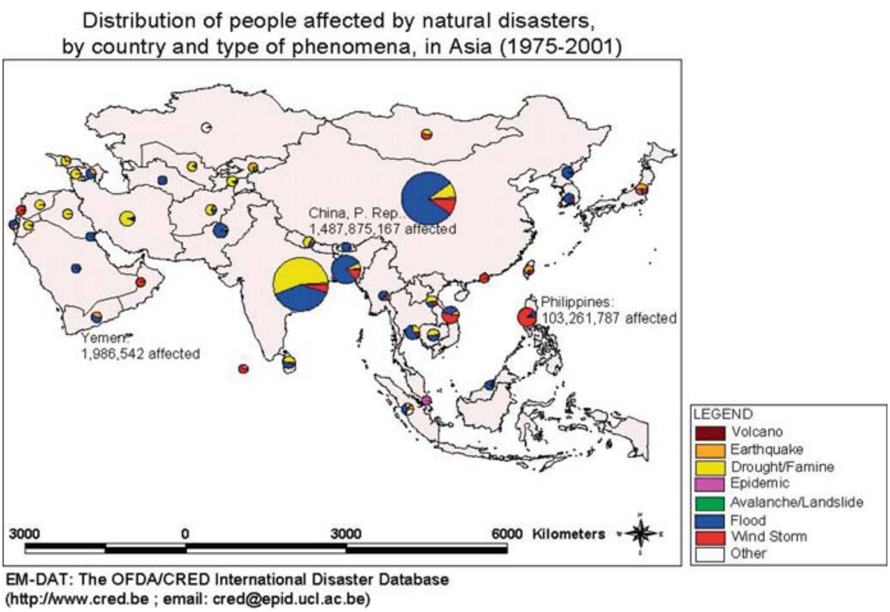


Fig. 32.1. Distribution of people affected by natural disasters by country and type of phenomena in Asia (1975-2001)

fected to varying degrees and most populations in the 12 most severely affected provinces were relying on water tankers to transport drinking water to meet their needs. More than 2.6 million ha of irrigated farms, 4 million ha of rainfed agriculture and 1.1 million ha of orchards were affected. In the livestock sector, 75 million heads of animals were affected, inflicting an estimated loss of US $ 900 mil-

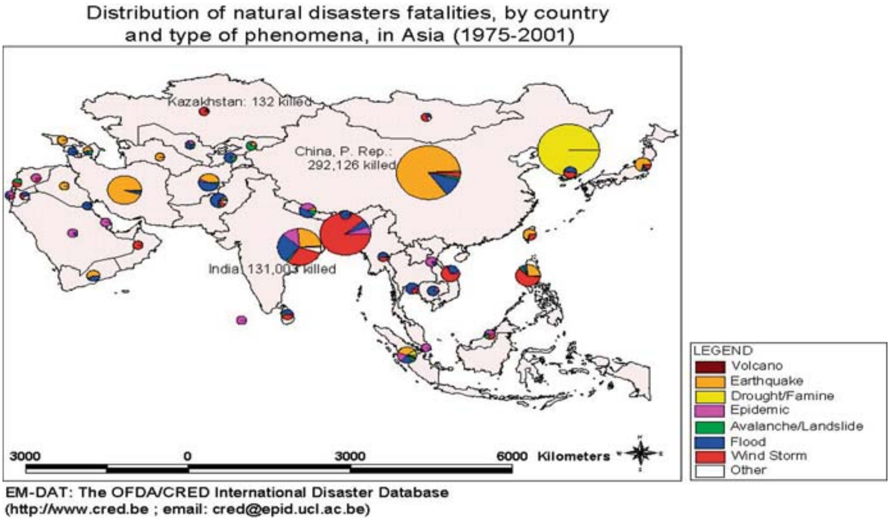


Fig. 32.2. Distribution of natural disasters fatalities by country and type of phenomena in Asia. (1975-2001)

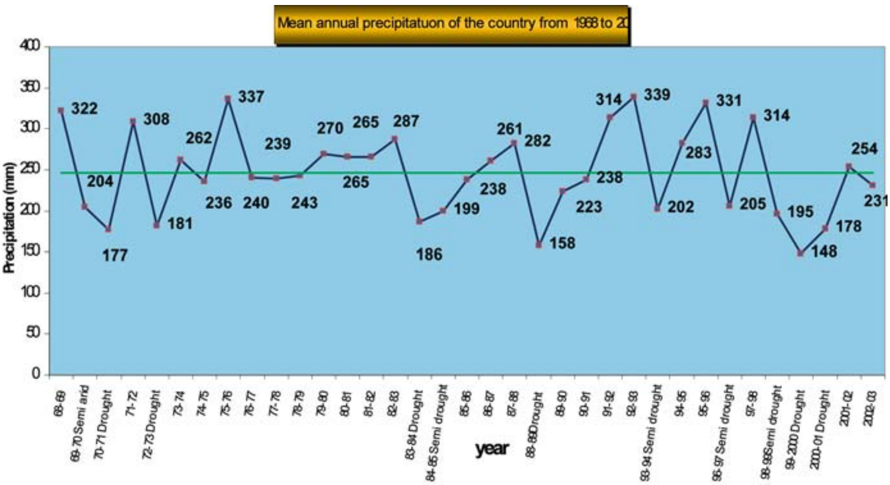


Fig. 32.3. Mean annual rainfall in I.R. of Iran (Islamic Republic of Iran Meteorological Organization, Rainfall statistics, www.irimet.net)

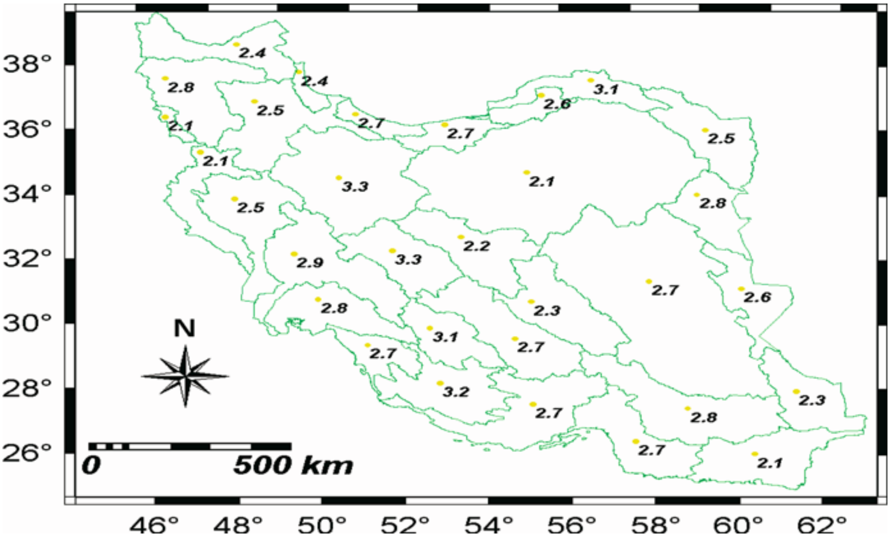


Fig. 32.4. Drought occurrence frequency in Iran (regardless to drought severity) (Islamic Republic of Iran Meteorological Organization, Drought issue, www.irimet.net/irimo/drou.html)

lion to some 200,000 livestock herders. The total loss due to drought equalled to 6% of GNP. The Parliament allocated US$ 500 million to mitigate the effects of the drought. The Cabinet declared June to December 2001, as the "Water Crisis Period" and issued decrees to conserve water.

32.2 Desertification and drought

According to UNCCD, desertification is defined as "land degradation in the arid, semi-arid and sub- humid areas resulting from various factors, including climatic variations and human activities". Asia contains the largest amount of land affected by desertification of any continent in the world, just under 1,400 million ha. Some 71% of its drylands i.e. one-third of its entire area is moderately to severely degraded. Based on the Iran's National Action Programme to Combat Desertification and Mitigate Drought Effects (NAP), land degradation rate is accelerating during the past decades as shown in Table 32.1.

Table 32.1. Land degradation ('000 ha) during the past decades in Iran

1951	1961	1971	1981	1991
9	15	81	149	1,007

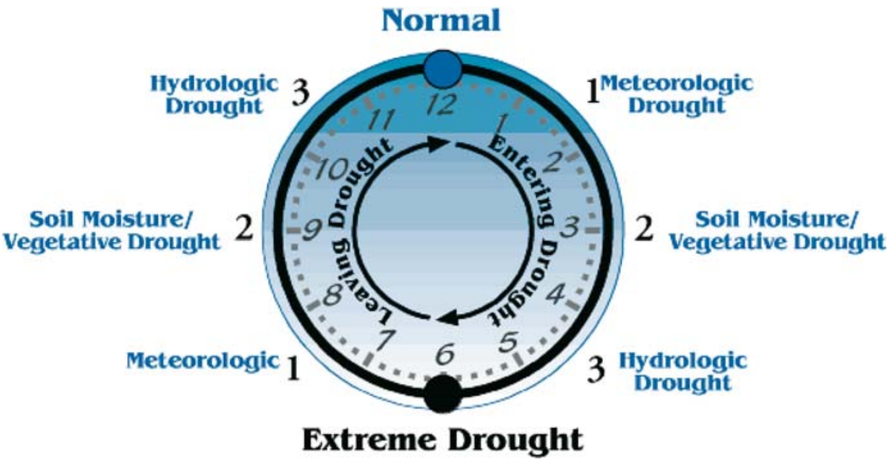


Fig. 32.5. Drought cycle

Like any other country in the region most of the land degradation is due to overgrazing, overuse of land, poor irrigation methods, climate variations and deforestation. Land degradation reduces the capacity of soil to absorb water, resulting in reduced replenishment of ground water and increased possibility of flood.

As shown in Table 32.1, land degradation rate has been increasing during the past 2 decades at a high rate. It should be noted that during the same period of time, the country suffered from drought more than any other time.

32.3 Drought concepts

Drought is a natural hazard that results from a deficiency of precipitation from expected or "normal" which, when extended over a season or longer period of time, is insufficient to meet the demands of human activities and the environment. Drought must be considered a relative, rather than absolute, condition and it occurs in virtually all climate regimes.

Drought differs from other natural hazards in various ways. Drought is a slow-onset natural hazard that is often referred to as a creeping phenomenon. It is a cumulative departure from normal or expected precipitation, that is, a long-term mean or average. This cumulative precipitation deficit may build up quickly over a period of time, or it may take months before the deficiency begins to appear in reduced stream flows, reservoir levels or increased depth to the underground water table. Owing to the creeping nature of drought, its effects often take weeks or months to appear. Precipitation deficits generally appear initially as a deficiency in soil; therefore agriculture is often the first sector to be affected as shown in figure 32.5.

It is often difficult to know when a drought begins. Likewise, it is also difficult to determine when a drought is over and according to what criteria this determination should be made. Is an end to drought heralded by a return to normal precipitation and, if so, over what period of time does normal precipitation need to be sustained for the drought to be declared officially over? Since drought represents a cumulative precipitation deficit over an extended period of time, does the precipitation deficit need to be erased for the event to end? Do reservoirs and groundwater levels need to return to normal or average conditions? Impacts linger for a considerable period of time following the return to normal precipitation. Therefore, is the end of drought signalled by meteorological or climatological factors, or by the diminishing negative impact on human activities and the environment?

Another factor that distinguishes drought from other natural hazards is the absence of a precise and universally accepted definition. There are hundreds of definitions, adding to the confusion about the existence of drought and its degree of severity. Definitions of drought should be region and application specific or impact specific. Droughts are regional in extent and each region has specific climatic characteristics. Droughts that occur in the North American Great Plains will differ from those in Northeast Brazil, southern Africa, Western Europe, eastern Australia or the North China Plain. The amount, seasonality and form of precipitation differ widely between each of these locations.

Temperature, wind and relative humidity are also important factors to include in characterizing drought from one location to another. Definitions also need to be application specific because drought impacts will vary between sectors. Drought conjures different meanings for water managers, agricultural producers, hydrologic power plant operators and wildlife biologists. Even within sectors, there are many different perspectives of drought because impacts may differ markedly. For example, the effects of drought on crop yield may vary considerably for maize, wheat, soybeans and sorghum because they are planted at different times during the growing season and do not have the same water requirements and sensitivities to water and temperature stress at various growth stages. Irrigated and rain-fed farming do not react the same to the water deficiency. So even in one region, different concepts may exist to realize drought conditions.

Drought impacts are non-structural and extend over a larger geographical area than damages that result from other natural hazards such as floods, tropical storms and earthquakes. This, combined with drought's creeping nature, makes it particularly challenging to quantify impacts and even more challenging to provide disaster relief for drought than for other hazards. These characteristics have hindered the development of accurate, reliable and timely estimates of the severity and impacts, such as drought early warning systems and ultimately, the formulation of drought preparedness plans.

32.4 Drought aspects

Drought is a multi-faceted phenomenon which is an inevitable part of normal climate fluctuation and should be considered as a recurring environmental feature. Since drought affects wide range of aspects of daily life, so different scientists from different disciplines have developed definitions in order to facilitate the realization of the onset and the severity of drought.

Some of the aspects of drought are as: Meteorological, Hydrological, Agricultural and Socio-economic (Wilhite and Glantz 1985).

- *Meteorological drought* is usually defined by a precipitation deficiency threshold over a predetermined period of time. The threshold chosen, such as 75% of normal precipitation, and duration period, for example 6 months, will vary by location according to user needs or applications. Meteorological drought is a natural event and results from multiple causes, which differ from region to region.

- *Hydrological drought* is even further removed from the precipitation deficiency since it is normally defined by the departure of surface and subsurface water supplies from some average condition at various points in time. Like agricultural drought, there is no direct relationship between precipitation amounts and the status of surface and subsurface water supplies in lakes, reservoirs, aquifers and streams because these hydrological system components are used for multiple and competing purposes, such as irrigation, recreation, tourism, flood control, transportation, hydroelectric power production, domestic water supply, protection of endangered species and environmental and ecosystem management and preservation. There is also a considerable time lag between departures of precipitation and the point at which these deficiencies become evident in surface and subsurface components of the hydrological system. Recovery of these components is slow because of long recharge periods for surface and subsurface water supplies. In some drought-prone areas such as the western United States, snow pack accumulated during the winter months is the primary source of water during the summer. Reservoirs increase the resilience of this region to drought because of their ability to store large amounts of water as buffer during single-or multi-year drought events.

Socio-economic drought differs markedly from the other types of drought because it reflects the relationship between the supply and demand for some commodity or economic good, such as water, livestock forage or hydroelectric power that is dependant on precipitation. Supply varies annually as a function of precipitation or water availability. Demand also fluctuates and is often associated with a positive trend as a result of increasing population, development or other factors.

The interrelationship between these types of drought is illustrated in Figure 32.6. Agricultural, hydrological and socio-economic drought occurs less frequently than meteorological drought because impacts in these sectors are related to the availability of surface and subsurface water supplies. It usually takes several weeks before precipitation deficiencies begin to produce soil moisture deficiencies leading to stress on crops, pastures and rangeland. Continued dry conditions for several months at a time bring about a decline in stream flow and reduced reservoir and lake levels and potentially, a lowering of the groundwater table. When drought conditions persist for a period of time, agricultural, hydrological and socio-economic drought occurs, producing associated impacts. During drought, not only are inflows to recharge surface and subsurface supplies reduced but demand for these resources increases dramatically as well.

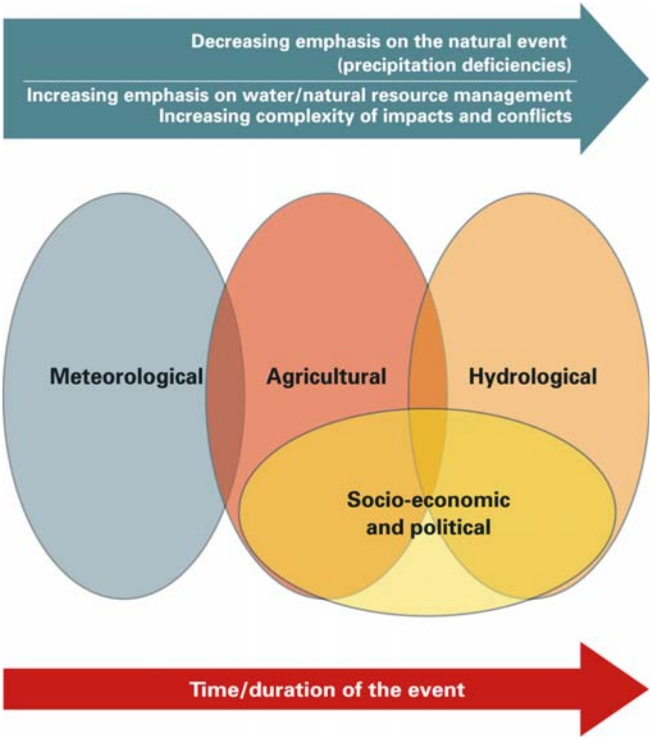


Fig. 32.6. Inerrelationships between meteorological, agricultural, hydrological and socio-economic drought. (Source: National Drought Mitigation Center, University of Nebraska – Lincoln, USA)

32.5 Drought indices

In order to measure any feature and phenomenon, some definite, accurate and sharp indices should have been developed. Drought as a recurring phenomenon needs to be measured and is no exception.

Indices used to track and define drought have been around for nearly a century now. Some of the common drought indices used are: Palmer Drought Severity Index (PDSI), Crop Moisture Index (CMI), Standardized Precipitation Index (SPI), Percent of Normal Rainfall, Daily Stream Flow, Snow pack, Soil Moisture, Daily Soil Moisture Anomaly, Rainfall Deciles approach, Stream Flow Forecast. Some of these indices are presented in Table 32.2.

No one definition covers all possible forms of drought and no single index can possibly capture all the various definitions. Indeed, a long way has been passed for using an index or indicator to evaluate drought. Figure 32.7 shows the process of drought indices development.

PDSI (Palmer 1965) is one of the drought indices that is commonly used worldwide. In this index a water balance approach has been modelled and it is unique, so many countries use it to detect drought conditions. In fact, this index proved to be a turning point in the evaluation of drought indices in the United States (Heim Jr.

Table 32.2. Brief overview of some of the drought indices

Name	Basis	Positive attributes	Negative attributes
Stansardized Preciption Index (SPI)	Long term prescipation records fitted to a probability	Can be used over different time scales, early warning of drought with a number for severity, less complex than other indices	Values can c hange from preliminary data to updated data
Palmer Drought Severity Index (PDSI)	Precipitation, temperature, and soil moisture	Earlies drought index in U.S.	Can lag behind actual droughts, not appropriate for mountainous or extreme climate areas, time-scale can be misleading
Surface Water Supply Index (SWSI)	Snowpack, precipitation, reservoir storage, and streamflow	Can describe state of water supply specific to particular regional conditions	Changing elements requires new algorithms, comparing between basins difficult because so regionspecific
Reclamation Drought Index (RDI)	Precipitation, snowpack, streamflow, and reservoir levels	Added benefit of including evaporation through the temerature component	Compring between basins difficult because basins specific

2002). It has become the gospel of drought indices becoming ingrained in the mind sets of researchers and is used in decision making and policy formulation.

Many examples can be given to contradict the drought indices application. Following are some examples:

- The outcome of the drought indices does not suggest a same outcome. As an example, two drought maps for the year 1997-98 (Figure 32.8) based on SPI (left map) and Deciles approach (right map) show that according to the Deciles approach most of the country is affected by a severe drought while at the same time no part of the country suffers from drought based on SPI.
- Rangeland is one of the sub-sectors of agriculture covering around half the world land area that is highly affected by drought and information on the onset, end and severity of drought is quite important to the ranchers who are the main stakeholders. The American Society for Range Management (SRM) glossary (Kothmann 1974) uses a meteorology-based definition of "prolonged dry weather, generally when precipitation is less than 3 quarters of the average amount". The given definition by SRM can not be a definitely accurate and applicable one for determination of drought in rangeland while Holecheck et al. (1999) based on a research on forage yield in Chihuhuan desert rangelands in New Mexico suggested that range forage is correlated to rainfall in the growing period (July-September) than total annual rainfall (Table 32.3).

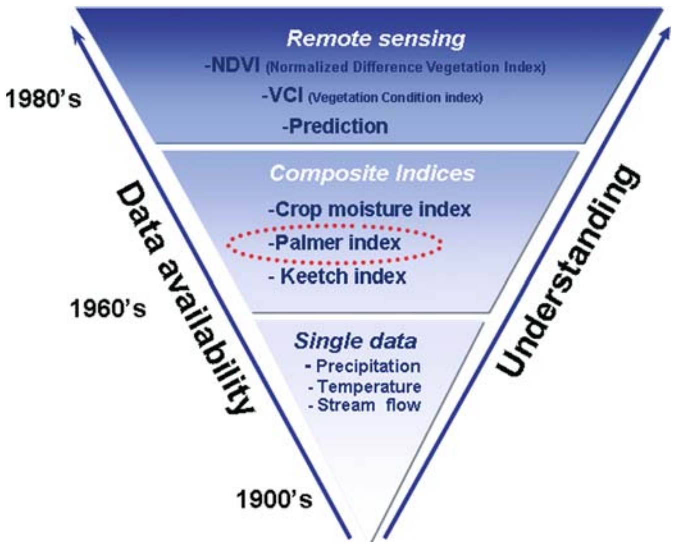


Fig. 32.7. Drought indices development process

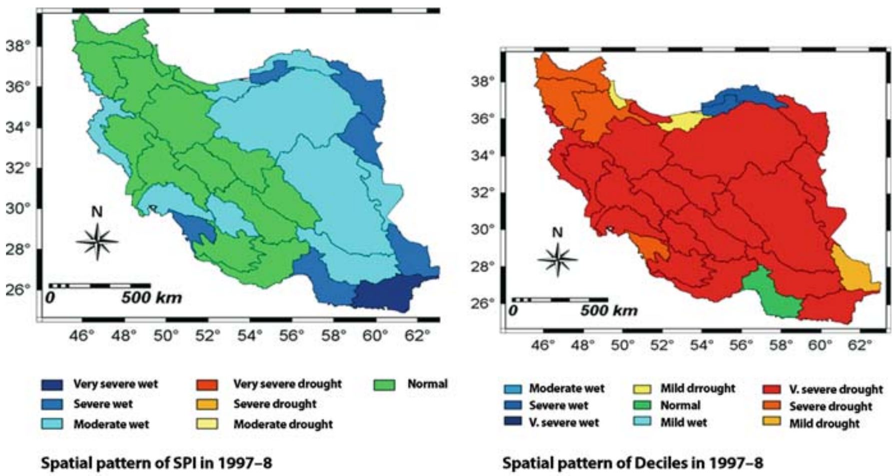


Fig. 32.8. Comparison of drought maps based on SPI and Rainfall Deciles approach for 1997-98

32.6 Drought, Poverty and desertification

Needless to say, drought is a major disaster affecting the people, especially in the rural areas, who maintain their livelihood from farms and natural resources. Since the people in the rural areas are quite dependant on the sources available to them

Table 32.3. Relationship between forage yield and time of rainfall

Year	Total Rainfall (inches)	Rainfall during the growing period (July-Sept) (inches)	Forage yield (lb $acre^{-1}$)
79	9.8	5.5	230
80	9	3.8	98
81	10.4	6.2	230
82	9.8	5	76
83	8.7	3.2	50
84	13.6	5	128
85	13.2	7	218
86	17	7.9	483
87	9.4	6.2	184
88	11.8	7	310
89	7.6	4	189
90	10.7	7.5	270
91	15.1	7.2	488
92	15.4	4.9	750
93	9.9	5.3	20/3
94	7	2	6
95	6.7	4	59
96	7.9	5	145
97	11.6	5.5	284
98	8.2	3.8	173
Average	10.6	5.3	229

which are prone to drought leading to low products and eventually lower income so they are extremely vulnerable to drought.

Poverty is both a cause and a consequence of desertification. Indeed this vicious circle affects not only people but also the economies of affected countries. The first victims of desertification are the prime sources of fertile soil, vegetation cover and agricultural crops. Over time, the productive capacity of land diminishes, and population that depend on them become predisposed to poverty. Figures 32.9 and 32.10 indicate the relationship between drought, poverty and land degradation.

32.7 Drought monitoring

Many new tools are now available to us to detect drought progress. The marvels of modern technology (now taken for granted) – satellite, GIS, the Internet (information sharing), access to near real-time data and super computing capabilities—have changed the way we track and define drought. On both the spatial and temporal level the game has changed as managing water resources becomes even more critical into the next century. The goal of these new tools is to better monitor and predict a drought's onset, intensity, duration and spatial extent along with its impacts. Our tool box has never been better equipped but there is still much to do and improve upon. Many data and products are now available weekly or daily, rather than using grid-based format. In addition, more and more site-specific information (compared to a climate division or coarser scale product) is coming on the every month, leading to the generation of a suite of near real- time products updated daily. Given the unique challenges of detecting the onset of drought coupled with the complex nature of its impacts, improved tools are needed to predict and assess drought a finer spatial and temporal resolution.

To monitor drought and provide early warning requires a comprehensive and integrated approach. The collection of climatic, hydrological data is fragmented between many agencies or ministries in most countries but the analysis of climate and water data is most effective when it is coordinated under a single authority. This authority can be a single agency of ministry or an interagency authority that is responsible for analyzing data and producing useful end products or decision- support tools for delivery to users. Stakeholders must be involved from the early stages of product development to ensure the information will serve their diverse needs in terms of timing and content. A delivery combination of internet, extension, and print and electronic media delivery may be required.

Monitoring and early warning systems to date have typically been based on a single indicator or climatic index. Recent efforts to improve drought monitoring and early warning have provided new early warning and decision-support tools and methodologies in support of drought preparedness planning and policy development. The lessons learned can be helpful models for future countries. An effective monitoring, early warning and delivery system continuously tracks key drought and water supply indicators and climate-based indices, and delivers this information to decision makers. This allows for the early detection of drought conditions and timely triggering of mitigation and emergency response measures, the key ingredients of a drought preparedness plan.

An integrated drought monitoring systems can be divided into five essential components (Svoboda et al. 2002):

- Determination of applicable climate indicators and resultant trigger levels;
- Identification of data requirements and data network sources.
- Acquisition and analysis of reliable data.

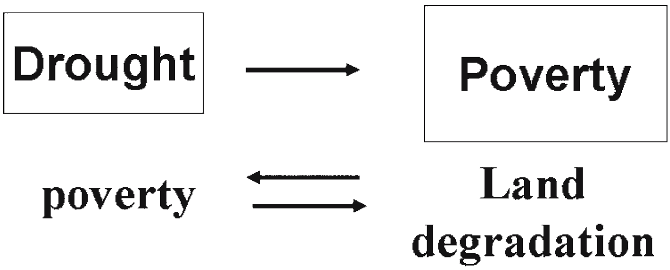


Fig. 32.9. Relationship between drought, poverty and land degradation

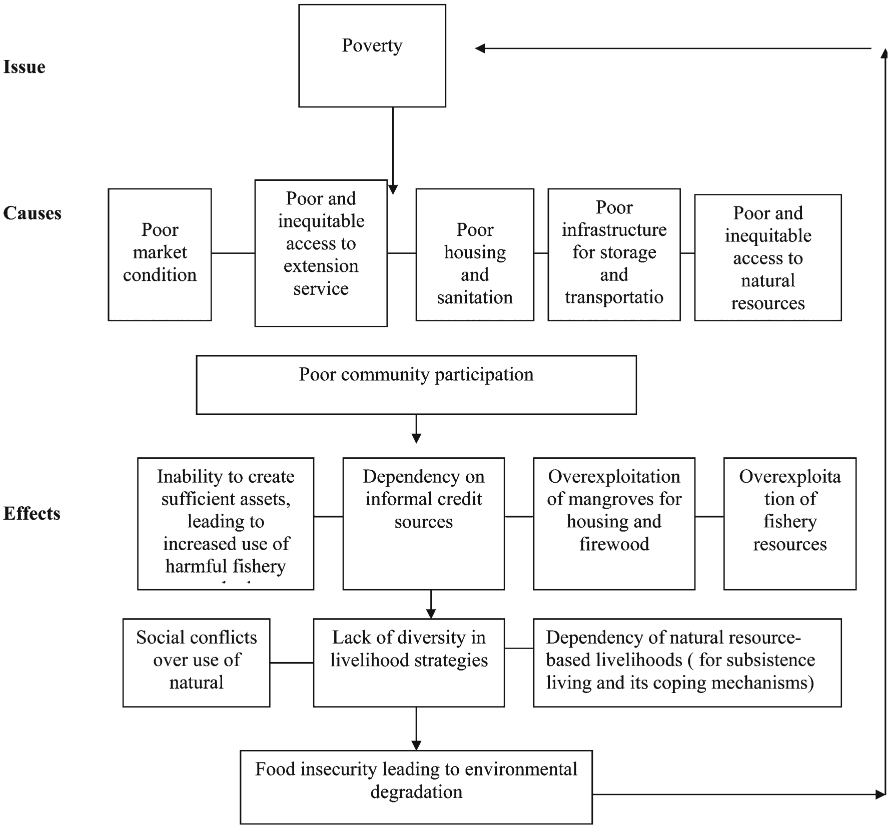


Fig. 32.10. Cause and effect of poverty and land degradation

- Synthesis of the data and generation of practical, useful products (application).
- Information dissemination.

As pointed out here, in order to have a good and workable drought monitoring system, applicable climate indicators and resultant trigger levels, should have been developed otherwise the value of the system would be depreciated.

In the monitoring process, the stakeholders should be involved during the formulation of the drought indices and data collection. Regarding monitoring of the drought impacts on rangelands, a model (Figure 32.11) has been developed as follows. Along with the meteorological indices (rainfall, soil moisture), some indicators including range cover, range condition, range yield and livestock condition should be measured. Some of this information is provided by the ranchers, some by meteorological district offices and some by the department of water supply district offices. NGOs could also help the monitoring unit and act as a key player to collect the data.

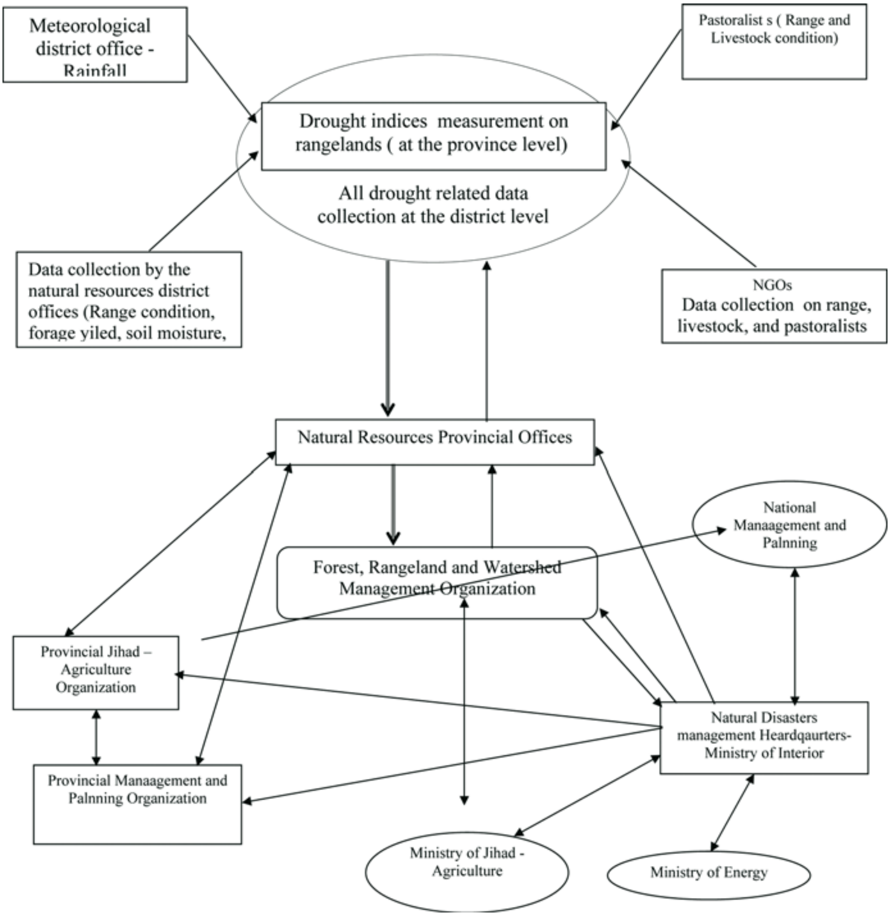


Fig. 32.11. Drought monitoring in rangelands

32.8 Drought management

Drought management is something new and it goes back to 1960s that attracted the attention of governments and scientists. Although many initiatives have been undertaken and some countries have developed their drought national strategy, some gaps still exist. The early works suggested division of droughts into 3 phases i.e. before, during and after drought occurrence.
- Preparedness (before drought outbreaks);
- Crisis management (during drought);
- Relief assistance (after drought).

Although they had identified correctly the three phases and devised the measures to be undertaken at each phase, since drought management knowledge was lacking, the final efforts were mainly focused on relief assistance and little with preparedness. Even now, after four decades of work on drought management, many countries only made limited efforts in this regard and they provide the people with relief assistance. Most African countries are among them and they spend local funds along with international aids to help people against famine. Since the budget is very tight in the LDCs and developing countries so the budget which should have been spent for the development and research is mostly spent for drought relief.

In early 1990s, the National Drought Mitigation Centre at the University of Nebraska developed a model for drought management. The model consisted of 10 components in a 10-step process which was mainly focused on hydrological drought management. This methodology has been used by many states in the United States and also by several foreign governments. The purpose of the planning process is to derive a plan that is dynamic, reflecting the changing government policies, technologies, and natural resource management practices. The 10-steps in this process are:
- *Appoint* a drought task force;
- *State* the purpose and objectives of the preparedness plan.
- *Seek* stakeholder participation and resolve conflicts.
- *Inventory* resources and *identify* groups at risk.
- *Develop* organizational structure and *prepare* the drought plan.
- *Identify* research needs and fill institutional gaps.
- *Integrate* science and policy.
- *Publicize* the drought plan, *build* public awareness.
- *Teach* people about drought.
- *Evaluate and revise* drought preparedness plan.

The above process is intended to serve as a checklist to identify issues that should be addressed in plan development, with appropriate modifications.

Although the model was a good achievement but still it did not answer our needs.

Wilhite (1996) developed a more complicate one (Figure 32.12) which deals with different stages of drought management namely: risk management and disaster management which they comprise some components. The drought management

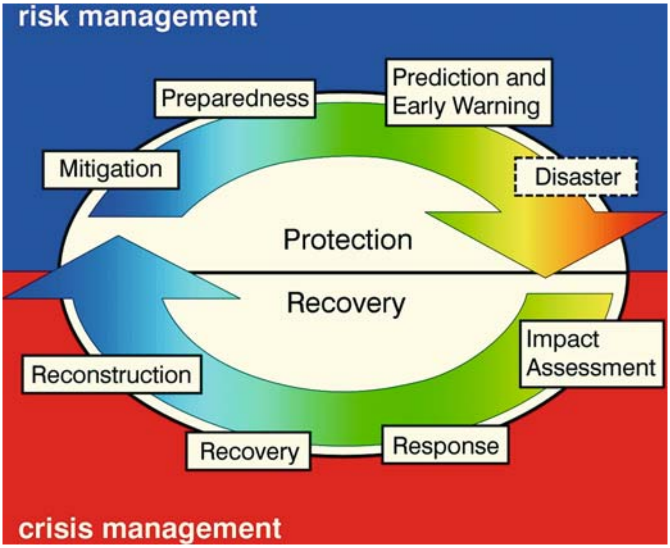


Fig. 32.12. The Cycle of Disaster Management (Source: Dr Donald Wilhite, NDMC, University of Nebraska – Lin-coln)

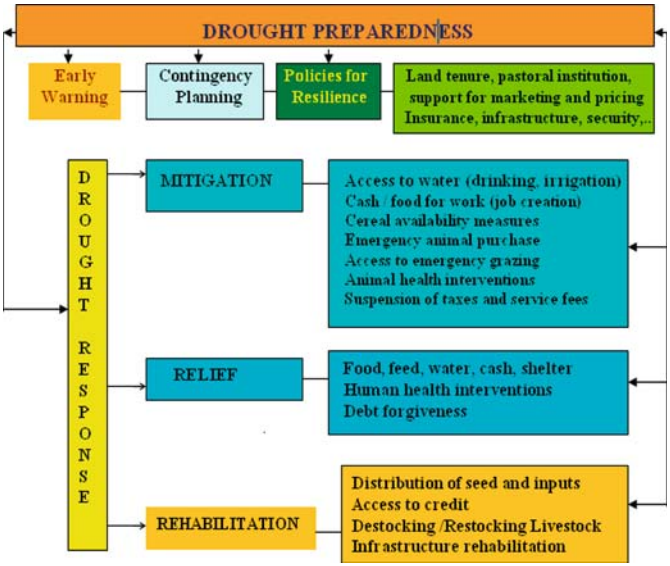
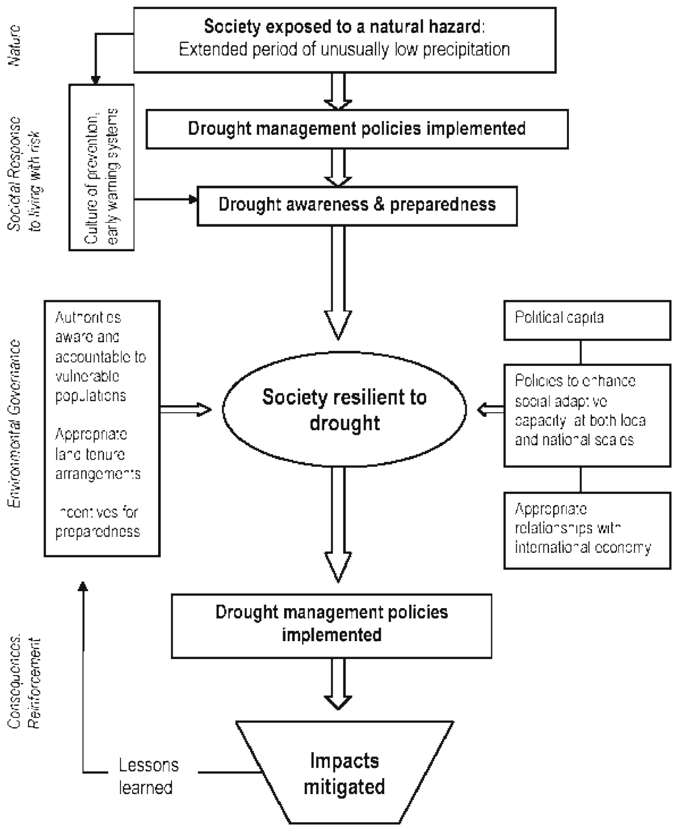


Fig. 32.13. Drought preparedness

task force or the members of the committee for NAP formulation should identify the drought affected sectors and sub-sectors and develop measures and policies that should be taken by all stakeholders including farmers and government.

Fig. 32.14. A resilient society to drought



The main achievement of the disaster management cycle is the movement towards drought preparedness as shown in Figure 32.13.

When drought management cycle is complete the vulnerability of the community would be less thus the loss and damages are going to be low (Fig. 32.14).

References

Ameziane,.T. 2002, Drought Preparedness and Risk Management in the

Mediterranean Region, Mediterranean Regional Roundtable, Athens, Greece, December 10-11, 2002, 18 pp

Amezaine, Tayeb, 2006, National strategy and action plan on drought preparedness, management and mitigation in the Agricultural sector, National Workshop, Karaj 31 Jan - 1 Feb

Badripour, H. 2006, Identification of strategies and basics of drought management in rangeland ecosystems before, during and after drought occurrence, 225 pp, Farsi language

Badripour, H.,2004, Iran's country pasture/ forage resources, FAO website, http://www.fao.org/ag/agP/AGPC/doc/Counprof/Iran/Iran.htm

Center for Research on the Epidemiology of Disasters, http://www.em-dat.net/

Forest, Rangeland and Watershed management Organization, 2004, Iran's National Action Programme to Combat Desertification and Mitigation of Drought Impacts of I.R.Iran, 2002, Draft version, UNCCD

Heim RR Jr. (2002) A Review of Twentieth Century Drought Index used in the United States. B Am Meteorol Soc 83:1149-1165

Holecheck JL, Rex DP, Herbel CH (2003) Range Management: Principles and practices. Prentice Hall College, Fifth Edition.

International Strategy for Disaster Reduction, 2004, Living with Risk, A global review of disaster reduction initiative, 387 pp, http://www.unisdr.org/eng/about_isdr/bd-lwr-2004-eng.htm

Islamic Republic of Iran Meteorological Organization, Rainfall statistics, MACROBUTTON HtmlResAnchor www.irimet.net

Islamic Republic of Iran Meteorological Organization, Drought issue, MACROBUTTON HtmlResAnchor www.irimet.net/irimo/drou.html

Kothmann MM (1974) A glossary of terms used in range management. Soc. Range Management, Denver, Colorado

Palmer WC (1965) Meteorological drought. Research paper no 45. U.S. Weather Bureau, Washington DC, USA

OFDA/CRED International Disaster Database, http://www.cred.be

Sabetraftar, A. 2006, Study and analysis of drought impacts on the national water resources quantity and quality and related practices plans, National strategy and action plan on drought preparedness, management and mitigation in the Agricultural sector, 31 Jan - 1 Feb 2006, Karaj, I.R.Iran

SIDA, 2004, Environmental Degradation and Disaster Risk, 43 pp, http://www.unisdr.org/eng/risk-reduction/sustainable-development/Environmental-Degradation-and-Disaster-Risk.pdf

Sivakumar, M.V.K, 2004, Operational agrometeorological services, International perspectives, requirements for agrometeorological services- Proceedings of the inter-regioanl workshop, March 22-26,2004, Manila, Philipines

Sivakumar.M.V.K. and D.A.Wilhite, Drought preparedness and drought management, National Drought Mitigation Center, University of Nebraska, 16 pp

Steele, P., Gonazalo Oviedo and David McCauley, 2006, IUCN-ADB, Poverty, Health and ecosystems: 321 pp, www.adb.org/Documents/Books/Poverty-Health-Ecosystems/adb-iucn-phe.pdf

Svoboda MD, Hayes MJ, Wilhite DA, Tadesse T (2002) Recent advances in drought monitoring, National Drought Mitigation Center, University of Nebraska, 5 pp

Thurow. T.L. and A.Charles and JR.Taylor. 1999.View point: The role of drought in range management. J.Range Management, 52: 413-419 September 1999.

United Nations Inter-agency Assesment Report on the Extreme Drought in the Islamic Republic of Iran, 2001, Tehran, I.R.Iran

United States Drought Monitor website, http://drought.unl.edu/dm/

Vigers.K.2003 , Drought management in Mexico's Rio Bravo Basin, Master's thesis, University of Washington,

Wilhite, D.A. 1991, Drought planning: A process for state government, water Resources Bulletin, Volume 27, No 1, pp 29-38

Wilhite DA (1996) A methodology for drought preparedness. Nat Hazards 13:229-252

Wilhite DA, Glantz MH (1985) Understanding the drought phenomenon, The role of definitions. Water Int 10:11-20

Wilhite, D.A.2000, Drought: A global Assessment (2 volumes). Routledge publishers, London U.K. 700 pp

Climate and National Action Programs in Latin America

Gertjan B. Beekman

Abstract. The Program to Combat Desertification and Mitigate the Effects of Droughts in South America is being implemented at a regional scale. The general objective is to provide a sound basis for addressing dry land degradation and drought in Argentina, Brazil, Bolivia, Chile, Ecuador and Peru, in accordance with the UNCCD principles. Other countries, such as, Colombia, Paraguay, Uruguay and Venezuela have manifested their interest in participating in the Program and to share experiences and expertise among the countries in the Region. The Meso-America countries, are also willing to engage in the same approach of the Program, significantly expanding the basis for south-south and north-south cooperation. In Latin America, the vast majority of the 34 countries that have adhered to the UNCCD have elaborated their National Action Programmes (NAP's) in accordance with their commitments towards the Convention. Currently, a number of them are engaged in the process to have their respective NAP's fully implemented and guided by national policies targeted to control the continuous land degradation associated either with natural climatic variations or anthropogenic activities.

The main objective of the Convention is to secure the long-term commitment of its Parties to combat desertification and mitigate the effects of drought through effective action at all levels, with a view to contributing to the achievement of sustainable development in affected areas. The Convention calls on the affected countries to develop National Action Programs to Combat Desertification and Drought (NAPCD), within the framework of national development plans. These include strategies and priorities, paying special attention to the related socioeconomic factors, addressing the underlying causes of dry land degradation, promoting the participation of local populations particularly women and youth, and providing an enabling environment by issuing as necessary new laws and policies. Through the Program a set of socio-economic and environmental indicators were identified in all participating countries and a common base line of indicators was derived in order to establish a common ground for the simulation of future scenarios. This is particularly of importance regarding the climate indicators such as temperature, precipation and evaporation that constitute components of the aridity index used to delimit the arid, semi-arid and the dry sub-humid areas in the region. The global warming trend is likely to change the distribution patterns of such indicators and redefine the boundaries of the aforementioned areas. These changes, as predicted by future scenarios, should be taken into account in NAP implementation and be given due consideration in the formulation of public policies towards combating desertification.

33.1 Environmental Effects

Environmental degradation increases as national and international environmental systems are restricted and regulation, both direct and indirect, is minimized. Loss of biodiversity, toxic chemical waste accumulation, deforestation, desertification and climate change worsen. The ambitious objectives of Agenda 21 (Earth Summit 1992) and of environmental conventions, again considered to some extent at the summit on Sustainable Development in Johannesburg (2002), continue essentially rhetorical. The Millennium Development Goals-MDG's are also showing signs that targets may not be met. The MDG's direct development planning towards priority goals. Each of the goals interacts with disaster risk potentially contributing to the reduction of human vulnerability to natural hazard.

National development sustainability initiatives are launched but the efforts are few and isolated. The same is often true of the initiatives, many converted into action plans, emerging from numerous sub-regional and regional conferences and fora, and from bilateral and multilateral agreements. However, the NAP's, in some cases rely heavily on community participation as is the case of the Brazilian NAP which was elaborated with a multitude of stakeholders and with the direct participation of the public or civil society fully represented. The demands and expectations of the public are to be carried out at the NAP's implementation phase. Political awareness is flaring up and the issue to combat desertification is drawn into to the political agenda of active congress representatives who are engaged in the pursuit of the means of implementation for the required actions to be effective. The National pluri-annual plan takes into account and provides budget provisions for the envisioned actions that are to produce a change in scenario and provide improvements in the overall quality of life.

33.2 Reducing Climate Related Disaster Risk

Improving natural resources management, adopting policies to confront vulnerability and applying preventive measures, lessen the impact of natural disasters on people and ecosystems. The vulnerability of areas susceptible to land degradation or desertification to both natural and human origin is reduced thanks to early warning systems in the zones most vulnerable to the effects of drought. Scenarios are devised to simulate the behavior of environmental processes, and to help integrate management and monitoring.

Climate change is the most serious unsolved environmental problem in the three decades from 2002 henceforth. The Intergovernmental Panel on Climate Change (IPCC) has released reports stressing the seriousness and concerns about the integrity of the climate system. The Latin American and Carribbean (LAC) region is prone to extreme meteorological events and is exposed on average every year to tropical cyclone hazard with relatively high vulnerability found in Honduras, Nicaragua (Hurricane Mitch in 1998), Guatemala, Mexico and neighboring countries. Higher vulnerability is likely to be aggravated by global climate change. Venezuela has faced serious torrential downpours leading to disastrous mudslides and life losses in the recent past.

Global climate change brings with it long-term shifts in average weather conditions and the possibility of the increasing frequency and severity of extreme weather events. The effects of climate change increase uncertainty and the complexity of risk for the whole society. The lack of capacity to manage and adapt to climate related risks is already a central development issue in many developing countries. These regions have larger and more concentrated vulnerable populations. The national economies are dependent on agricultural production and are less equipped to deal with extreme weather events.

The lack of capacity to manage risks associated with current climate variability will likely also inhibit countries from adapting to the future complexity and uncertainty of global climate change. If development is to be achieved in countries affected by climate risks and if development is not to aggravate climate change risks, an integrated approach to local climate risk reduction needs to be promoted. Successful risk reduction approaches already practiced by the disaster risk community should be mainstreamed into national strategies and programmes as envisaged by NAP's. (Final Decisions-CRIC-5).

In the short run, it will be necessary to promote integrated climate risk management since the climate change is likely to be experienced as an increase in both frequency and magnitude of extreme hydrometeorological hazards, such as tropical cyclones, floods and droughts. Climate change will affect most aspects of life. Therefore, it is also important that guiding principles be established for ensuring the mainstreaming of climate change concerns with ongoing human development practices. Key sectors of economic planning -- agriculture, tourism, land use planning, public health, environmental management and basic infrastructure provision -- will all need to take climate change into consideration.

33.3
Harmonization of Indicators of Desertification in Latin America and establishment of a common "base line"

In Latin America, the vast majority of the 34 countries that have adhered to the UNCCD have elaborated their National Action Plans (NAP's) in accordance with their commitments towards the Convention. Currently, a number of them are engaged in the process of having their respective NAP's fully implemented as guided by national policies targeted to control the continuous land degradation associated either with natural climatic variations or anthropogenic causes and activities.

There is a growing perception that due to the visible effects of climate change, science and technology should go hand in hand with the richness of the traditional knowledge of the rural communities in preventing and monitoring climatic phenomena. Therefore, at regional meetings, it was proposed to consider traditional knowledge and practices as a part of the strategies for establishing early warning systems for extreme events.

One of the major potentials of the region lies in the amount of traditional knowledge for the control and rehabilitation of degraded land and management of water, soil and forests. The identification and validation of this knowledge and related practices has been, although not in a systematic manner, carried out over many decades and now country Parties can confidently apply them to affected zones. Therefore, country Parties are encouraged to disseminate and use appropriate traditional knowledge, and when suitable, in combination with modern technologies and techniques, always considering local population's needs and conditions.

The entire region has made important advances in the identification of indicators and benchmarks of desertification and drought: many countries of the region have national diagnosis, that have been used while formulating the NAP, as baselines for monitoring and assessment. Significant efforts have been made of country Parties to integrate social indicators when assessing desertification processes highlighting the importance of establishing clear linkages between land degradation and poverty.

The LAC countries underline that the various proposals on benchmarks and indicators create a fragmented scenario that does not allow comparisons, neither between zones nor countries. Additionally, they stress that in general data collection requires significant economic resources, personnel and time which many affected countries cannot afford.

In this respect it is continuously stressed that developed country Parties provide financial and technical support to the use and dissemination of existing indicators and benchmarks to monitor and assess desertification and drought in affected country Parties. Also, it is considered of utmost importance to recognize the importance of the monitoring and assessment processes for desertification and drought and to make all necessary efforts to apply indicators and benchmarks in these processes involving local communities in a participatory manner.

Additionally, there is a willingness of the LAC country Parties to harmonize their monitoring and assessment systems by means of exchanging information and through south-south cooperation in order to develop an integral and comparable tool aimed at monitoring and assessing drought and desertification on a regional scale in an efficient and timely manner. The country Parties in the region expect the international cooperation agencies to provide the necessary and required technical and scientific support in this respect.

In order to streamline the various demands, an innovative approach was considered by the LAC country Parties, calling upon the UNCCD Secretariat, the international scientific community and international cooperation agencies, to explore the possibility of establishing in the near future an observatory to monitor and assess the desertification process in the region. This observatory should be supported through TPN 1 on benchmarks and indicators and be devoted to collect, process, manage and disseminate scientific information for the benefit of each country of the region. The region must capitalize on the outcomes in this field and to this aim act along with the initiatives undertaken by international agencies and generate terms of reference for coordinated and joint actions.

The country Parties are committed to develop and adapt modern technologies for combating desertification and mitigating the effects of drought. Those countries that have made more progress in this field are to continue and reaffirm their recent efforts in sharing information and consolidating bilateral and multilateral cooperation to help other countries in the region access the appropriate technology, knowledge and know-how.

Over the last years, the region has made remarkable progress in widening and deepening the diagnosis of vulnerability and productive capacity of their ecosystems, mainly watersheds and high mountains ecosystems. A wide range of projects addresses water and soil resources assessment and management, vegetation coverage and soil protection as well as livestock production systems. A number of countries have also adopted comprehensive and pertinent measures for sustainable management of water and the elimination of sources of soil contamination due to mining activities and solid waste disposal.

However Country Parties recognize the uneven development within the region in the use and sustainable management of the natural resources due to technical capacities, institutional enabling environment, availability of funds and priority assigned by the governments. It is also acknowledged that there is limited project articulation among government and non-governmental organizations as well as those entities responsible for NAP implementation and monitoring.

A significant move in the direction, to meet the expectations of Country Parties to harmonize indicators and benchmarks relevant to desertification processes was provided by the "Program to Combat Desertification and Mitigate the Effects of Droughts in South America", which has provided support in this regional effort focusing its activities initially in six countries. The general objective was to provide a sound basis for addressing dry land degradation and drought in Argentina, Brazil, Bolivia, Chile, Ecuador and Peru, in accordance with the UNCCD principles.

This initiative is being carried out by a joint effort, represented by the Inter-American Development Bank (IDB), responsible for the administration of the financial resources of a non-reimbursable fund from the Government of Japan and the Inter-American Institute for Cooperation on Agriculture (IICA), as the executing Agency, of the Program.

Additionally four Country Parties: Colombia, Paraguay, Uruguay and Venezuela, have expressed their interest to join the Program in order to construct a broader platform in the region based upon harmonized criteria and procedures on how to deal with a problem that presents common features throughout the region.

A similar move was taken by the MesoAmerican countries that convened during the XI GRULAC Meeting held in Panama, expressing their willingness to harmonize the activities in the region with respect to combating desertification, based on the same premises of the Program to Combat Desertification and Mitigate the Effects of Droughts in South America as implemented by IICA and the IDB.

The overall objective of these countries as well is, to improve the socio economic conditions of the communities affected by desertification, by adopting a novel production and development model, as well as, promote a behavioral change through the use of new technologies, capacity building and training taking into account sustainable development. The involvement of the various stakeholders in this process is regarded essential.

The specific objectives are:

- gather experiences that can be replicated throughout the region in respect to harmonized indicators aimed at identifying and measuring the effects of de-

sertification considering the following aspects: physical, biological, agricultural, socio economics and institutional,
- capacity building of personnel in monitoring and measuring techniques to combat desertification,
- promote a close participation process of the affected communities in the use of indicators, as well as, in the design and application of countermeasures to counteract the effects of desertification and
- enhance and strengthen institutional capacity to deal with land degradation issues.

The involvement of the Meso-American countries, represents the aggregation of eight more members interested in the premises of the Program, namely, Honduras, El Salvador, Guatemala, Nicaragua, Panama, Costa Rica, Mexico and Dominican Republic.

33.3.1
Objectives and common interest

Within the context of the general aim, among others, there is a general interest of the countries to exchange experiences and applicable methodologies and adequate technologies based on south-south cooperation. In this respect, a valid experience can be highlighted on how a base line of indicators was derived as a result of several national workshops, as well as, the concept and construction of the Desertification Indicator Management System-SIGINDES, to be utilized as a planning and decision making tool.

The specific objectives are:
- to improve the institutional capacity in the participating countries to combat the socio-economic and environmental problems caused by dry land degradation and drought,
- to develop and apply the use of standard indicators of desertification, and
- to contribute to the reduction or address the causes for dry land degradation and drought.

These objectives will be pursued with due consideration of gender and indigenous community participation.

All original and currently six participating countries of the Program, have ratified the United Nations Convention to Combat Desertification (UNCCD). Since 1996, the six selected countries have been working on a methodology for the selection of Desertification Indicators (physical, biological/agricultural, and socio-economic and institutional). Ultimately, this effort has proven fruitful through the support of the Program and a common base line of indicators was established and utilized as a common standard for the Program′s objectives. More recently, the identification of indicators of participation was also included in the list of indicators to be considered by the Program.

33.3.2
Program description

This initiative comprises the following activities: (i) harmonization and application of existing indicators / data at the pilot level with baseline information; (ii) design of policy proposals to address desertification issues; (iii) institutional strengthening / training, and public awareness / information dissemination. These activities are consistent with priority areas set out in the Conference of the Parties of the Convention and in the NAPs of the participating countries.

Special attention is to be given to traditional expertise and practices, and their improvement, as well as the collection, analysis and exchange of information on relevant matters to address desertification and drought. The selection of socio-cultural Desertification Indicators will take into consideration traditional practices in dry-lands of the region, compiled in 1999 as mandated by the Conference of the Parties of the UNCCD. Traditional practices will be monitored considering the geographic location of indigenous population in the Pilot Sites in order to assess which management practices are more conducive with prevention or mitigation of desertification, so that good practices could be extracted and disseminated. Likewise, gender issues will be addressed where appropriate. This approach is already being put into practice in the implementation of the first Pilot Projects in Argentina and Brazil.

33.3.3
Frame of Reference

33.3.3.1
Background

Desertification is the degradation of the productive capacity of land in arid, semiarid and dry-sub-humid areas. In the region, at the beginning of the 1990′s the total population affected by dry land degradation, without considering Central America and the Caribbean, was around 100 million. The majority of the population was poor (25% of the total regional population); in about 5 million km^2 of vulnerable dry lands (25% of the total regional area).

Most dry land degradation is caused by inappropriate land-use practices that convert usable land to marginal land to barren land. Examples include excessive grazing; cutting vegetation for fuel; soil-depleting cropping; soil salinization and water logging; and poorly planned public works. Periodic droughts make dry lands increasingly un-usable.

The main objective of the Convention is to secure the long-term commitment of its Parties to combat desertification and mitigate the effects of drought through effective action at all levels, with a view to contributing to the achievement of sustainable development in affected areas. The Convention calls on the affected countries to develop National Action Programs to Combat Desertification and Drought (NAPCD), within the framework of national development plans. These include strategies and priorities, paying special attention to the related socioeconomic factors, addressing the underlying causes of dry land degradation, promoting the participation of local populations particularly women and youth, and providing an enabling environment by issuing as necessary new laws and policies.

The countries participating in this project (Brazil, Argentina, Bolivia, Chile, Ecuador and Peru) all have extensive dry lands prone to desertification and have asked the Bank to provide them with technical assistance. As a result, the IDB contributed to the financing of the NAPCDs in these – as well as other – countries in the region. These NAPCDs identify key dry land areas within the countries, set priorities for public and private interventions to prevent and fight desertification and mitigate the effects of drought. Emphasis is given to the bottom-up approach with local communities, NGOs, private sector, institutions of civil society, and local governments, working together in the decision-making to formulate and execute the programs.

33.3.3.2
Summaries on desertification indicators by nation in participating countries

- In Brazil, around 15% (1 million km²) of the land is semiarid and subject in large areas to degradation processes, often combined and aggravated by recurrent drought, impacting a population of some 16 million poor inhabitants. The economic losses directly derived from both phenomena are not yet properly assessed. As for desertification, rough estimates indicated in the country's NAP (1997) suggest annual losses close to US$300 million, disrupting social and productive structures. The observed losses in Northeast Brazil for 1993 were equivalent to 30% of agricultural output of food products. A more comprehensive NAP was elaborated and formally launched on 17 June 2004 during the CCD+10 meeting held in Fortaleza –Ceará. Moreover, Brazilian States and Federal agencies incur expenditures that cost usually US$1 to $1.5 billion during extreme years (2 out of 5 years) or close to $600 million yearly adjusted. All together, combined annual losses equate to 1% to 2% of Northeast GDP, and significant investment is used just to rebuild social and productive structures disrupted by the phenomena of drought and land degradation.
- Up to 60% of the landmass of Argentina (around 1.6 million km²) is subject to desertification. This includes the northern highland provinces of Salta and Jujuy, the down slopes and valleys at the base of the Andes including the important agricultural area of Mendoza, and most of Patagonia, affecting a population of 9 million inhabitants.
- In Bolivia, about 41% (450,000 km²) of the land is affected, involving a similar percentage of the national population (around 5 million people) in three key areas: the highland plateaus, the Yungas valleys leading down from the mountains and the Chaco region to the southeast.
- Much of Chile's agricultural production derives from areas subject to the effects of desertification: the irrigated valleys in the northern arid and semiarid areas of the country down to Region IV, and south of Santiago down to Region VII.

The areas considered vulnerable amount to about 45% (340,000 km^2) of the national land surface, affecting 1.5 million inhabitants.
- In Ecuador, the affected geographic areas are relatively small, but significant, in terms of population affected. These include most of the coastal province of Manabi and adjacent areas of Guayas; mountainous areas in the southern province of Loja; and the southern coastal area abutting Peru.
- In Peru, about 22% of the landmass (283,000 km^2) with 20 million people of the country is vulnerable to desertification. Of particular importance are the irrigated valleys of the coastal plain, where most people live. In those areas, soil salinization is a significant problem. Also, much of the Andean highlands are affected by over-cultivation and overgrazing.

33.3.4 The project's strategy

The reduction or loss of the biological or economic productivity and complexity of dry lands (e.g. rainfed or irrigated cropland, or range, pasture, forest and woodlands) has its roots in land uses or from a process or combination of processes, including those arising from unsound human activities and habitation patterns that affect the livelihood of local populations. With this Program, Desertification Indicators (meaning very sensitive characteristics of the dry land environment to degradation processes) will be used, monitored and evaluated in Pilot Project Sites of the participating countries, to standardize their use for dryland degradation prevention and control, aimed at desired results towards policy formulation and application. This in fact will represent a step forward, regarding public policies formulation envisaging structural changes. The primary purpose is to promote scenario changes by physical intervention to control and to reverse the situation of environmental degradation and the overall process of desertification.

Efforts to prevent or control dry land degradation processes within the region, have given rise to the need for early warning systems and early warning information technology to cope with them timely and effectively.

33.3.5 Harmonization and compilation existing indicators/data

This component was aimed at revising a methodology for the selection of Desertification Indicators (physical, biological/agricultural, and socio-economic and institutional) from a pool of sources already available, based on clear criteria for their selection (usefulness for specific purposes, cost effectiveness of collection or analysis). The revision and implementation of a methodology to identify test and adjust key indicators that can be used throughout the region for the identification and evaluation of desertification processes in order to recommend appropriate control measures was deemed necessary.

As a next step the definition of the base-line of indicators as adopted will be tested in various affected dry land areas (Pilot Projects). These tests will be used to improve the usefulness of the Indicators and the generation of comparable data. Applying a sound monitoring and evaluation system, such as the SIGINDES, at the Pilot Project sites, this testing will be carried out. This component was extensively discussed during the workshops organized by the respective National Focal Points of the participating countries. The vast majority of the stakeholders had the opportunity to attend these events enabling an in depth debate on the selection of feasible indicators to be adopted nationally and henceforth regionally.

The specific activities of this component are as follows:

33.3.5.1
Indicators

The methodology to be used will take elements from indicator models designed in the participating countries. The methodology is based on levels of interpretation, analysis and aggregation of information, going from basic information to analyzed information to Indicators. If, for example, the information relates to human exploitation of the soil, possible indicators are the degree of erosion, salinization, contamination, compaction, or organic matter content. Once the indicators can be measured, they can be more effectively addressed with the use of appropriate technology. Indicators can also be integrated to summarize the state of desertification in a given area.

The lines of thought regarding the discussion on indicators as conducted by the Program by means of a series of specific workshops organized in the participating countries has been outlined in more detail henceforth.

Indicators help to reflect and communicate a complex idea. They are everywhere and are part of our everyday lives. They are used to observe, describe, and evaluate actual states, to formulate desired states or to compare an actual with a desired state. These simple numbers, descriptive or normative statements can condense the enormous complexity of the world around into a manageable amount of meaningful information (fig. 33.1).

To support a monitoring network as envisaged by the Program a set of indicators should be evaluated in order to monitor progress towards meeting the targets and goals set out together with the institutional and the community stakeholders. (Beekman 2005).

Indicators, as mentioned, are used to simplify, quantify, communicate and create order within complex data. They provide information in such a way that both policy-makers and the public can understand and relate to them. They help to monitor progress and trends in the use and management of natural resources, and associated aspects to control and reverse the process of environmental degradation and its consequent social impacts, over time and space.

Possibly, the most widely used and known approach to indicator development is the cause-effect approach. The pressure-state-response (PSR) conceptual framework was first introduced by the Organization for Economic Cooperation and Development (OECD) in 1994. Several cause-effect classifications have been developed such as the Driving Force-Pressure-State-Impact-Response (DPSIR). The Driving Force-state-Response (DSR) framework of the United Nations Commis-

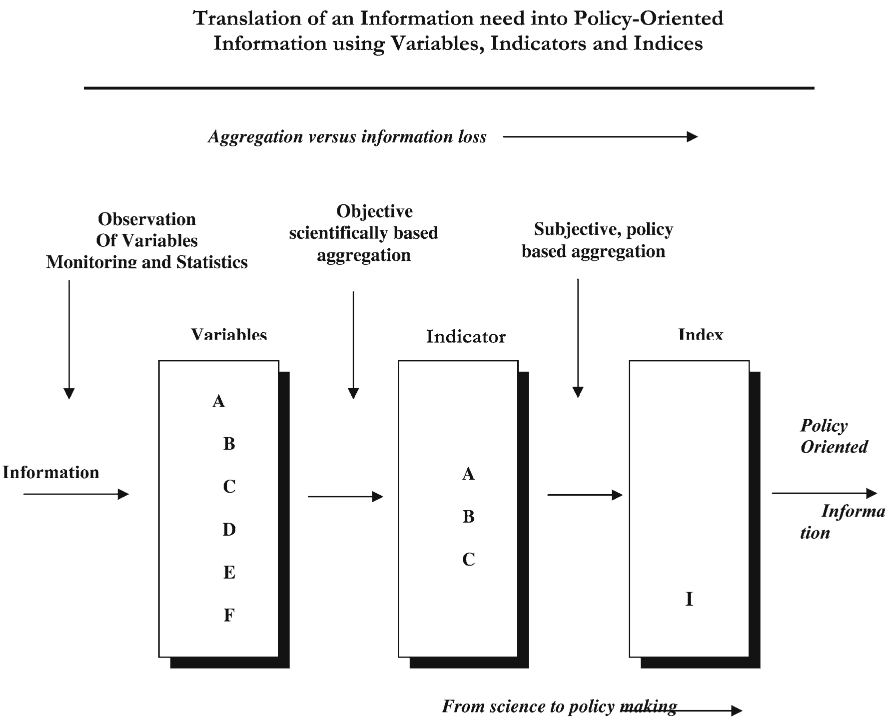


Fig. 33.1. This figure shows the difference between variables, indicators and indices, which all represent different stages of information collation, indicators take variables and condense them into manageable information sets, which then are further condensed by indices. These can be translated into policy-oriented informa-tion. (Source: Lorentz 1999)

sion on Sustainable Development was used for the indicators of Agenda 21. The Driving Force-Pressure-State-Exposure-Effects-Action (DPSEEA) framework is used in the burden of disease studies of the WHO (The United Nations, World Water Development Report 2003).

Although this is the most applied approach and offers a very promising guideline for indicator development, it all too often fails to take the entire system into consideration because of the subjectivity involved in understanding the pressure, state and responses. Similarly, indicators can help in the comparison of results in many areas or countries and examine potential links between changing conditions, human behavior and policy choices. Because 'good indicators are easy to understand, they offer a tool for raising awareness about desertification water issues that cut across every social and political group.

The development of indicators is not an easy task, for it involves a great amount of work in collection, storage, retrieval, analyses and systematization of data. The need for clarity and ease of understanding means that indicators often condense large volumes of data into brief overviews and reduce the complexities of the world into simple and unambiguous messages.

The need for scientific validity, on the other hand, requires that indicators must simplify without distorting the underlying patterns or losing the vital connections and interdependencies that govern the real world. They must therefore also be transparent, testable and scientifically sound. Because the same indicator has to satisfy often conflicting but equal important social, political, financial and scientific objectives, deriving indicators becomes an objective maximization exercise constrained by available time, resources and partnership arrangements.

The solution lies in identifying or developing common denominators in as many cases as possible, so that comparisons may be made. If data can be gathered according to commonly agreed or standardized norms, then lessons can be drawn that may be transposable from one case to another.

Indicators can tell a different story or message according to specific contexts, for particular purposes and for specified target groups, and therefore resist universal application. Both the design and the use of indicators involve many personal and negotiated decisions, explicit and implicit assumptions, normative and subjective judgment, and disciplinary and method-specific rules. They are based on beliefs, internalized values and norms and on one's perception of "reality".

In establishing indicators, the criteria must be absolutely clear. Yasuda and Murase (2002) propose the following six criteria:

- *Relevance:* The numerical values of an indicator should represent the degree of 'what should be measured' directly;
- *Clarity:* Ambiguity and arbitrariness should be excluded from measuring with an indicator;
- *Cost:* The cost of the evaluation by an indicator should be affordable low;
- *Continuity:* Availability of coherent data both in historical and regional scope should be respected;
- *Comprehensibility:* Definition/expression of an indicator should be intuitively/easily comprehensible to users;
- *Social benefit:* Net social benefit that an indicator yields, as it is applied, should be maximized.

The main functions of indicators are thus simplification, quantification, communication and ordering. Indicators can relate and integrate information and allow comparison of different regions and different aspects.

33.3.5.2 Purpose and Use of Indicators

Clearly, the growing interest in the use of indicators and indices is closely connected to the increasing complexity of policy problems and the large amount of available data. In the water sector, beyond their face value, indicators can provide various types of information such as:

Descriptive: Describing the state of the resource, or social target group, is the most common use of indicators. In terms of water resources an example of the descriptive use of indicators could be by presenting the values of available water resources, water demand, internal renewable water resources and water supply on a regional scale.

This could be presented on maps clearly showing differences in resources, demand and supply of water. Similarly, maps with social indicators could be produced showing number of landowners holding land titles, average annual income of the family, and number of associations or cooperatives as an indicator of social organization among others. Such maps could eventually indicate a human development stage (HDI) to be utilized as guidelines for development policies.

Showing Trends: Regular measurement of indicators provides time series, which can show trends that may provide information on the system's functioning or response to management. The increase of productivity and yield of agricultural systems run by resettled groups through associations or cooperatives may be an indicator of economic success and sustainability. Benchmarking is important to show scenarios over time.

Communication: Indicators can be instrumental to communicate policy objectives and results to the public. Such indicators help promote action and could reflect the degree of participation of a community.

33.4 Monitoring System

The selected set of Desertification Indicators will be applied in the Pilot Projects Sites (preferably two per country) in drylands selected by the NFI, preferably within a municipality. The Pilot Sites will be well-defined micro or sub-watersheds, supporting agricultural (i.e. crops, livestock, agro forestry, forestry) and other economic activities. The Pilot Sites will have good secondary information on their natural resource base. The desertification monitoring system will be designed and implemented based on a geographic information system (GIS), satellite products and conventional information in order to follow up the Desertification Indicators. Some of these elements are already being gathered from the Pilot Projects that are carried out in Argentina.

The monitoring process will start with known baseline information. Periodic evaluations will be done to build up the information needed to prevent and halt desertification processes. To design the monitoring system specific expertise will be brought in by the Program and in close collaboration with local experts from the participating countries will define said system for its application in the Pilot Sites. In this context, the operational guidelines, software and other applications for the effective implementation of the system will also be identified and be made available for each country.

33.4.1 Monitoring as a key component of Early Warning

As mentioned earlier, indicators are constituted by observable variables that can be aggregated objectively and scientifically based and thereupon in turn be aggregated subjectively into indices based upon an established set of policies. Therefore, the proper data and information translated into indicators and the adoption of benchmarks may enable the production of scenarios based on trends either utilized in hindcasting or forecasting. In this respect the design of a network or early warning system is essential to systematically monitor, in "quasi" or real time, the selected variables and relay them for processing and analysis.

Lessons and experience are key elements when hindcasting is considered and when there is concern to follow and record all historic steps or important landmarks and events related to all stages of a Plan, Program or Project. Therefore, the so called "Waste Cycle" (Beekman 2005) should be born in mind in order to avoid repetition of ill-fated experiences that are usually costly. The trial and error approach can be avoided if the experience and knowledge has been acquired and has been paid for already. In other words, this is also an attempt to build a structure based upon facts.

Observation or monitoring is instrumental if carried out in a careful, unprejudiced way when the facts that are established in this manner would constitute a secure, objective basis for science. "If, further, the reasoning that takes us from this factual basis to the laws and theories that constitute scientific knowledge is sound, then the resulting knowledge can itself be taken to be securely established and objective" (Chalmers 1999).

Observation, as a primary source of data, has always been a part of natural science, as well as, other areas of human interest. In more pragmatic terms, monitoring or observation put into practice is a matter of cost and when this is brought into the real world, decision makers must be convinced of its relevance and on the long run cost saving results. Although the "Waste and Loss Cycle" sequence can be applied in virtually any process a specific example related to Water Resource planning could be cited, such as the design of networks (e.g. hydrometric measurements).

Turning generalities into specifics is a basic problem in network design. If it is to be designed in some ideal sense, the costs and the benefits of the data acquired should be defined. Then these costs and benefits should be stated in a mathematical form as an objective function. Maximizing the "value" or minimizing the "cost" of the objective function, subject to well-defined constraints, would yield the optimal design for the network.

Cost and benefits of data must be assessed for inclusion in any network design procedure. Costs are definitely the easier of the two to assess. However, there are uncertainties even in the cost estimates.

Historical records are usually available which assess past allocations or budgets for data collection, processing and dissemination. True costs are not usually available without considerable interpretation, but allocations are at least a fair index of costs. Projections of future costs are more uncertain. What has been said of costs is even truer of benefits of data networks. What is the worth of data? If changing technology affects costs, it affects benefits even more. Benefits of data are related to the uses of the data. The worth of data may be measured in terms of its impact upon the design and management decisions. The benefits foregone because of the lack of data can be used to measure the worth of data.

The measurement of such worth for project design is rather straightforward, even though it contains a large element of uncertainty. For other than project design however, the uses for data and their effect on any resulting decision are diverse and diffuse. Predicting uses of the future is at best an art. In order to circumvent the problems of uncertainty and difficulty in determining cost and worth of data, very often design criteria are developed around surrogate measures. The most popular surrogate is to establish an accuracy criterion. Thus, data are collected in such a way as to minimize the variance of the estimate of some observed variable subject to a budgetary constraint.

The use of surrogate values may be a necessary expedient, but the fiction must not be treated as fact. Accuracy is a means to an end. The relation of worth to accuracy may be direct in some instances but it also may be quite complex. Thus, the level of accuracy should be a design variable rather than the objective function criterion, which determines the design of a network.

At given points in space, the time series of events constitute the basic set of data pertaining to a specific phenomenon. The utility of historical data sequences is measured by the extent to which they may be used to reduce the uncertainty as to what the time series of events will be over future time spans.

Decision theory is a way of thinking rather than a theory as such. Its purpose is to assess the network in terms of the impact of data on decisions. Collecting more data should reduce the element of uncertainty in decision making. The value of the reduction in uncertainty is the measure of benefits of data. These benefits can be compared to the cost of the data. In order to apply decision theory one must determine the decisions which will be based on the data, how the data affect those decisions, and, in particular, how the data affect the expected value of the decision maker's objective function. Decision theory attempts to include attitudes toward risk (or risk aversion) and provides a framework for including "soft" information based on experience as well as, "hard" information based on data measured in the network/project or for network/project design.

The sequence or "domino effect" of the "Waste Cycle" is briefly outlined below. Far from being a dramatization of the negative aspects of "not doing as told to do otherwise" it is the aim to highlight the possible effects of a shaky start at the beginning of a process. The purpose is to perceive and to predict possible outcomes and to utilize the "Waste Cycle" as a tool for discussion, to redefine envisaged directives, and get back to the track and aim at the originally targeted objectives.

- *Monitoring:* If observation or monitoring is poor or does not exists, due to any possible reason such as: economic constraint; outright disregard for its importance; no time to construct a record of a historic data set; ignorance a.s.o. (No monitoring is the first step towards future problem making);
- *Data collection:* Data requirements are often formidable and the collection task problems are compounded by "scaling' problems, both temporal and spatial. General policy objectives such as the sustainable development have served to highlight the need for more comprehensive data sets, but also the need of appropriate

sustainability indicators to aid monitoring. With the paucity or scarcity of data, its translation into information becomes inconsistent, and the basic statistic moments can not be derived properly from small samples neither trends or internal cycles can be established within proper significant levels. From the deterministic point of view the same difficulties arise for natural laws are hard to determine;

- *Information:* When information is insufficient the descriptors, of an event or phenomena, do not depict facts faithfully, making predictions or forecasting merely guess exercises;
- Modeling of Scenarios: When scenarios are simulated based upon unreliable information, spatial and temporal outcomes may not be representative even if sophisticated information systems are utilized such as Geographic Information Systems interfaced with mathematical models and databases. Such results tend to be unrealistic and deficient;
- *Strategic Planning:* This phase of program or project design depends heavily on the previous steps. With inadequate or "blurred and out of focus pictures", inputs for planning is likely to be inadequate;
- *Policies:* Become exposed and bound to criticism. No regulatory frame will resist on weak foundations;
- Accomplishment of Programs and Projects: When this phase is carried out embodying the aforementioned flaws no optimal requirement in terms of performance can be attained;
- I*ndicators of Performance:* Very likely indicators will be pointing away from the originally targeted objectives and will respond erratically producing distorted feedback;
- *Targets Missed:* If they are not met, economic expectations will be frustrated and the misguided initial steps will backfire by producing unfavorable results in terms of revenues on the investments made. At this point, probably all interested parties and stakeholders (shareholders?) will be wondering and demanding extensive auditing on: What happened? When? Why? Who is responsible?
- *Rehabilitation:* Eventually, salvage maneuvers and last ditch efforts are required to rescue an ill-fated project. However, in order to introduce corrective measures, some background history will be necessary to explain what occurred. This in turn should provide the means to make the difference and meet future positive outcomes and results. At any rate, the simple fact of over doing work bears additional expenses and cost over-runs. This is another proof that the very initial step encompassing, observation, monitoring and data gathering is a fundamental prerequisite for any process or cycle to be successful!
- *Feedback loops:* On the basis of the assessment a decision may be made or, the whole process may be restarted with an alternative framing of the issue, a new structure and renewed analysis and a reassessment may be conducted, before decision makers are satisfied with the optimized outcomes. Once the decision on the maximized and optimized framework to be adopted has been made, a set of possible policy instruments such as standards, regulations, economic incentives, voluntary incentives should be implemented. The performance of the whole cycle is to be observed and monitored over time and re-evaluated on the basis of scientific and social feedback in a cyclical process as depicted (Fig. 33.2).

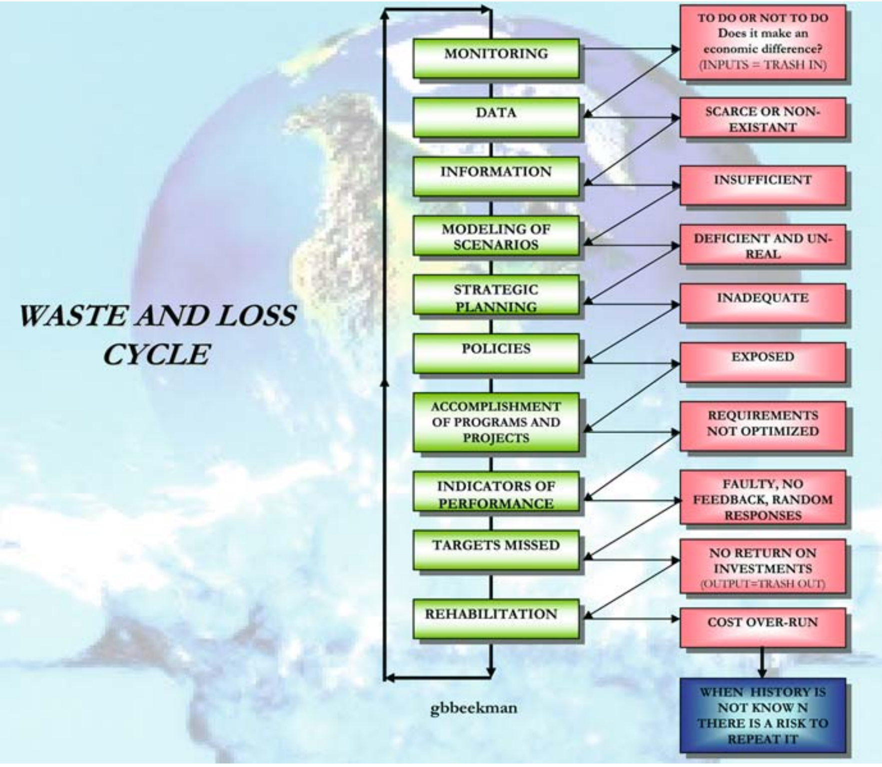


Fig. 33.2. Waste and Loss Cycle

Desertification Indicator Management System-SIGINDES: This system is currently being developed with the support of the Program relying on the inputs provided by the University of Chile, IADIZA-Argentina in addition to the data bases on socio-economic indicators as developed by a previous project conducted by ECLAC when the REDATAM-data base/system was constructed with data collected from Argentina, Brazil and Chile. Currently this database is being updated with the insertion of the socio-economic indicators from Ecuador, Peru and Bolivia. Another database input will be provided by RIOD (International NGO's to Combat Desertification) which is in the process of constructing a database on Indicators of Participation. Other software components of interest of the system that could make it more useful and comprehensive can be aggregated as additional contributions and arranged in a user-friendly manner.

The SIGINDES upon completion will have as a core element the Monitor (Santibáñez et al. 1997) developed years ago by the Center of Agriculture and Environment at the University of Chile. The aim of this software is to act a management system to interface databases associated to a map-producing tool capable to generate any display based on the variable or set of variables stored in the database. Basically it can be considered a Geographic Information System that interacts as an interface between data bases and models utilized to simulate scenarios that represent a diagnosis of a given situation of desertification or future scenarios based on assumed changes that represent a prognosis due to possible changes of the variables either due to natural causes or anthropogenic activities. Therefore, the Monitor within the SIGINDES context is able to simulate scenarios reflecting the change of state of variables considering a varying time scale as defined by the user of the system. One of the objectives of the Program is to make the SIGINDES available to institutions representing the participating countries, as well as, those interested in the exchange of experiences in combating desertification as an international cooperation effort.

33.5 Institutional strengthening/training

In order to ensure the wide application and human resources sensibilization, awareness and capacity to analyze the data to be collected, appropriate training material will be produced for different target groups (land users and community leaders; local government officials, private institutions, press, NGOs; and decision makers). They will be guidelines on desertification processes, their prevention and control, and guidelines on Desertification Indicators, prepared by local universities in dry land areas.

Depending on the target group, short courses will be delivered by specialized professionals. Courses for public officials should enable them to interpret and analyze the data to be generated by the monitoring system and as a consequence prepare adequate response programs or policies addressing the causes of desertification. Courses for land users and community leaders should provide them with the necessary understanding of the effects of desertification as well as provide them with options that will mitigate, reduce or adapt to said effects.

Furthermore, a post-graduate / or specialty track university program (curricula, teacher profile, costs per student) will de developed for interested universities in the participating countries and in the region. The participating universities will be selected on the basis of certain criteria, such as geographical location and proven interest in desertification programs. The universities will design this program in collaboration with national institutions involved in the gathering and interpretation of Desertification Indicators, to ensure an adequate human resources needs profile / demand for technical expertise.

33.6 Design of policy proposals to address desertification/public awareness

Based upon the results of the above-mentioned testing period for the application of the monitoring system and based on the selected Desertification Indicators, draft policy and / or program proposals will be prepared. This activity will also be accompanied by actions to raise public awareness on desertification issues. These actions will be performed with the support of community councils or other local NGOs or groups, and made public through different communication media.

33.7
Expected outcome/results

It is expected that the principal outcome of this operation will be the formulation of congruent indicators to measure desertification, and as such the production of readily comparable data for various countries in South America. Furthermore, for this information to be translated into concrete actions addressing desertification occurrences, it will be complemented by training activities for specific target groups, and other actions leading to an improved institutional capacity of agencies responsible for measuring and interpreting environmental data as well as for policy making. Furthermore, the design of sound local and specific policy proposals will be an important output of this operation, which will also be supported by the production of awareness material, and the design of academic postgraduate programs or specialty tracks. It is expected that these products lead to the long-term sustainability of the efforts initiated with this Program.

33.8
Environmental and social aspects

The Program has been designed for environmental protection and sound use of the natural resource base of dry lands in the region. Its inputs are basically technical assistance; training and policy design on environmental issues related to degradation control and sound management of dry lands for stakeholders and the well being of local communities. It also includes dissemination of information and the preparation of graduate training programs on dry land management at the national and regional levels.

33.9
Beneficiaries/benefits

The Program will contribute to raising community awareness of and sensitivity to significant environmental problems associated with desertification. Tools will be developed on a regional scope to assist experts and local communities address the causes of desertification. The consolidation of socioeconomic and environmental indicators on a regional level, as well as their application and analysis at pilot sites, will provide key information conducive to the formulation of policies and programs addressing the causes of desertification.

Complementary to the above, it is expected that the training sessions tailored to specific target groups will contribute to the improvement in the planning and management of natural resource use. Additional activities envisioned for institutional strengthening will further support that aspect. Also, the training sessions will promote the conservation and protection of dry land's natural resource base, as well as promote the adoption of environmental friendly agricultural practices and other environmentally appropriate uses of dry lands.

Furthermore, this Program will strengthen existing cooperation on dry land management and conservation activities, among governmental and non-governmental institutions on a national and regional level. This cooperation will ensure continued exchange of technical expertise on desertification/dry land management issues, and as such enrich the formulation of policies or programs in this field.

The project will contribute to raising community awareness of and sensitivity to significant environmental problems associated with desertification. Tools will be developed on a regional scope to assist experts and local communities address the causes of desertification. The consolidation of socioeconomic and environmental indicators on a regional level, as well as, their application and analysis at pilot sites, will provide key information conducive to the formulation of policies/ programs addressing the causes of desertification.

This approach is aimed at fostering and promoting the conservation and protection of dry land's natural resource base, as well as promote the adoption of environmental friendly agricultural practices and other environmentally appropriate uses of dry lands.

33.10 Conclusions

As described throughout this text, besides having the overall objective and the specific objectives of the Program carried out and having achieved one of its main targets is the harmonization of indicators of desertification at regional level, seconded by the Desertification Indicators Management System-SIGINDES about to be implemented in the Region. Other aspects could be highlighted as well.

The Program has represented an invaluable instrument in the Region in terms of institutional building and in the process of generating knowledge on how to approach the issues of desertification in a comprehensive manner, as well as, providing important means to foster the exchange of experiences among the institutions of the participating countries.

The means for the implementation of the Program, as provided by the financial resources from the Government of Japan in close cooperation with the Inter-American Development Bank-IDB were essential in the pursuit of concepts to design policies and strategies backed by methodological approaches and techniques on how to tackle, control and reverse socio-environmental degradation processes that eventually may lead to desertification.

By abiding to the premises of Agenda 21, Chapter 12 and more recently to the Millennium Development Goals, and the Climatic Change Scenarios, it has been proven essential to consider the strong role played by the international cooperation and its firm engagement in this overall effort to construct partnerships to support NAP´s and other initiatives aimed to combat desertification.

References

Abraham E (2004) Recopilacion y Harmonizacion de Indicadores de Desertificacion; Program to Combat Desertification and Mitigate the Effects of Drougth in South America, Agreement ATN/JF – 7905-RG IICA/IDB.

Beekman GB (2005) Social Change And Resettlement Related To Water Resources Planning And Development, Doktorandus Thesis, Royal Technology Institute-Kth, Stockholm-Sweden.

Chalmers AF (1999) What is this thing called science?, 3rd ed. – Univ. of Queensland Press.

Lorentz CM (1999) Indicators for Sustainable Management of Rivers, Thesis, Vrije Universiteit Amsterdam.

Plan of Operations. Program to Combat Desertification in South America, Document of the Inter-American Development Bank-IDB, Agreement ATN/JF- 7905-RG

Santibáñez F et al. (1997) Metodología Unificada para el Monitoreo y la Evaluación de la Desertificación en América Latina: Indicadores de Desertificación. Universidad de Chile. Santiago, Chile.

The United Nations, World Water Development Report (2003) Water for People Water for Life, UNESCO, Paris, France

UNCCD (2006) Final Decisions of CRIC-5, August 2006.

Conclusions and Recommendations

Mannava V. K. Sivakumar and Ndegwa Ndiang'ui

34.1 Introduction

Participants in the workshop met in the three working groups to discuss important issues concerning climate and land degradation and develop appropriate conclusions and recommendations under the following three major headings:
- Current use of weather and climate information for monitoring and assessing land degradation and in developing sustainable land management practices.
- Promoting more effective use of weather and climate information for reducing land degradation.
- Weather and climate information to improve the implementation of National Action Programmes (NAPs) of the UNCCD

34.2 Conclusions

34.2.1 Current use of weather and climate information for monitoring and assessing land degradation and in developing sustainable land management practices.

a) The following weather and climate data are available both historically and in real-time:
- Precipitation
- Air and soil temperature
- Wind speed and direction
- Sunshine hours
- Derived evaporation
- Solar radiation
- Rainfall estimates and NDVI from satellite data
- Climate information and prediction products and customer services.

b) Despite the availability of such useful data and products, the following constraints limit their optimum use:
- Inadequacy of data/information coverage and verification due to poor infrastructure

- Lack of ready accessibility
- Inconsistent quality of data/products
- Weak cooperation between producers and users
- Weak communication/dissemination strategies
- High costs attached to data/information which impede accessibility
- Lack of tailor-made products for users
- Lack of timely delivery of data and products.

34.2.2
Promoting more effective use of weather and climate information for reducing land degradation

a) There is a range of stakeholders with a role in land and water management. This diversity must be appreciated in the development of any strategy to address land degradation.
b) The wealth of hydro-meteorological data and information in both developing and developed countries is not fully available to local populations and end users for several reasons, including restriction of access by the data holding institutions.
c) There is a lack of clear differentiation between raw data, summarized data, interpreted information and final integrated assessment of land degradation phenomena.

34.2.3
Weather and climate information to improve the implementation of National Action Programmes (NAPs) of the UNCCD

a) In some countries, National Meteorological and Hydrological Services (NMHSs) are not currently included as members of bodies responsible for the implementation of NAPs.
b) Although climate and weather information is routinely collected, in some cases this information is not accessable to the agencies/departments who are responsible for implementing NAPs.
c) Currently, in some of the NAPs, adequate use of climate and weather information is not being made.
d) In some countries, lack of adequate trained personnel and weak institutional capacity is recognised as a constraint in efficient use of climate and weather information.

34.3 Recommendations

34.3.1 Current use of weather and climate information for monitoring and assessing land degradation and in developing sustainable land management practices.

- Countries need to improve spatial coverage of meteorological stations, in collaboration with private or agrometeorological networks if possible.
- There is a need to improve the availability of specialized data (precipitiation, temperature, soil moisture and temperature, and evaporation).
- It is necessary to adopt ISO standards in data and products.
- Tailor-made products should be developed together with users and made available in a timely manner.
- The delivery of products should be facilitated through provision of adequate resources and capacity should be strengthened in the use of these products.
- Data and information should be made as accessible as possible for the public good, and where necessary, they should be packaged for end users especially for those engaged in sustainable land management with the recognition that different users have different data and information needs.
- There is a need to allow selective cost-recovery of data/product delivery; and
- Institutions developing climate variability and climate change information should be encouraged to examine various scale projections that take into consideration feedbacks between land cover change and land degradation on future precipitation and temperature patterns to aid adaptation and mitigation.

34.3.2 Promoting more effective use of weather and climate information for reducing land degradation

- More detailed spatial resolution of climate data is needed for area specific assessments. There is the need to maintain the density and quality of the stations, as well as maintenance and operational aspects, of existing networks.
- Networks of stations needs to be improved in areas that are highly susceptible to land degradation, for example mountainous areas.
- Detailed, accurate and spatially distributed rainfall intensity data are needed that can be used for surface erosion assessment and modeling, and draining structures design.
- Historical climate data and climate change scenarios are needed for future strategic planning, agro-climatological zoning and crop pattern scheduling.
- Meteorological and relevant remote sensing data alone are not sufficient. Any integrated assessment of land degradation may need a combination of various data including hydrological information, soil data, socio-economic information, etc.

- Targeted weather forecasts at all levels are needed at very local scales to help stakeholders make the appropriate decisions.
- The important role of WMO in standardizing meteorological data should be continued and enhanced.
- Every effort should be made to identify relevant entities outside the WMO structure that operate and maintain networks (national or international) and are in possession of climate information. The release of that information to the interested stakeholders should be pursued.
- Interpretation of information and integrated land degradation assessments need to be delegated to appropriate institutions and experts with competence in the respective scientific areas.
- Dissemination of information and final products for specialized demand driven applications requires additional training of technology transfer specialists and local staff. In this respect the following are the specific needs in the area of training and capacity building to make more effective use of weather and climate information for reducing land degradation:
  - Training and capacity building needs to be organized in a proactive way for stakeholders at all levels in order to make the final information useful for the end users and assure long term sustainability of the technology and information transfer process;
  - Prior to any training and capacity building initiative there must be a clear identification of needs by the final end users;
  - End users must be put in a position to fully understand the implications and value of the information provided;
  - The uncertainties and risks of the decision making process need to be reduced and eventually fully explained;
  - Every step from raw data collection up to the final integrated assessment needs to be covered by specific training and capacity building activities;
  - National Meteorological and Hydrological Services (NMHSs) need to be strengthened in their capacities in performing the raw data collection and interpretation tasks as well as improving their visibility in the local and National media. This would assure the very much needed long term sustainability of the National Services concerned;
  - Similar training and capacity building efforts in other areas of competence such as land use planning, soil survey, etc. are needed to have an integrated approach to land degradation assessment and mitigation.

34.3.3 Weather and climate information to improve the implementation of National Action Programmes (NAPs) of the UNCCD

- Weather and climate data should be made available in a timely manner and be synthesized for use in the implementation of NAPs. Hence, it is important to strengthen the capacity of NMHSs in the acquisition, analysis and dissemination of data.

- A Multi-Disciplinary Team (MDT) of data providers and data users for developing early warning systems for drought and desertification should be established at the national level to determine how information would be analysed and packaged for the end users.
- MDTs should take into account local community knowledge to complement scientific expertise.
- Given the current technological advances in the availability of satellite data, greater efforts should be made for the use of these data in the implementation of NAPs.
- Given the current concerns with recurrent droughts and their impacts on local communities, it is important to develop and implement a National Drought Policy (NDP) that supports effective implementation of the NAPs.
- Representatives of NMHSs should be included in the national delegations to the sessions of UNCCD COPs to ensure that the issue of climatic factors in land degradation is effectively addressed.
- NMHSs, in collaboration with agricultural extension services and national coordinating bodies of UNCCD, should provide seminars on weather, climate and land use to farmers to promote implementation of NAPs.

Workshop Statement

An International Workshop on Climate and Land Degradation organized by the World Meteorological Organization, the United Nations Convention to Combat Desertification (UNCCD) and the Tanzania Meteorological Agency was held in Arusha, Tanzania, from 11 to 15 December 2006. The workshop was co-sponsored by the OPEC Fund for International Development (OFID), the United Nations Development Programme (UNDP) and the United Nations Educational, Scientific and Cultural Organization (UNESCO). The workshop focused on how climate induces and influences land degradation and what measures need to be taken to enhance the applications of weather and climate information to combat land degradation.

Land degradation is a threat to natural resources with consequences on food security, poverty, and environmental and political stability. The workshop noted that trends in land degradation are assessed differently in various parts of the world. The increasing occurrence of climate extremes (for example heat waves, droughts, heavy precipitation) is having an impact on land degradation processes, including floods, mass movements, soil erosion by water and wind and salinization in all parts of the globe. Climate variability, climate change and land degradation are intimately linked and are generating unexpected effects eg., an increased occurrence of fire-weather conditions in large parts of the globe. In combating land degradation, bottom-up and top-down participatory management approaches that foster income generating activities are required.

The workshop recommended that:

1. As the relationship between locally observed land degradation processes and their aggregation at different scales (National, Regional, and Global) requires further exploration of scale transfer methodologies and procedures, it is essential to improve the monitoring of land degradation as well as climate at these scales. Global assessments need to take into account the reality of land degradation as perceived by local populations;
2. There is a need to strengthen the knowledge and understanding as well as the functions of ecosystems (thresholds, resilience and dynamic equilibria) in order to better understand, predict and value the risks of land degradation and fully understand the complex interrelations between land use and environment;
3. Innovative and adaptive land management responses to inherent climatic variability and natural hazards (droughts, floods, landslides, sand and dust storms, wildland fires etc.) must be identified and implemented for sustainable land management;

4. Land management practices in affected areas, particularly in Africa and other developing countries, should focus on improving the amount of rainfall that is used in biomass production. This can be facilitated by the provision of unlimited hydro-meteorological data and increased human and institutional capacity building;
5. The network of climatological, hydrological and agrometeorological stations around the world should be increased and strengthened to provide data on rainfall intensities, soil temperature and soil moisture for land degradation monitoring, assessment and for the implementation of the NAPs. Climatological and hydrological end products should be developed in coordination with end user needs by relevant and competent personnel and institutions;
6. There is a need to adopt an integrated approach backed up by institutional support and regeneration of affected areas by means of agro-ecological practices and other physical interventions to reduce land degradation. Direct interactions between National Meteorological and Hydrological Services (NMHSs) and the land users can help enhance the direct communication of weather and climate information. There is a need to develop a cost-effective system to communicate early climate forecasts to various stakeholders, in particular to farmers, so that they can improve their land management practices; and
7. Given the current concerns with recurrent droughts and their impacts on local communities, it is important to develop and implement a National Drought Policy (NDP) that supports effective implementation of the NAPs.

Subject Index

E

H

I

J

K

L

Printing: Krips bv, Meppel
Binding: Stürtz, Würzburg