Chapter 17
Desertification and Desertification Indicators Classification (DPSIR)

Robert H. Armon

Abstract Desertification is one of the main driver of global famine and intensive urbanization. Fertile soil that passes the process of desertification cannot be reversed and it is lost for many decades. Basically the process is the degradation of soil. Soil degradation is not necessarily continuous. It may take place over a relatively short period between two states of ecological equilibrium. The processes of soil degradation are mainly water erosion, wind erosion, salinization and/or sodification, chemical degradation, physical degradation, and biological degradation. The concept of DPSIR (driver, state, impact, and response) has been adopted by the European Environment Agency and other organizations for soil strategy. For example, in this model: *state indicators* are soil water availability, land suitability, erosion vulnerability, etc.; *pressure indicators* are human and environmental harmful effects, such as deforestation, ground water overexploitation, forest fire, etc.; *response indicators* are represented by corrective measures, such as sustainable farming, ground water recharge, terracing, storage of runoff water, etc.; *driving forces indicators* represent human activities that impact land degradation, such as intensified agriculture, overgrazing, uncontrolled tourism, and population increase; and finally *impact indicators* of the desertification process, e.g., loss of plant productivity and farm income, flooding of low land, dam sedimentation, etc.

Keywords Desertification • Evapotranspiration • Soil • Crust • Desertification indicators classification (DPSIR) • Deforestation • Urbanization

17.1 Background

There are many definitions of the desertification process; however, the next two seems to best describe the process: *"Desertification is land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors including climatic variations and human activities"*; and *". . .desertification is best reserved for the ultimate step of land degradation, the point when land becomes irreversibly*

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R.H. Armon, O. Hänninen (eds.), *Environmental Indicators*,
DOI 10.1007/978-94-017-9499-2_17

sterile in human terms and with respect to reasonable economic limitations" UNCOD (1978).

In most cases, a typical desert is directly linked to diurnal high and low temperature variations, as well to precipitation deficit, and therefore continental deserts are dry and hot. However, it should be mentioned that the area at the poles and the Himalayas (or other high altitude zones) are also deserts, to be precise, cold deserts, due to their continuous frozen state and the subsequent low water availability. In terms of water budget, defined by the equation $P - PE \pm S$ (where P is precipitation, PE is potential evapotranspiration rate, and S is surface storage capacity of water), deserts receive very low precipitation while evapotranspiration surpasses it by several folds, creating a high water deficit expressed by specific or the lack of vegetation. The water balance and hydrological cycle can also be connected by a similar equation called the water balance equation:

$$\mathbf{R = P - ET - IG - \Delta S}$$

where $R = \text{runoff}$ $P = \text{precipitation}$, $ET = \text{evapotranspiration}$, $IG = \text{deep/inactive groundwater}$, and $\Delta S = $ the change in water storage in soil and rocks in a certain area and time. The interrelations between these parameters can be used as an indicator of how much water is available (from runoff or groundwater) in the soil.

In general, deserts can be divided into five forms: (1) mountain and basin; (2) plateau landforms called Hamada deserts [mainly barren, hard, rocky plateaus, with very little sand, i.e. *northwest Sahara desert*]; (3) regs [with rock pavement surface covered with closely mesh packed, angular or rounded pebble and cobble size fragments, i.e. *Mojave Desert*]; (4) ergs [called also sand/dune sea or sand sheet if flat, is an extensive, flat desert area covered with wind-swept sand and almost no vegetation, i.e., *Issaouane erg, Algeria*]; and (5) intermontane basins [a semi-arid geologic structural basin filled with sedimentary rocks and an annual precipitation of 15–25 cm, i.e., *Bighorn Basin, Wyoming*]. Most of these forms are a result of æolian deflation caused by wind attributable to lack of vegetation due to low precipitation.

The easiest approach to understanding the actual meaning of the desertification concept is to walk and live in this extreme environment. There are several specific characteristics of "the desert" that fit the accepted definition of these geographical regions: (1) daily high temperature variations (>45 °C/113 °F in summer and <0 °C/32 °F at nighttime in the winter); (2) severe water deficit through evaporation, and lack of water resources (in spite of some flow of groundwater) and rain; (3) lack of ground vegetation due mainly to the first two points; and (4) poor soil quality that does not allow agricultural development (Dregne 1983; UNEP 1994).

17.2 Land Degradation

Land degradation describes how one or more of the land resources, such as soil, water, vegetation, rocks, air, climate and relief, has changed for the worse (Stocking and Murnaghan 2001). The change may prevail only over the short term,

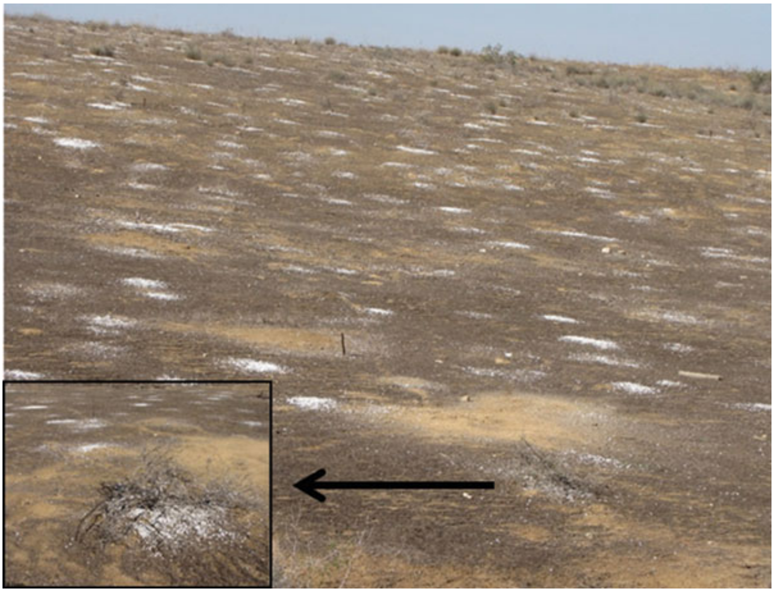

Fig. 17.1 Land degradation in the northern part of the Negev semi-arid zone, as a result of rain shortage, death of certain shrubs and their companion snails (seen as ground white spots) (Courtesy of Dr. E. Zaady, Agriculture Research Organization – Volcani Center, Israel, 2013)

with the degraded resource recovering quickly. Alternatively, it may be the precursor of a strong deterioration process, causing a long-term, permanent change in the status of the resource. It therefore includes changes to soil quality, the reduction in available water, the diminution of vegetation sources and of biological diversity, and the many other changes caused by inappropriate uses that challenge the overall integrity of land. An excellent example of such a condition has been described in the northern part of the Negev (a semi-arid area located in the southern part of Israel) (Zaady et al. 2012; Sher et al. 2012). The annual average precipitation in this area was ~200 mm; however, in the last decade it has dropped to half this amount. As a result, a process of shrub death occurred leaving behind white spots of dead white snails (gastropods reliant on shrubs as a habitat). The disappearance of these shrubs affected many ecological parameters: rain accumulation, soil biocrust changes, nitrogen loss, and the departure of animals associated with the shrubs' existence! (Fig. 17.1).

17.3 Soil Degradation

Soil is defined as a natural, three-dimensional body with definable boundaries that commonly, but not always, consists of horizons made up of mineral and organic materials, contains living matter, and can support vegetation (Soil Survey Staff 1996; Denti 2004).

Soil degradation is defined by FAO/ UNEP/ UNESCO (1979) as “A process which lowers the current and/or the potential capability of soil to produce (quantitatively and/or qualitatively) goods or services. Soil degradation is not necessarily continuous. It may take place over a relatively short period between two states of ecological equilibrium.” The processes of soil degradation are mainly water erosion, wind erosion, salinization and/or sodification, chemical degradation, physical degradation, and biological degradation. Soil degradation is considered the most critical component of land degradation and, in the framework of irreversible land degradation, the main factor of desertification (Mainguet 1994).

17.4 Proposed Framework for Desertification Indicators Classification (DPSIR)

A search among the vast mass of publications on desertification indicator systems found the concept of DPSIR (driver, state, impact, and response) has been adopted by the European Environment Agency and other organizations for soil strategy (Rubio 1990). Figure 17.2 schematically presents the main five components (each owning its special indicators) of the DPSIR approach and their interrelations. For example, in this model: *state indicators* are soil water availability, land suitability, erosion vulnerability, etc.; *pressure indicators* are human and environmental harmful effects, such as deforestation, ground water overexploitation, forest fire, etc.; *response indicators* are represented by corrective measures, such as sustainable farming, ground water recharge, terracing, storage of runoff water, etc.; *driving forces indicators* represent human activities that impact land degradation, such as intensified agriculture, overgrazing, uncontrolled tourism, and population increase; and finally *impact indicators* of the desertification process, e.g., loss of plant productivity and farm income, flooding of low land, dam sedimentation, etc.

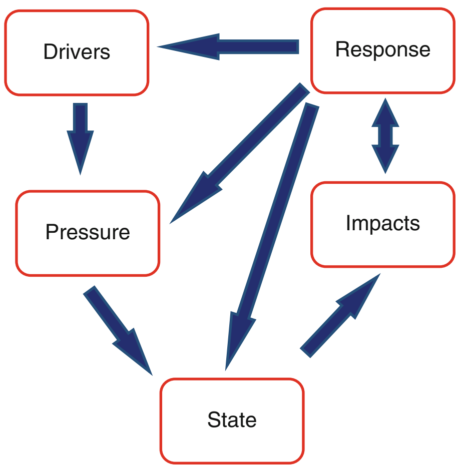

Fig. 17.2 DPSIR framework for system conditions used for classification of indicators (Gentile 1998, 2003)

A detailed description of indicators of desertification is presented in Table 17.1. Among the many suggested, the most valuable indicator of desertification is the lack of water (Imeson 2012; Berry and Ford 1977). Global water scarcity is obvious from the map showing the vast global areas of dry lands (Fig. 17.3). It is interesting to note that many urban systems overlap dry land systems (North America, Middle East, and parts of the Indian peninsula), contributing to an enhanced desertification process. Another important parameter linked to water and desertification is the constant process of deforestation in certain areas of the globe (Fig. 17.4). Continuous loss of forested areas without replacement (absence of reforestation) may cause water and soil loss, global warming, and biodiversity decline.

17.5 Other Indicator Concepts (Imeson 2012)

Beside the DPSIR approach for desertification indicators, some other concepts have been suggested, as follows:

1. *Rangeland Health* – use of physical and biological indicators to assess soil health (state and transition; resilience and functions), soil and site stability, hydrologic function, and/or biotic integrity (Pellant et al. 2005, Herrick et al. 2010) defined as:
   - **Soil and site stability** is the capacity of a site to limit redistribution of loss of soil resources (including nutrients and organic matter) by wind and water.
   - **Hydrologic function** characterizes the capacity of the site to capture, store, and safely release water from rainfall, run-off, and snowmelt (where relevant), to resist a reduction in this capacity, and to recover this capacity following degradation.
   - **Biotic integrity** is defined as the capacity of a site to support characteristic functional and structural communities in the context of normal variability, to resist loss of this function and structure caused by disturbance, and to recover following such a disturbance.
2. *Functions and ecosystem services* (de Groot 1992) – defines ecosystem functions as "*the capacity of natural processes and components to provide goods and services that satisfy human needs, directly or indirectly*." Ecosystem services can be simply defined as a set of ecosystem functions that are useful to humans (Kremen 2005; Herrick et al. 2010).
3. *Soil conservation function* – soil aggregation behavior, infiltration characteristics (clay dispersion as indicator), and soil response to slopes and catchments to extreme rainfall (Hunsaker and Carpenter 1990).
4. *Soil quality* – represented by soil functions and stability (Table 17.2)
5. *Land and soil habitat functions* – explained as the loss of fertile topsoil that produces important crops vital for humans and animals (Huxley 1890).

Table 17.1 List of candidate indicators related to causes or processes of land/soil degradation and desertification (Adapted from Anonymous 2008)

Indicator	Parameters					
Climate	**Air temperature**	**Rainfall**	**Aridity index**	**Potential evapotranspiration [ETo]**	**Rainfall seasonality**	**Rainfall erosivity**
	(° C) nearby hot spot areas	Yearly av. (mm) nearby hot spot areas	Bagnouls-Gaussen Index (BGI)	Penman-Monteith modified method[a]	Walsh and Lawler equation[b]	Fournier index (FI)
			$\mathbf{BGI} = \sum_{\mathbf{i=1}}^{\mathbf{n}} (\mathbf{2ti - Pi})\mathbf{k}$		$\boldsymbol{SIi} = \frac{1}{\boldsymbol{Ri}} \sum_{n=1}^{n=12} \boldsymbol{Xin} - \frac{\boldsymbol{Ri}}{12}$	$\mathbf{FI} = \sum_{i=1}^{12} \mathbf{Pi}^2/\mathbf{p}$
					$\boldsymbol{Ri}$ = particular annual precipitation	$\boldsymbol{Pi}$ = total precipitation in month i
			$\boldsymbol{ti}$ = monthly av. temperature (°C); $\boldsymbol{PI}$ = monthly precipitation (mm); $\boldsymbol{k}$ = proportion of month during which $2ti - Pi > 0$		$\boldsymbol{Xin}$ = monthly precipitation for month **n**	$\mathbf{p}$ = mean annual precipitation

Water	**Quality**	**Quantity**	**Ground water exploitation**	**Water consumption/water demands**
	Low salinity (low ratio of Na^+ to Ca^{+2} Mg^{+2}), sodium adsorption ratio (SAR) (mol/L), conductivity (μS)	Surface and groundwater estimates	Measured by: (1) water consumption by sector; (2) rivers, springs, and groundwater flow reduction; (3) appraisal of recharge rate in the hydrological area	Indicator is determined by dividing total consumption (WC) by total demands (WD) in all sectors (WC/WD)
	$SAR = [Na^+]/\{([Ca^{2+}] + [Mg^{2+}])/2\}**(1/2)$.			Low-WC/WD <0.5
				Moderate- WC/WD = 0.5–1
				High- WC/WD = 1–2
				Very High- WC/WD >2

Soil	**Drainage**	**Parent material**	**Rock fragments**	**Slope aspect**	**Slope texture**	**Water storage capacity**	**Exposure of rock outcrop**	**Organic matter in surfaces horizon**	**Degree of soil erosion**	**Electrical conductivity**
	Defined by the depth of hydro-morphic features (Fe, Mn) and groundwater depth	Site geo-logical map	From rock fragments of 2 mm and up in soil surface	Relative to magnetic North; NW, NE, SW, SE and plain	Related to its silt, sand, and clay components	The amount of water stored in soil available for plants growth	Bedrock exposure on soil surface	Percentage of plant material	Different exposure of parental material	Salt content of soil called salinization
Vegetation	**Major land use**	**Vegetation cover type**	**Plant cover**	**Deforested area**						
	Agriculture, pasture, shrub land, forest, min-ing, recreation, urban areas, etc.	Vines, olives, cereals, pine/oak forest, almonds, oranges, vegetables, cotton, bare land, etc.	Percentage of soil covered by green vegetation. Leaf area index (LAI) is also an expression that can be measured.	Annual deforested area as a percentage of the total land surface (mainly according to satellite-based earth observation and field data collection)						
Water runoff	**Drainage density**	**Flooding frequency**	**Impervious surface area**							
	The length of streams in a drainage basin/area of the basin	Yearly probability of damaging flood occurrence	Changes in soil use such as urbanization. Soil sealing by housing, industry, transport, waste disposal, and military that makes soil impervious							
Forest fires	**Fire frequency**	**Fire risk**	**Burned area**							
	Historic fire frequency	Structure and dominant vegetation as related to flammability and combustion capacity and recovery efficiency	Average area burned/decade on a defined territorial surface							
Agricultural	**Farm ownership**	**Farm size**	**Net farm income**	**Parallel employment**						
	The percentage of rented agricultural land (the Σ of arable land, kitchen gar-dens –“horticulture,” permanent pas-tures, meadows, and permanent crop) in the owner-farmed agricultural area	The ratio between the number of farms belonging to size classes of less than 2 ha and the number of farms belonging to size classes of more than 50 ha	Defined as Net Farm Income (NFI) = Total Output (A) − All Inputs(B) + net public receipts (subsidies-farm taxes)	The percentage of off-farm income of the Total Family Income (Farm + Off-Farm incomes)						

(continued)

Table 17.1 (continued)

Cultivation	**Tillage operations**	**Frequency of tillage**	**Tillage depth**	**Tillage directions**	**Mechanization index**
	Cultivation practices using the various tillage implements (e.g., mouldboard, chisel, duck foot chisel, harrow, etc.)	Tillage operations number/year by farmer	The depth effected by tillage operations (mouldboard and chisel plough, cultivator, harrow, etc.) that disturb the soil	The soil tillage directions such as: parallel, perpendicular, or in oblique lines, depending on the slope gradient, farm size and shape.	The motor vehicles, machinery, and plant used by the farm expressed as horsepower/hectare of the utilized agricultural area.

Husbandry	**Grazing control**	**Grazing intensity**
	Management of an equilibrium between herbivores and the resource base of rangeland to achieve a sustainable production (number of grazers, fencing, no grazing in very wet soils, fire protection of grazing area, etc.)	The pressure imposed on the growing vegetation by grazers. It can be calculated by assessment and comparison of stocking rate (SR) and grazing capacity (GC)
		$\boldsymbol{SE} = \frac{Number\ of\ grazing\ animals\ (SE)}{Area\ grazed\ (ha)}$
		$\boldsymbol{GC} = \frac{Area\ grazed\ (ha)\ \times\ maximum\ forage\ production\ \left(\frac{kg}{ha}\right)}{Monthly\ equivalent\ of\ a\ SE\ (kg)x\ Grazing\ period\ (months)}$
		E.g., High grazing intensity SR > 1.5GC

Land management	**Fire protection**	**Sustainable farming**	**Reclamation of affected areas**	**Soil erosion control measures**	**Soil water conservation measures**	**Terracing (presence/absence)**
	Presence of protective infrastructure against forest fires	Agricultural system favorable to humans and other species	Application of various methods to recover areas affected by acidification, salinization, and heavy metals contamination	Actions to reduce soil erosion: e.g., contour farming, stabilization structures, vegetated waterways, strip cropping, terraces, and small water reservoirs	Techniques such as: mulching, weed control, temporary storage of runoff in small ponds, soil surface management for maximum water vapor adsorption, cultivation, etc.	Terraces presence to reduce water erosion of cultivated erodible soil and also for water conservation

Land use	Land abandonment	Land use intensity	Period of existing land use	Urban area	Rate of change of urban area	Distance from the sea shore
	Decreased land productivity resulting in land use: from agriculture to pasture	The degree of mechanization and application or not of fertilizers and pesticides. Estimation of intensity is:	Related to cumulative long effects on land protection/degradation by present and past land use	Mainly along the cost, urban expansion into semi-natural and agricultural areas	Dispersal of built-up structures within semi-natural/agricultural areas (ha/10 years/10 km^2)	Assessment of water quality effect on soil salinization risk
		SSR = X · P · F/R				
		SSR-sustainable stocking rate				
		R-required annual biomass/animal (sheep, goat)				
		X-fraction of grazed and non-grazed soil				
		P-averaged palatable biomass after dry season				
		F-averaged fraction of soil covered with annual plant species				

Water use	Irrigation percentage of arable land	Runoff water storage	Water consumption per sector	Water scarcity
	The irrigated land area as a percentage of total arable land	Volume of runoff water stored into soil or in small ponds	Annual water consumption for: domestic, industrial, and agricultural uses (m^3/year)	Assessment of the change between water availability per capita and the water consumption per capita in the past 10 years
				WAC-water availability/person
				WCC-water consumption/person
				WHO (World Health Organization) standard to identify risk of water scarcity is 1,000–2,000 m^3; < 1,000 m^3 areas are considered as water scarcity

Tourism	Tourism intensity	Tourism change
	Defined as number of overnight stays by tourists/10 km^2/year at peak season	Assessment of tourism destination changes in the last 10 years in a specific area. Comparison of number of overnight stays in a specific area/year to the average number of tourists overnight stays in the last 10 years

(continued)

Table 17.1 (continued)

Social	Human poverty index	Old age index	Population density	Population growth rate	Population distribution
	UN Development Programme (UNDP) defines human poverty index as follows:	The percentage of population > 65 divided to total population	Indicates the level of human pressure on natural resources	Defines population growth rate that impacts long-term sustainability of natural resources	Defines population distribution related to land management, e.g., Urban vs. Rural, Mountainous vs. Lowland, Coastal vs. Inland populations
	$HPI-2=[0.25\,(P2^3+P4^3+P5^3+P6^3)]^{0.33}$	$R=\frac{\mathit{Population\ 65\ years\ old\ and\ older}}{\mathit{Total\ population}}\cdot 100$	$\text{Population Density}=\frac{\mathit{No.\ of\ individuals}}{\mathit{Area\ of\ the\ region\ in\ which\ they\ live}}$	$PGR=\frac{(\mathit{Birthrate}+\mathit{Immigration})-(\mathit{Mortality\ Rate}-\mathit{Emigration})}{\mathit{Population\ Size}}$	
	P2-illiteracy rate P4- % of people not expected to survive over 60 years	R -old age index	$=\frac{People}{km^2}$	PGR-Population growth rate	
	P5-% of people with disposable income < 50 % of the median				
	P6-% of people in long term unemployment				

Institutional	Subsidies	Protected area	Policy enforcement
	Assessment of CAP (Common Agricultural Policy) structure impacts farmers' choice of agricultural use and management practices	Area of protected land expressed as a percentage of the total land. Protected areas commonly include: biodiversity conservation, cultural heritage, scientific research, recreation, natural resources maintenance, etc.	The effectiveness of implementation/enforcement of regulations/ actions by environmental protection bodies

[a] Allen and Pruitt (1986)
[b] Walsh and Lawler (1981)

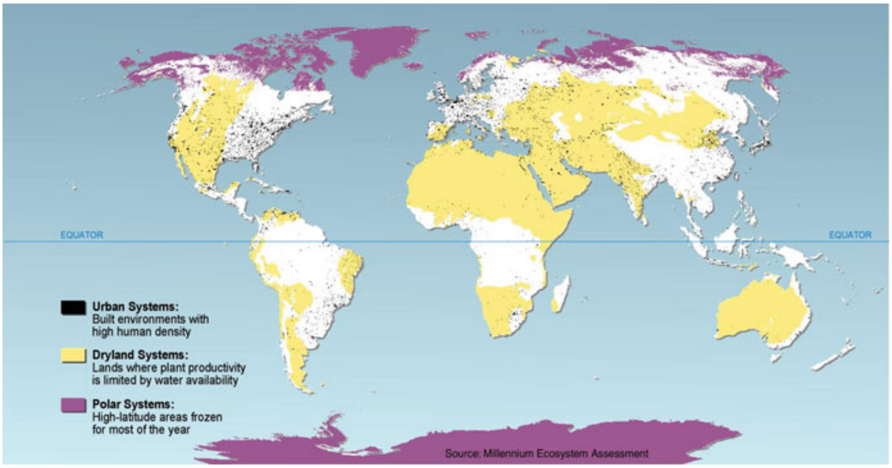

Fig. 17.3 The association between global dry lands and high density urbanization (with permission of: Millennium Ecosystem Assessment)

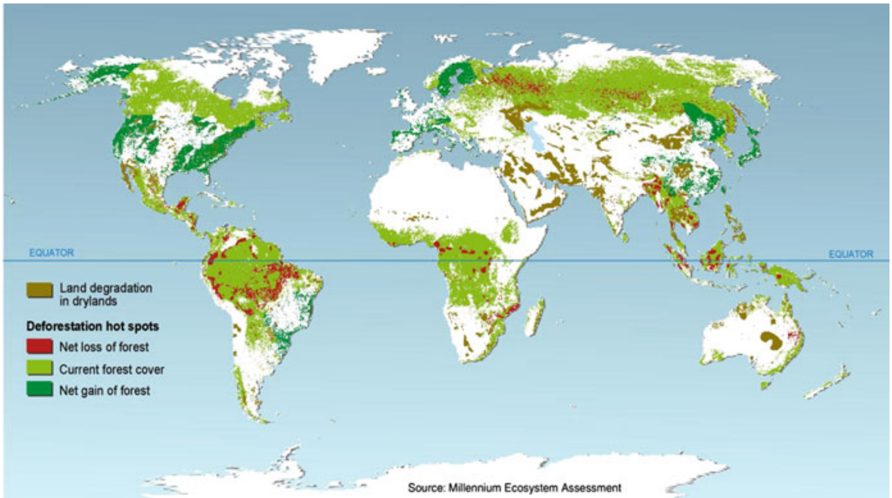

Fig. 17.4 Deforestation as one of the main causes of land degradation (with permission of: Millennium Ecosystem Assessment)

6. *Hydrology and water balance* – based on indicators such as soil moisture, infiltration, erosion, and sediment load.
7. *Dynamic and complex systems (Desertification Response Units – DRU)* – based on hierarchy theory applied in semi-arid regions for interlinked structures from microscopic soil level to general landscape level (Imeson et al. 1996).
8. *Adaptive management and panarchy* – based on hierarchy theory and resilience, it integrates policy, processes in interacting human terms, and physical

Table 17.2 Soil quality indicators: measures of soil functional state (After Doran and Parkin 1996)

Indicator category	Related soil function	Measurement methods
Chemical	Nutrient cycling, water relations, buffering	Electrical conductivity, soil nitrate phosphate and potassium, soil reaction (pH)
Physical	Physical stability and support, water relations, habitat,	Aggregate stability
		Available water capacity
		Bulk density
		Infiltration
		Slaking
		Soil crusts
		Soil structure and macropores
		Soil texture and stone content
Biological	Biodiversity, nutrient cycling, filtering	Earthworms
		Particulate organic matter
		Potentially mineralizable nitrogen
		Respiration
		Soil enzymes
		Total organic carbon
		Root Health Rating

systems (Imeson 2012). In France, for example sediment flows are managed by taking into consideration the interaction between hill slope and river channel dynamics to conserve soil. Another form of management includes watersheds treatment as a whole system with feedbacks from land use, hydrology, and sediment transport.

9. *Human use and appropriation of environment, land, and water* – as humans use most land and water sources, thus contaminating them, the key indicators are the disappearance of rivers and spread of desertification.
10. *Sustainable land use and traditional knowledge* – based on many indicators directly related to field assessment and vectorial change.
11. *Key indicators* – such as soil stability, runoff, water balance, sediment yield, subsidies, and ignorance that represent single complex system behavior with feedback to anthropogenic actions (see Table 17.1).

17.6 Summary

Desertification is a natural continuous process intensified by human activity (FAO/UNESCO/WMO 1977). Indeed, humans are to some extent able to combat this natural process with some success (see Israel experience, Boeken 2008; Carmi and Berliner 2009; Rewald et al. 2011). In order to detect desertification processes there is an obvious prerequisite for well-established indicators (Imeson et al. 1996). As previously shown in this chapter, the desertification process is a highly complex system that needs a comprehensive indicators concept (Table 17.1). Among these indicators, the DPSIR approach seems to be the most accurate and has been embraced globally. However, while organizing the present chapter on desertification indicators, it became very clear that water is a key indicator of the process, interrelated with soil and human agricultural activity. In the context of "you cannot milk the cow and not feed her," any agricultural activity has to take into account that nowadays "sustainability" is the name of the game in modern agriculture in order to prevent soil and land degradation. Furthermore, consistent with certain well-selected indicators, even non-agricultural desertification-related processes can be prevented.

References

Allen RG, Pruitt WO (1986) Rational use of the FAO Blaney-Criddle formula. J Irrig Drain Eng 112(IR2):139–155

Anonymous (2008) Manual for describing land degradation. Compiled by the Agricultural University of Athens, Department of Natural Resources Development and Agricultural Engineering (NRDAE) (ed) http://www.desirehis.eu/wimba/WP2.1%20Indicators%20manual/page_01.htm

Berry L, Ford RB (1977) Recommendations for a system to monitor critical indicators in areas prone to desertification. Program for International Development, Clark University, Worcester

Boeken B (2008) The role of seedlings in the dynamics of dryland ecosystems – their response to and involvement in dryland heterogeneity, degradation and restoration. In: Leck M, Parker VT, Simpson R (eds) Seedling ecology and evolution. Cambridge University Press, Cambridge, pp 307–330

Carmi GP, Berliner P (2009) The effect of soil crust on the generation of runoff on small plots in an arid environment. Catena 74(1):37–42

de Groot RS (1992) Functions of nature: evaluation of nature in environmental planning, management and decision-making. Wolters Noordhoff BV, Groningen

Denti GD (2004) Developing a desertification indicator system for a small Mediterranean catchment: a case study from the Serra de Rodes, Alt Empordà, Catalunya, NE Spain. Dissertation, University of Girona

Doran JW, Parkin TB (1996) Quantitative indicators of soil quality: a minimum data set. In: Doran JW, Jones AJ (eds) Methods for assessing soil quality. SSSA Inc, Madison

Dregne HE (1983) Desertification of arid lands. Harwood Academic Publishers, New York. 242 p

FAO/UNEP/UNESCO (1979) Provisional methodology of soil degradation assessment, Rome: FAO. 73 pp

FAO/UNESCO/WMO (1977) World map of desertification. United Nations conference on desertification. Nairobi, 29 August–9 September 1977, Document A/CONF.74.2

Gentile AR (1998) From national monitoring to European reporting: the EEA framework for policy relevant environmental indicators. In: Enne G, d' Angelo M, Zanolla C (eds) Proccedings of the international seminar on indicators for assessing desertification in the Mediterranean. ANPA, Rome/Porto Torres, 18–20 September, pp 16–26

Gentile AR (ed) (2003) EEA assessment and reporting on soil erosion. Technical report 94

Herrick JE, Lessard VC, Spaeth KE et al (2010) National ecosystem assessments supported by scientific and local knowledge. Front Ecol Environ 8(8):403–408. doi:10.1890/100017

Hunsaker CT, Carpenter DE (eds) (1990) Ecological indicators for the environmental monitoring and assessment program. U.S. Environmental Protection Agency, Office of Research and Development, Research Triangle Park. EPA 600/3-90/060

Huxley TH (1890–93) Selected works of Thomas Huxley Westminster edition containing III evolution and ethics (1893) and IV Capital the Mother of Labour (1890) Appeltons, 334 pp

Imeson A (2012) Desertification, land degradation and sustainability. Wiley-Blackwell, Hoboken

Imeson AC, Perez-Trejo F, Cammeraat LH (1996) The response of landscape units to desertification. In: Thornes J, Brandt J (eds) Mediterranean desertification and land use. Wiley, Chichester, pp 447–468

Kremen C (2005) Managing ecosystem services: what do we need to know about their ecology? Ecol Lett 8(5):468–479

Mainguet M (1994) Desertification: natural background and human mismanagement, 2nd edn. Springer-Verlag, Berlin/Heidelberg

Pellant M, Shaver P, Pyke DA et al (2005) Interpreting indicators of rangeland health, version 4. Technical Reference 1734-6. U.S. Department of the Interior, Bureau of Land Management, National Science and Technology Center, Denver, CO. BLM/WO/ST-00/001+1734/REV05. 122 pp

Rewald B, Rachmilevitch S et al (2011) Influence of saline drip-irrigation on fine root and sap-flow densities of two mature olive varieties. Environ Exp Bot 72:107–114

Rubio JL (1990) European desertification indicators. Symposium on desertification in the Mediterranean Area, C.E.E. (DG XII), Firenze (Italy), (CIDE's Report), June 1991

Sher Y, Zaady E, Ronen Z et al (2012) Nitrate accumulation in soils of a semi-arid ecosystem following a drought induced shrub death. Eur J Soil Biol 53:86–93

Soil Survey Staff (1996) Keys to soil taxonomy. US Government Printing Office, Washington, DC

Stocking MA, Murnaghan N (2001) Handbook for the field assessment of land degradation. Earthscan Publication, London

UNCOD (1978) United Nations Conference on Desertification. 29 Aug–9 Sept 1977 Round-up, plan of action and resolutions. UNCOD-UNEP, New York, p 43

UNEP (1994) United Nations convention to combat desertification in those countries experiencing serious drought and/or desertification particularly in Africa. Text with annexes. U.N. Environmental Programmes for the Convention to Combat Desertification (CCD)

Walsh RPD, Lawler DM (1981) Rainfall seasonality: description, spatial patterns and change through time. Weather 36:201–209

Zaady E, Sher Y, Ronen Z et al (2012) Changes in soil biological characteristics and shrub mortality following drought in the northern Negev desert (In Hebrew with English abstract). Ecol Environ 3:44–52