



## KEYNOTE PAPER

# Climate Change and Water Resources Management in Arid and Semi-arid Regions: Prospective and Challenges for the 21st Century

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The overgrowing population and the recent droughts are putting water resources under pressure and calling for new approaches for water planning and management if escalating conflicts are to be avoided and environmental degradation is to be reversed. As countries are using their water resources with growing intensity, poor rainfall increasingly leads to national water crises as water tables fall and reservoirs, wetlands and rivers empty. Global warming could cause further changes, further variability and further uncertainty. The UK Hadley Centre's global climate model was run at a spatial scale of 2.5 by 3.75° (latitude and longitude) grid squares to simulate the global climate according to scenarios of greenhouse gas concentration emission. Runs of the model assuming the emission scenario proposed by the Intergovernmental Panel on Climate Change in 1995 are analysed here for the 2050s time horizon. Outputs provide estimations of climate variables, such as precipitation and temperature, at a monthly time step. Those results, assumed representative of future climatic conditions, are compared to mean monthly values representative of the current climate and expressed in terms of percentage change. The results show that, for the dry season (April–September), by the 2050s, North Africa and some parts of Egypt, Saudi Arabia, Iran, Syria, Jordan and Israel, are expected to have reduced rainfall amounts of 20–25% less than the present mean values. This decrease in rainfall is accompanied by a temperature rise in those areas of between 2 and 2.75°C. For the same period, the temperature in the coastal areas of the Mediterranean countries will rise by about 1.5°C. In wintertime, the rainfall will decrease by about 10–15% but would increase over the Sahara by about 25%. Given the low rainfall rate over the Sahara, the increase by 25% will not bring any significant amount of rain to the region. In wintertime, the temperature in the coastal areas will also increase but by only 1.5°C on average, while inside the region it will increase by 1.75–2.5°C.

In southern Africa (Angola, Namibia, Mozambique, Zimbabwe, Zambia, Botswana and South Africa), results suggest an increase of the annual average temperature ranging between 1.5 and 2.5°C in the south to between 2.5 and 3°C in the north. The summer range is between 1.75 and 2.25°C in the south, and increases towards the north to between 2.75 and 3.0°C while the winter range is between 1.25 and 2°C in the south, and increases towards the north to between 2.5 and 2.75°C. On the other hand, the annual average will decrease by 10–15% in the south and by 5–10% in the north. The annual average decrease is 10%. However, some places will have an increase *i.e.* by 5–20% in South Africa in wintertime. In the Taklimakan region (Tarim Basin) west of China, the annual average temperature is shown to increase by 1.75–2.5°C. Annual average rainfall should increase by 5–25% in most of the region but decrease by 5–10% in some small parts. In summer, an increase by 5–15% is indicated in most of the region, and an increase by up to 25% or more during the wintertime.

In the Thar Desert (India–Pakistan–Afghanistan), estimations suggest that the annual average increase in temperature ranges from 1.75 to 2.5°C, ranging from 1.5 to 2.25°C in winter and from 2 to 2.5°C in summer. Annual average precipitation is shown to decrease by 5–25% in the region. The winter will have values closer to the annual average but the summer will have more decrease and most of the region will see a decrease closer to 25%.

In the Aral Sea basin (Kazakhstan, Turkmenistan and Uzbekistan), estimates suggest an annual average increase in temperature ranging from 1.75 to 2.25°C, higher in summer (between 2 and 2.75°C) than in winter (between 1.5 and 2°C). Rainfall should increase by 5–20% annually, in summer increasing by 5–10% in the north but decreasing by up to 5% in the south, while in wintertime, both south and north should undergo increases of 5–10% and 20–25%, respectively.

In Australia, results indicate an increase in the annual average temperature ranges of 1–1.5°C in the south to 2.5–2.75°C in the north, slightly higher during the summer than in the winter. The summer range is between 1 and 2°C in the south and increases towards the north to 2.5–3.0°C while the winter range is between 1 and 1.5°C in the south, and increases towards the north to between 2 and 2.25°C. Rainfall annual average is shown to decrease by 20–25% in the south and by 5–10% in the north.

Given the above-mentioned facts, in order to meet the water demands in the next century, some dams and water infrastructure will be built in some countries and a new paradigm by rethinking the water use with the aim of increasing the productive use of water will have to be adopted. Two approaches are needed: increasing the efficiency with which current needs are met and increasing the efficiency with which water is allocated among different uses. In addition, non-conventional sources of water supply such as reclaimed, recycled water and desalinated brackish water or seawater is expected to play an important role.

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## 1. Introduction

There has been a decrease in rainfall throughout the Mediterranean region, southern Africa and the Sahel, the Aral Sea basin and Australia over the past century.

Most of the attention is given to the impact of climate change on the increase in temperature through the use of 'global warming' or 'greenhouse effect'. However, some of the most severe impacts of climate change are likely to come not from the expected increase in temperature but from the changes in precipitation, evapotranspiration, runoff and soil moisture, which are crucial factors for water planning and management. The hydrologic system as an integrated part of the earth's geophysical system affects and is affected by the climatic condition. Changes in temperature affect evapotranspiration rates, cloud characteristics, soil moisture, storm intensity and snowfall and snowmelt regimes. Meanwhile, changes in precipitation affect the timing and magnitude of floods and droughts, shift runoff regimes and alter groundwater recharge rates. Vegetation pattern and growth rates and the changes in soil moisture regime will also be affected.

Some regions can expect an increase in the amount of precipitation, which will lead to changes in agriculture production and natural ecosystem (IPCC, 1988, 1990). In other areas, soil moisture may diminish, especially where a moisture deficit in the soil is already experienced such as in Africa. A 1–2°C rise in air temperature accompanied by a 10% reduction in the amount of precipitation may cause a 40–70% drop in mean annual river runoff, which will substantially affect agriculture, water supplies and hydroelectricity.

With respect to agriculture, there are two scenarios of impact (Jager & Ferguson, 1991).

In temperate regions:

- (1) the growing season will increase, benefiting the crop yield;
- (2) increased CO<sub>2</sub> may also benefit crops;
- (3) increase in disease and pest incidence could occur; and
- (4) the demand for irrigation water will increase.

In tropical regions:

- (1) the growing season will be reduced, adversely influencing crop yield;
- (2) higher temperature and high humidity would cause higher sterility in rice;
- (3) increased CO<sub>2</sub> may benefit dry matter production but not grain yield;
- (4) an increase in disease and pests' incidence could occur and new pests may emerge;
- (5) the uncertainties of the monsoon will make crops more vulnerable to water deficit; and
- (6) cloudiness or low radiation will adversely influence crop yield.

## 2. Possible climate change

The hydrological cycle can be affected by the future climate change in many ways (Oliver & Oliver, 1994). These effects are briefly described in the following sections.

### 2.1. Changes in precipitation

Generally, on average it is expected that it will be a wetter world. Climate models predict an increase in the

global mean of precipitation of 3–15% for a temperature increase of 1.5–3.5°C (IPCC, 1996). This average masks significant variation in regional precipitation patterns with some regions showing an increase, some a decrease and remarkable inter-annual variability. Increase in precipitation is associated with middle to high latitude continents mostly during wintertime with slight decrease in summertime. Precipitation in arid and semi-arid regions is likely to decrease.

## 2.2. Evaporation and transpiration

Evaporation of water depends largely on the availability of both energy and water. With temperature rise, the available energy for evaporation and the atmospheric demand for water from land and water surfaces increases. More water can be held by a warmer atmosphere as well as by moving air (due to changes in wind speed). Climate models suggest an increase of 3–15% in the evaporation if the CO<sub>2</sub> concentration is doubled. Potential evaporation of humid temperate regions could rise by 40% (IPCC, 1996). Transpiration from plants is affected by several factors such as plant type, plant cover, root depth, stomata behaviour and CO<sub>2</sub> concentration. There are different and conflicting messages on how plants will be affected by climate change. Some studies suggest that plants will decrease their water use if exposed to higher CO<sub>2</sub> levels. Other studies suggest that higher levels of CO<sub>2</sub> will increase the leaf area index (LAI) that counterbalances the improvement in the water use efficiency.

## 2.3. Changes in soil moisture

The change in soil moisture is simply calculated as a difference between the input to and output of the soil system. Input to the system is mainly precipitation and output is mainly evaporation, transpiration, surface runoff into rivers and lakes, drainage and deep percolation to groundwater. Soil moisture is vital for crop growth and food production as well as for supporting natural vegetation and determining its type and extent. Changes in climate in terms of precipitation patterns and evapotranspiration will directly affect soil moisture status, surface runoff and groundwater recharge. In regions with decreasing precipitation, soil moisture may be substantially reduced. It could also be reduced in regions with increasing precipitation as long as the evaporation due to high temperatures is greater than the increase in precipitation. Soil moisture is expected to increase in wintertime in the northern latitudes where precipitation significantly outweighs the increase in evapotranspiration (Gleick, 1998). At the same time,

a large-scale drying of the soil surface is expected due to higher temperatures during summer and insufficient precipitation increases or reduction in rainfall. Agriculture production and water demand will be greatly affected by such drying. The latter is also expected to take place in south-central Asia and Latin America as the increase in evapotranspiration is likely to exceed the increase in precipitation.

## 2.4. Changes in snowfall and snowmelt

Snowfall and snowmelt in some regions could be the most important hydrologic impact of climate change. Changes in temperature could lead to important changes in water availability and quality and affect the management of reservoirs and irrigation systems. Temperature increase could increase the ratio of rain to snow in cold months, decrease the length of snow season and increase the rate and intensity of warm season snowmelt. These effects could lead to an increase in average winter runoff and average peak runoff, peak runoff taking place earlier in the year, and spring runoff ending sooner, with faster reduction in soil moisture. In some regions, more attention should be given to the flood risks rather than to droughts. Higher temperature causes early snowmelt and will have implications for reservoir storage capacity and operation and for the availability of stored water for domestic and agricultural use later in the year.

## 2.5. Changes in storm frequency and intensity

Climatic extremes and storm events resulting from the changes in the hydrological cycle could have a severe impact on societies. It is not clear what global climatic changes may do to the variability of climatic conditions in terms of frequency and intensity of extremes. Little work has been done on the extreme events such as cyclones, hurricanes and more systematic impacts such as those caused by El Niño. However, there are some indications that the variability (internal standard deviation) of the hydrologic cycle increases when the mean precipitation increases and vice versa (Gleick, 1998). In a modelling study, the total area receiving precipitation decreased while the mean precipitation increased. Subsequently, one would expect more intense local storms and runoff as well as other changes in the hydrologic cycle. At present, there is little confidence in the prediction of such changes in variability. However, there are some indications that day-to-day and inter-annual variability of storms in the mid-latitudes will decrease. In addition, the models and empirical considerations suggesting that the frequency, intensity and area of tropical

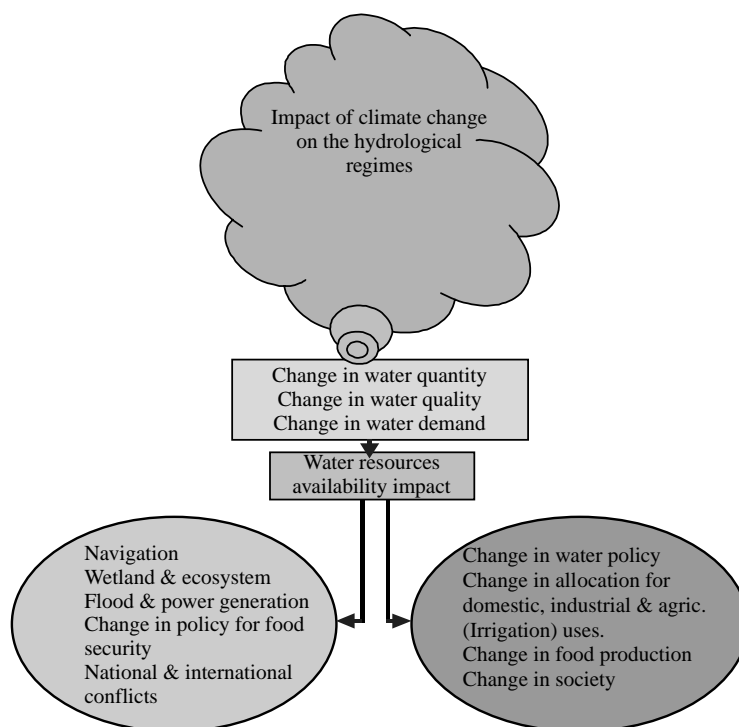


Fig. 1. Impact of climate change on the hydrological cycle

disturbances may increase. This area of work needs more modelling efforts.

## 2.6. Changes in runoff, flood and droughts

Climate and regional hydrologic models suggest that some significant changes in the timing and magnitude of runoff are likely to result from quite possible changes in climatic variables. Since society and natural ecosystems are dependent on river flows, any changes would be a good reason for concern. Flood impact may be as serious and widely spread as the adverse effect of droughts. There is indication that flooding is likely to become a serious problem in many temperate regions, which would require some measures not only for droughts and chronic water shortage, but also for flood control and associated damages to dams and reservoirs. If climate becomes more variable, some regions will be subjected to both increases in droughts and increases in floods. River flows have the potential to integrate changes in hydrologic characteristics over large areas and therefore may be used as a good indicator of climate change.

## 2.7. Hydrologic system and climate change

The water quantity and quality and subsequently the water demand will be affected greatly by the climate

change. The water resources availability is expected to affect river flow, which affects navigation, power generation and wetland and ecosystem conservation. The availability of water resources will require change in water policy, in food production and food security and might lead to national and international conflicts (Fig. 1).

Despite the gaps in data, inadequate climate monitoring, short records and bias in instrumental data, research results show that the changes in the hydrologic cycle are significant and sufficiently different from the past record to be the result of something else other than just a natural variability. The temperature data suggest that the average surface temperature of the earth has increased by 1°C over the past century. The 12 warmest years have occurred this century after 1980 and 1990, 1995 and 1997 were the warmest years in the past 500 years in the Northern Hemisphere (Gleick, 1998). These findings were supported by satellite images, which indicated an increase in length of the growing season by up to 12 days, vegetation bloomed up to eight days earlier in the spring and summer and continued to photosynthesize for four days longer. Precipitation patterns show some increase in precipitation outside the tropics, with a tendency to decline towards the subtropics, especially in the northern tropics of Africa.

Global precipitation has increased by 2.4 mm per decade since 1900 with a 2% increase in the mean value. At present, the global rainfall is about 2 mm yr<sup>-1</sup> higher

than that at the turn of the century (IPCC, 1996). Regional, national and global studies supported the trend of precipitation increase in the high latitudes of the Northern Hemisphere particularly in wintertime. In Europe, the data suggest that precipitation has increased in northern Europe and decreased in the south with strong seasonality associated with these changes with most of the increase occurring during autumntime. A decrease in precipitation has been observed in the subtropics and tropics from northern Africa to Indonesia and southeast Asia since 1960. Many parts of Africa already experience highly variable precipitation with significant regional variations and very high inter-annual variability. Lake Chad in northern Africa has shrunk from its greatest extent in the 1960s to about one-tenth that area in the 1980s (Gleick, 1998) because of the decrease in rainfall.

### 2.8. Climate change impact on water policy

While water management systems are often flexible, adaptation to new hydrologic conditions may be very costly. Water authorities should begin to re-examine engineering design assumptions, operational rules, system optimization and contingency planning for the present and future planned water management systems under a wider range of climatic conditions than are traditionally used. Water authorities should explore the vulnerability of both structural and non-structural water systems to possible future climate change, not only the past climatic variability. Government at all levels should re-evaluate legal, technical and economic approaches to manage water resources under possible climate changes. Co-operation between the water authorities and scientific communities will help in exchanging information on the state-of-the-art on climate changes and its impact on water resources. The timely flow of information from the scientific communities and water management communities and public would be very important.

Decisions on long-term water planning, the design and construction of new water supply infrastructure, the type and area of crops to be grown, urban water allocations and reservoir operation and water supply management to a great extent will depend on climatic condition and how humans respond and adapt to those conditions. Water planning and management have relied in the past on the assumption that the future climatic condition will not be different from the past condition. Water supply systems were designed based on these assumptions; dams are sized and built based on existing flows in rivers and the size and frequency of floods and droughts. Reservoirs are operated for multiple purposes based on the past hydrologic records. Irrigation systems are designed using historical information on temperature, water availability

and crop water requirements. Some infrastructures were designed to last 50 or 100 yr or even longer.

Past records of hydrological conditions may no longer be a reliable guide to the future. The design and management of structural and non-structural water resource systems should allow for the possible effects of climate change. The Aswan Dam in Egypt is an example. Inaugurated in 1971, it is a rock-filled dam, 110·70 m high above the riverbed, 980 m wide at the base and with a length of 3820 m. Lake Nasser is 450 km long and 10 km wide and is designed for the storage of 162 Gm<sup>3</sup>. There are three important levels in the lake. The level of 146 m with a capacity of 30 Gm<sup>3</sup> is the dead capacity of the reservoir only in relation to electricity generation. Electricity production stops at this level but, in times of emergency, Egypt can draw off an additional 24 Gm<sup>3</sup> of water and reduce the level of the lake to 123 m and to a dead storage capacity of only 6·8 Gm<sup>3</sup> of water. The live capacity of the lake is estimated at 90 Gm<sup>3</sup> when the lake reaches 175 m above sea level. The maximum water level of the lake is 182 m above sea level as shown in Fig. 2 (Kliot, 1994). These levels could be altered under possible climate change, *e.g.* the level below which the electricity generation stops could be different.

The Intergovernmental Panel on Climate Change (IPCC) in their report (IPCC, 1996) urged water managers to begin a systematic re-examination of engineering design criteria, operating rules, contingency plans and water allocation policies. Water demand management and institutional adaptation are essential components for increasing system flexibility to meet uncertainties of climate change. It puts more emphasis on demand management rather than construction of new facilities, introducing a change in the traditional water management approaches of the past, which relied on the construction of large and expensive infrastructures.

### 3. Predicting possible future climate change

In addition to the vast amount of data collected on the CO<sub>2</sub> emission (Marland *et al.*, 1994), a large number of global climate model (GCM) experiments have been completed recently. For this study, the experiments provided by the Intergovernmental Panel on Climate Change Data Distribution Centre (IPCC-DDC) were selected according to criteria defined by the IPCC Task Group on Scenarios for Climate Impact Assessments. These criteria comprise the use of the IS92a forcing scenario (that assumes an increase in levels of atmospheric CO<sub>2</sub> of 1% per annum), of historically forced integrations, and of forcing up to 2100 (IPCC, 1996). Historical forcing involves making the model fit the measured data, in this case measured levels of atmospheric CO<sub>2</sub>.

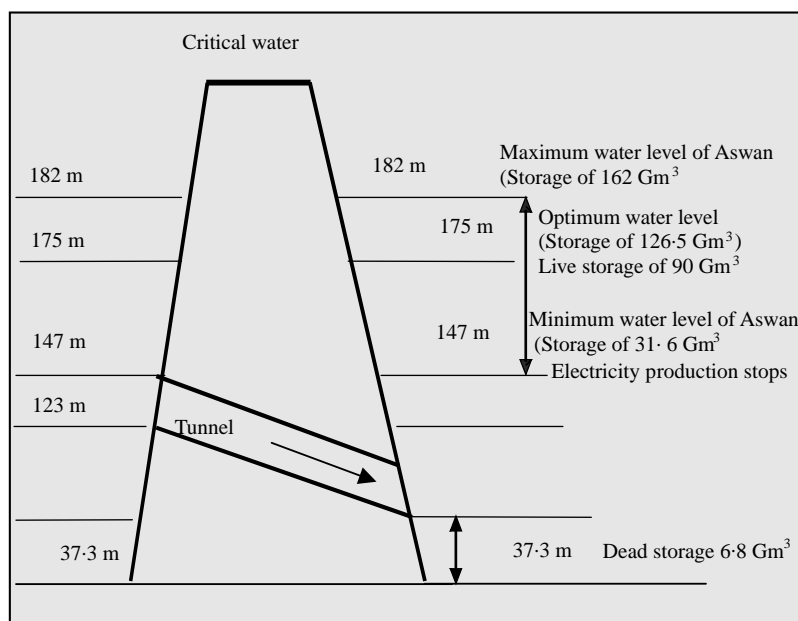


Fig. 2. Design criteria for the Aswan High Dam (after Kliot, 1994)

Results from a single GCM are exposed here. The model is the UK Hadley Centre's global climate model HadCM2, whose conceptual diagram is shown in Fig. 3. The model was run with a climate sensitivity (or increase of the global temperature due to the doubling of the effective CO<sub>2</sub>) of about 2.5°C. It models the climate back to 1860 to assure the best restitution of the current climate. It comprises 19 atmospheric levels and 20 ocean layers, and has a spatial resolution of 2.5 by 3.75° (latitude by longitude). Outputs provide estimations of climate variables, such as precipitation and temperature, at a monthly time step. Those results, assumed representative of future climatic conditions, are compared to mean monthly values representative of the current climate and expressed in terms of percentage change. The present analyses concentrate on results for the time horizon of the 2050s.

#### 4. Water resources and climate change in Africa

The drought of 1986 has affected at least 13 countries from the Sahel to southern Africa. In the 1980s, some African countries suffered severe water shortage, including Zimbabwe (1983 harvest down to a third), Botswana (rainfall halved) and Mozambique (rainfall lowest in recent history). However, the latter country was flooded in 2000. Drought has struck Kenya, Somalia and Ethiopia and famine was declared in the 1990s. The Sahel zone of west Africa is still under uninterrupted drought extending over the past 70 years. There is an agreement

that there has been a rise in global temperature during the last 100 years (Agnew & Anderson, 1992).

Africa has 53 countries and can be grouped into seven regions on the basis of geographic and climatic homogeneity, which has a direct influence on irrigation. These regions are the Northern, the Sudano-Sahelian, the Gulf of Guinea, Central, Eastern, Indian Ocean islands and Southern.

The statistics mentioned hereunder for different continents and regions are based on Aquastat information system by FAO (1999).

##### 4.1. Water resources

A distinction is made between the water resources generated from precipitation falling on the territory of the country or *internal renewable resources*, and *global renewable resources*, which includes transfers from neighbouring countries (mostly through rivers). In any case the values represent the maximum potential water resource.

The ratio between internal resources and precipitation can be considered as a 'runoff coefficient', which would take into account recharge of that portion of the aquifers, which, are not connected to the river network. This coefficient varies from 6% in arid areas to 32% in the humid zones of the Gulf of Guinea and 34% in Madagascar. The value varies from 2% in arid countries such as Libya, Niger or Botswana, up to values higher than 80% in the most humid areas of Sierra Leone and Liberia. Although they cover the largest part of the continent, the

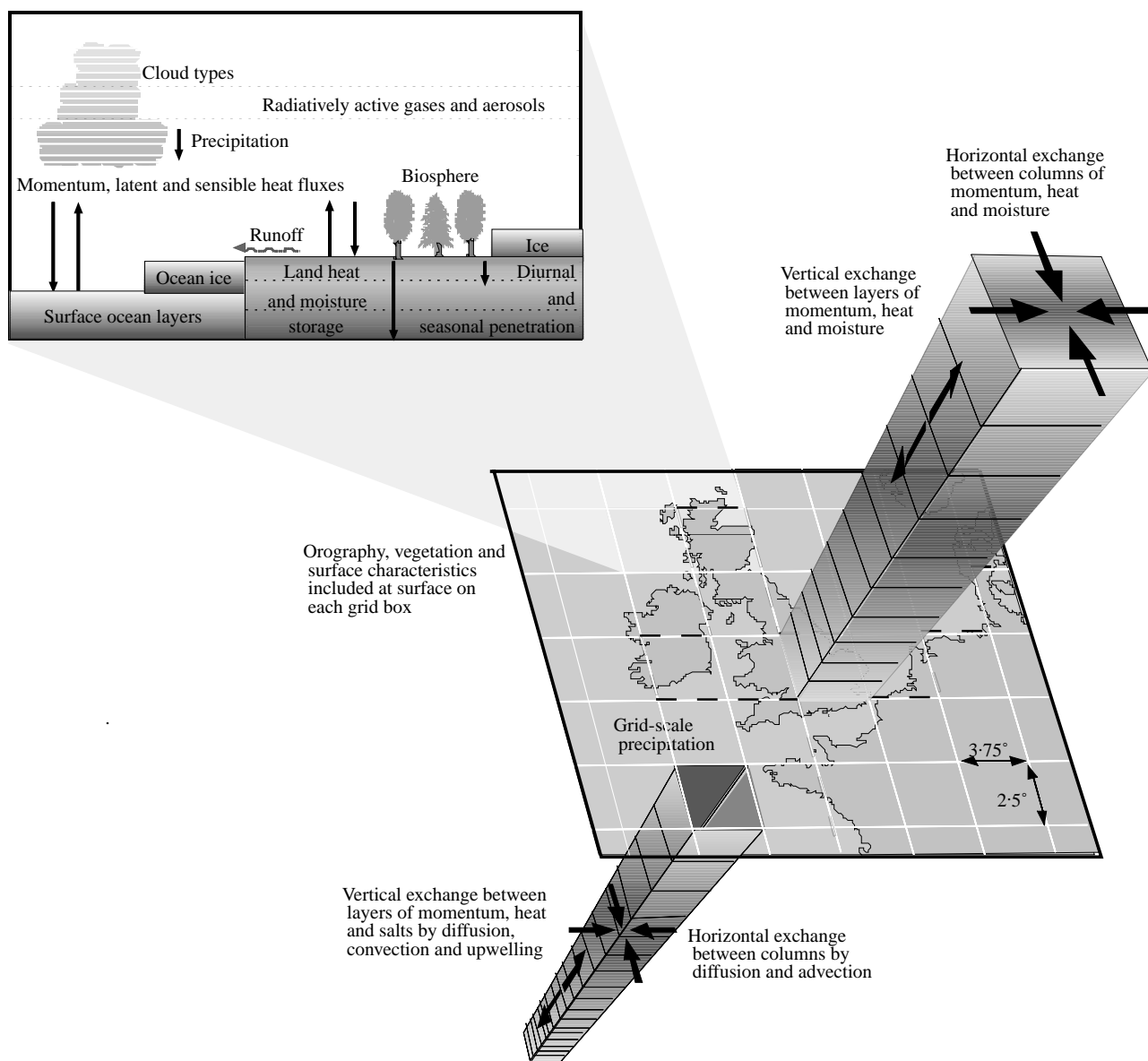


Fig. 3. Conceptual diagram of the UK Hadley Centre's global climate model HadCM2 (from Viner & Hulme, 1997)

Northern and Sudano-Sahelian regions contribute only respectively 1.2 and 4.3% of the total water resources of Africa. The Southern region also shows a very low runoff coefficient (9%).

#### 4.2. Withdrawals

About 85% of water withdrawals for the continent as a whole are directed towards agriculture but the amount varies considerably from one region to another. Arid regions, where irrigation plays an important role in agriculture, have the highest level of water withdrawal for

agriculture. The Northern region alone represents more than half of the agricultural withdrawal of the continent. Libya, Tunisia, Morocco and Algeria have almost no transfer from other countries. The rate of utilization of water resources is high. This situation requires a very strict management of the resources and leads to a competition between the sectors of water use. In Libya, the annual water withdrawal is higher than the volume of renewable resources, the difference coming from non-renewable resources (fossil water). Egypt and Mauritania also withdraw more water than is produced on their territory, but benefit from transfer from other countries through the Nile and Senegal rivers, respectively. Niger,

Somalia, Eritrea and Chad, in the Northern Hemisphere, and Namibia and Botswana in the south, have few internal renewable resources but benefit from important transfers. In these countries, withdrawal is still less than their internal resources, but some of it is already taken from incoming water.

Sudan, South Africa and Swaziland have high rates of use of their internal resources, but benefit from important resources and significant amounts of incoming water.

Wastewater treatment and reuse (Tunisia, Egypt and Morocco) and desalinated water (Cape Verde, Egypt, Libya, Mauritania and South Africa) are also indicators of scarce water resources.

#### 4.3. Irrigation potential and water managed areas

Seven countries concentrate about 60% of the irrigation potential of Africa (Angola, Sudan, Egypt, Democratic Republic of Congo (formerly known as Zaïre), Ethiopia, Mozambique and Nigeria), while at the other end of the list, 18 countries share only 5% of this potential.

The diversity of water management situations encountered in Africa requires some sort of classification, which would best represent the situation of irrigation in each country. The land on which water is used for the purpose of agricultural production has been referred to as *water managed areas*. The term *irrigated areas* has been limited to that part of the water managed areas equipped with hydraulic structures. Water managed areas comprise 14.3 million ha in Africa: the north represents more than 40% of the total. The part of water managed areas in national agriculture varies from less than 1% of cultivated land (Democratic Republic of Congo (formerly known as Zaïre) Uganda, Ghana, Togo and Comoros) to 100% in the most arid countries (Egypt and Djibouti, where agriculture is impossible without irrigation). Five countries (Egypt, Sudan, South Africa, Morocco and Madagascar), which cover 19% of Africa, hold more than 60% of the water managed areas. By adding Nigeria, Algeria, Libya, Angola and Tunisia, more than 80% of the water managed area is controlled by ten countries. In contrast, 28 countries, covering more than 30% of Africa, share a mere 5% of water managed lands.

Surface irrigation is by far the most widely used technique (more than 80% of the total). However, more than 1 million ha of irrigation by sprinkling have been reported, most of it being concentrated in the north (Libya, Egypt, Morocco and Tunisia), in Zimbabwe, in South Africa and, to a lesser degree, in Kenya and Zambia. In relative terms, sprinkler irrigation represents the most widely used technique in Botswana, Zimbabwe and South Africa, which benefit from a relatively long tradition in this

field. Finally, the most important areas under micro-irrigation are concentrated in Egypt and South Africa.

#### 4.4. Climate change in southern Africa (Angola, Namibia, Mozambique, Zimbabwe, Zambia, Botswana and South Africa)

All the scenarios correspond to the global climate model HadCM2 for the time horizon of the 2050s. They are expressed in percentage change (precipitation) compared to the Climate Research Unit (CRU) climatology corresponding to the baseline period 1961–1990 (New *et al.*, 1999). Two seasons are considered: October–March and April–September average temperature: annual baseline temperature according to the data of 1961–1990, ranges from 12.5 to 15°C in the south and from 20 to 25°C in the north. The summer range is between 15 and 17.5°C in the south and increases towards the north to between 22.5 and 27.5°C while the winter range is between 12.5 and 15°C in the south and increases towards the north to between 20 and 22.5°C [Fig. 4(g)–(i)].

Annual average baseline rainfall according to the data of 1961–1990, ranges from < 120 to 480 mm in the southwest to over 1200 mm in the north. The summer range is between < 50 and 150 mm in the region, while the winter range is between < 50 and 150 mm in the southwest and increases towards the north to over 800 mm [Fig. 4(a)–(c)].

#### 4.5. Climate change prediction

The annual average temperature is shown to increase in a range from 1.5 to 2.5°C in the south and from 2.5 to 3°C in the north. The summer range is between 1.75 and 2.25°C in the south and increases towards the north to between 2.75 and 3.0°C while the winter range is between 1.25 and 2°C in the south and increases towards the north to between 2.5 and 2.75°C [Fig. 4(j)–(l)].

The annual average rainfall decrease ranges from 10 to 15% in the south and from 5 to 10% in the north. The annual average decrease is 10%. However, some places will have an increase *i.e.* 5–20% in southern Africa in wintertime [Fig. 4(d)–(f)].

### 5. Water resources and climate change in the Near East

The Near East extends from the Atlantic Ocean (Mauritania and Morocco) in the west to Pakistan and Kyrgyzstan in the east and from Turkey and Kyrgyzstan in the north to Somalia in the south; it comprised 29 countries with a total area of 18.5 million km<sup>2</sup>, which is



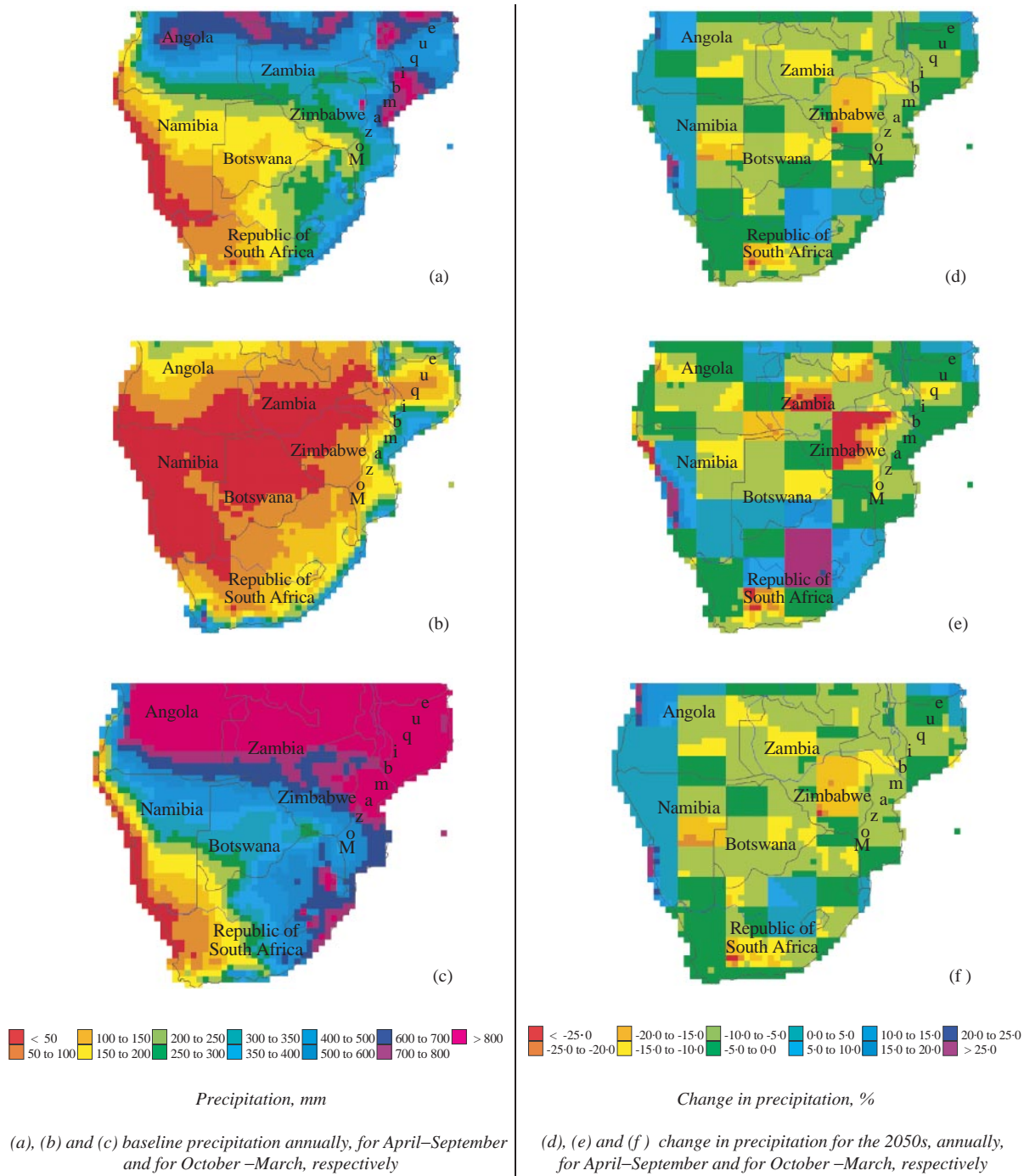


Fig. 4. — (Continued.)

about 14% of the total area of the world. The 29 countries have been grouped in five regions based primarily on geographic and hydro-climatic factors. These regions are: Maghreb—Algeria, Libya, Mauritania, Morocco and Tunisia;

North-eastern Africa—Djibouti, Egypt, Somalia and Sudan; Arabian Peninsula—Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, United Arab Emirates and Yemen; Middle East—Cyprus, Iraq, Jordan, Lebanon, Malta, Syria and Turkey; and

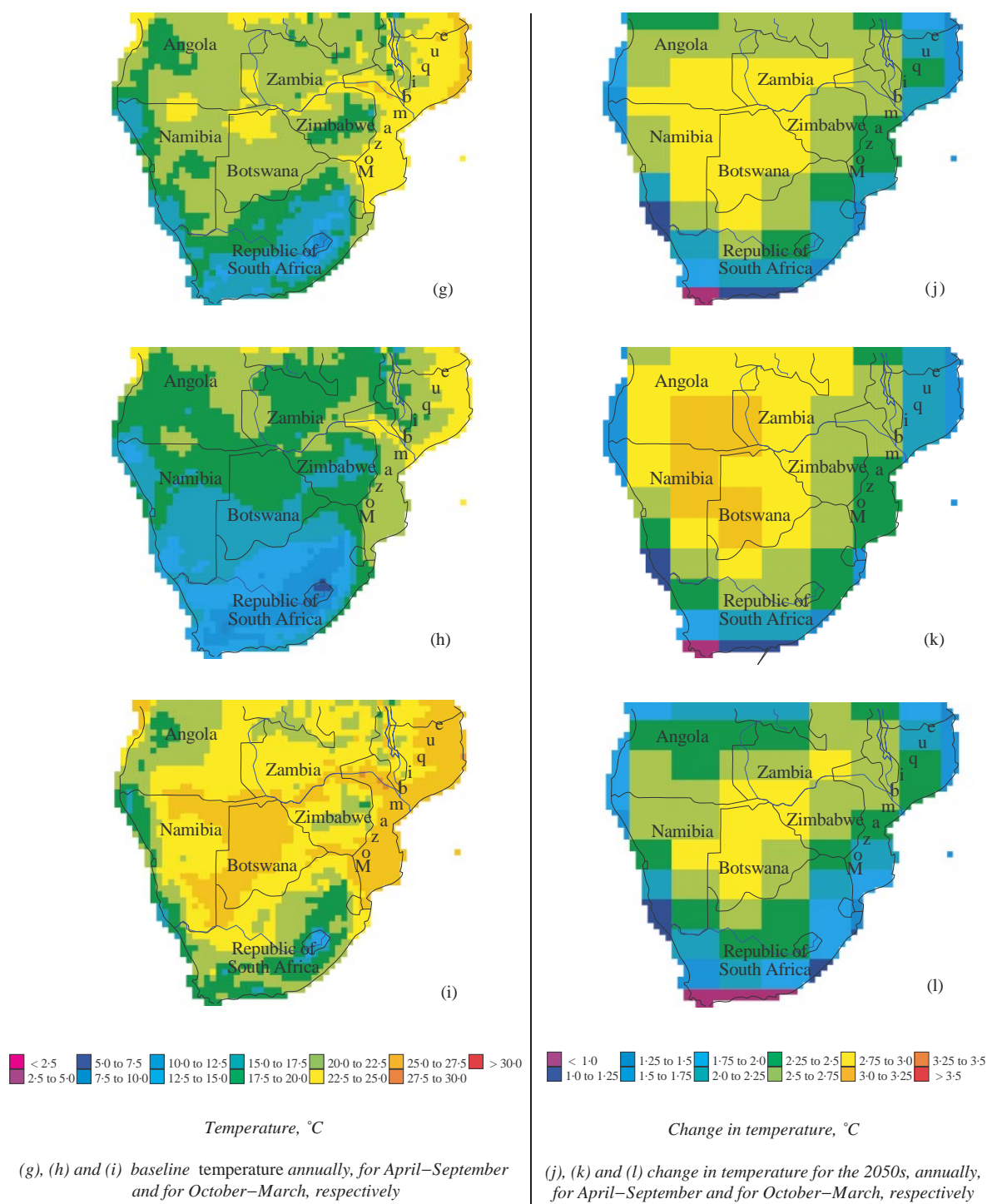


Fig. 4. Mean annual precipitation in mm and temperature in °C from the Climate Research Unit 1961–1990 and the global climate model HadCM2 prediction for the 2050s for precipitation in percentage and temperature in absolute value for southern Africa

Central Asia—Afghanistan, Iran, Kyrgyzstan, Pakistan, Tajikistan and Turkmenistan.

Owing to the aridity prevailing in the region, the Near East is the poorest region in the world in terms of water resources, globally and per inhabitant, even when

considering the contribution of rivers flowing from the bordering and more humid regions of tropical Africa (the Nile) or Himalayan Asia (the Indus). The most important rivers are the Nile in North-eastern Africa, which originates outside the region in the Equatorial Lake Plateau

and the highlands of Ethiopia, the Euphrates and the Tigris in the Middle East, the Amu Darya, the Syr Darya and Indus in Central Asia. Smaller rivers, such as the Jordan and the Orontes in the Middle East, also play an important role in international relations regarding water resources.

### 5.1. Water resources

The term internal renewable water resources (IRWR) is defined here as that part of the water resources generated from endogenous precipitation. It is computed by adding up surface runoff and groundwater recharge occurring inside the country's borders. Total renewable water resources refer to the sum of IRWR and incoming flow originating outside the countries' borders. A distinction is made between natural flow water resources (NRWR), computed by assessing the long-term yearly average of flow without any human-induced abstraction, and actual flow water resources (ARWR), which is the maximum theoretical amount of water actually available for a country. Actual flow takes into account abstraction in upstream countries and the volumes allocated through formal or informal agreements or treaties between countries. The Near East covers 14% of the total area of the world and contains 10% of its population, its water resources are only about 2% of the total renewable water resources of the world. The Maghreb, North-eastern Africa and the Arabian Peninsula have very limited water resources, with less than 10 mm annually on average and suffer severe water scarcity, with values per inhabitant varying between 200 and 700 m<sup>3</sup> yr<sup>-1</sup>. In contrast, the Middle East and Central Asia show much higher values, mostly thanks to the abundant flows generated in the mountainous areas of Turkey and in the Himalayas. The internal renewable water resources per inhabitant in the Near East are among the lowest in the world. The average for the region is 1577 m<sup>3</sup> per inhabitant yr<sup>-1</sup>, as against over 7000 m<sup>3</sup> yr<sup>-1</sup> per inhabitant for the whole world. It ranges from near zero for Kuwait, which has practically no internal renewable water resources, to about 10 000 m<sup>3</sup> per inhabitant yr<sup>-1</sup> for Tajikistan and Kyrgyzstan. For 16 out of the 29 countries the internal renewable water resources per inhabitant are below 500 m<sup>3</sup> yr<sup>-1</sup> and for 11 of them even the total actual renewable water resources are below 500 m<sup>3</sup> yr<sup>-1</sup>. For only four countries (Turkey, Kyrgyzstan, Tajikistan and Afghanistan) the internal renewable water resources per inhabitant are above 2000 m<sup>3</sup> yr<sup>-1</sup> and three of them act as 'water towers' for the region, with large amounts of water flowing to downstream countries. They are: Turkey (the Euphrates and the Tigris rivers mainly), Kyrgyzstan and Tajikistan (the

Amu Darya and the Syr Darya). Two countries, Syria and Sudan, are intermediate countries in that they depend to a large extent, around 80%, on upstream countries for their renewable water resources (mainly the Euphrates from Turkey and the Nile from Ethiopia), but on the other hand they are located upstream from other countries depending on the same rivers (Iraq and Egypt, respectively). Five countries depend for over 90% on other countries for their renewable water resources: Turkmenistan, Egypt and Mauritania for surface water and Kuwait and Bahrain for groundwater. To a lesser extent, but still over 50% dependent on other countries are Somalia and Iraq (FAO, 1997; Gischler, 1979; Seckler *et al.* 1998; World Bank, 1993; Shiklomanov, 1997; Shahin, 1996).

Several countries, that have few renewable water resources, overlie important non-renewable (fossil) ground-water basins, partly shared with neighbouring countries. In several countries (Saudi Arabia, Libya or the United Arab Emirates), by far the largest part of the total water withdrawn is fossil water, which cannot be considered sustainable in the long term, as the lack of present recharge would result in the slow depletion of the aquifers. Moreover, the water level decline and the resulting increase of the cost of pumping, as well as the deterioration of the water quality in some areas may also make the abstraction of fossil water less attractive with time.

### 5.2. Water withdrawals

In the Near East, 91% of the water withdrawal is directed towards agriculture. Central Asia has the highest level of water withdrawal for agriculture (95%). This is the region where the largest part of the cultivated area (80%) is irrigated, as compared to 16% in the Maghreb. Afghanistan is the country with the largest percentage of water withdrawal directed to agriculture (99%), Malta, with 12%, is the country with the lowest percentage. In Malta by far the largest part of the total water withdrawal, over 87%, is directed to the communities, due to the extremely high population density (1158 inhabitants km<sup>-2</sup>) and the extensive development of tourism in the country, among other reasons. In absolute terms, Central Asia represents over 58% of the total water withdrawal for the Near East, Pakistan alone withdrawing 30%. The water withdrawal per inhabitant varies from 20 m<sup>3</sup> yr<sup>-1</sup> in Djibouti (1985) to over 6000 m<sup>3</sup> yr<sup>-1</sup> in Turkmenistan (1989). At the regional level, the water withdrawal per inhabitant in Central Asia (1300 m<sup>3</sup> yr<sup>-1</sup>) is on average 3.6 times the water withdrawal per inhabitant in the Maghreb (360 m<sup>3</sup> yr<sup>-1</sup>).

### 5.3. *Use of non-conventional sources of water*

Water withdrawal, expressed as a percentage of internal renewable water resources is an indicator of the region's or country's capacity to rely on its own, renewable, sources of water. Values above 100% indicate that either renewable water flowing into the region or country from outside, or fossil, or non-conventional sources of water are used in addition to the internal renewable water resources. In 14 countries, annual water withdrawal is greater than the internal renewable water resources but five countries benefit from rivers flowing in from upstream countries, resulting in an annual water withdrawal that is lower than the actual renewable water resources. This is the case for Egypt (the Nile river), Turkmenistan (the Amu Darya), Mauritania (the Senegal river), Syria and Iraq (the Euphrates and Tigris rivers). The remaining nine countries are those of the Arabian Peninsula (except Yemen), Libya, Jordan and Malta. In these countries, water withdrawal is greater than the total actual renewable water resources and they have to rely on non-conventional water sources and on fossil water to satisfy water demand. The total use of desalinated water in the Near East is estimated at  $1727 \text{ Mm}^3 \text{ yr}^{-1}$ . In absolute terms, three countries, Saudi Arabia, the United Arab Emirates and Kuwait, are by far the largest users of desalinated water with 77% of the total for the region, with Saudi Arabia alone accounting for 41%. The total quantity of reused treated wastewater in the Near East is estimated at  $1200 \text{ Mm}^3 \text{ yr}^{-1}$ . Syria, Saudi Arabia and Egypt are the largest users of treated wastewater in absolute terms, accounting for almost 66% of all the wastewater reused in the region, with Syria alone accounting for almost 31%. Considering the use of both desalinated water and treated wastewater, the above five countries account for almost 80% of the total for the Near East.

The Arabian Peninsula is the region using the largest quantity of desalinated water and treated wastewater:  $1953 \text{ Mm}^3 \text{ yr}^{-1}$  or almost 67% of the total in the Near East Region. It is also the region where the contribution of non-conventional sources of water to total water withdrawal is greatest (8%). Central Asia uses the smallest quantity of desalinated water and treated wastewater:  $12 \text{ Mm}^3 \text{ yr}^{-1}$  or only 0.4% of the total in the Near East region. The contribution of non-conventional water sources to water withdrawal is also the lowest in this region (0.004%). In two countries (Malta and Kuwait), the contribution of non-conventional sources of water to total water withdrawal is over 50%. In three countries (Qatar, the United Arab Emirates and Bahrain) it is between 20 and 50%. For the remaining countries it is less than 10%. Table 1 illustrates the use of the non-conventional water resources in the near East Region (FAO, 1999).

### 5.4. *Irrigation potential*

Most countries of the Near East have to rely on fossil and non-conventional water. This means that, for those countries, any extension of existing irrigation would require more fossil or non-conventional water if no improvement in water use efficiency has been made.

By far the largest irrigation potential is concentrated in Pakistan and Iran and is based only on renewable water resources. One country, Cyprus, estimates that its irrigation potential is lower than the area equipped for irrigation at present, even including the future availability of non-conventional water. The reason for this is the increasing demand for water for domestic and industrial purposes and the groundwater depletion already taking place.

Arid countries, where no agriculture is possible without irrigation, tend to consider the cultivable area as the irrigation potential area, for the development of which they would certainly have to rely on the use of fossil groundwater and non-conventional sources of water.

### 5.5. *Water managed areas and irrigation*

Irrigation covers 47.7 million ha in the Near East. Central Asia represents 59% of this total, although it covers only 21% of the total area of the region. Pakistan alone, covering a little over 4% of the region, accounts for 33% of the irrigated areas. By adding Iran, Turkey, Iraq and Egypt, 72% of the areas under irrigation are controlled by five of the 29 countries, covering only 25% of the Near East.

### 5.6. *Irrigation techniques*

Surface irrigation is by far the most widely used technique, practised on 87.6% of the total area. Sprinkler irrigation is practised on 11.0% and micro-irrigation on 1.4% of the total area. In Libya and Saudi Arabia, sprinkler irrigation is by far the most predominant, while in Cyprus, Malta, Jordan and the United Arab Emirates, micro-irrigation is the most widely used technique, being practised on over half of their full and partial control irrigation areas. In Kuwait and Lebanon sprinkler irrigation and micro-irrigation techniques together are practised on more than 37 and 39% of their full and partial control irrigation area, respectively. In particular the arid countries, without large rivers, choose to develop more intensively the micro-irrigation and sprinkler irrigation techniques to save water.

**Table 1**  
**Use of non-conventional sources of water in the Near East Region (FAO, 1999)**

Country	Total water withdrawal		Desalinated water		Re-used treated wastewater		Use of desalinated water and treated wastewater	
	Year	Mm <sup>3</sup> yr <sup>-1</sup> [col (1)]	Year	Mm <sup>3</sup> yr <sup>-1</sup> [col (2)]	Year	Mm <sup>3</sup> yr <sup>-1</sup> [col (3)]	Mm <sup>3</sup> yr <sup>-1</sup> [col(4) = col (2) + col (3)]	% of total [100×col(4)/col (1)]
Afghanistan	1987	26 110·0		—		—	—	—
Algeria	1990	4500·0	1990	64·0		—	64·0	1·42
Bahrain	1991	239·2	1991	44·1	1991	8·0	52·1	21·79
Cyprus*	1993	211·0		—	1995	11·0	11·0	5·21
Djibouti	1985	7·5	1990	0·1		—	0·1	1·33
Egypt	1993	55 100·0	1990	25·0	1993	200·0	225·0	0·41
Iran	1993	70 034·0	1991	2·9		—	2·9	0·00
Iraq	1990	42 800·0		—		—	—	—
Jordan	1993	984·0	1993	2·0	1991	50·3	52·3	5·32
Kuwait	1994	538·0	1993	231·0	1994	52·0	283·0	52·60
Kyrgyzstan	1990	11 036·0		—	1990	9·0	9·0	0·08
Lebanon	1994	1 293·0		—	1991	2·0	2·0	0·16
Libya	1994	4600·0	1994	70·0	1990	100·0	170·0	3·70
Malta	1995	55·7	1995	31·4	1993	1·6	33·0	59·17
Mauritania	1985	1 630·0	1990	1·7		—	1·7	0·10
Morocco	1991	11 045·0	1992	3·4		—	3·4	0·03
Oman	1991	1 223·0	1995	34·0	1991	26·0	60·0	4·91
Pakistan	1991	155 600·0		—		—	—	—
Qatar	1994	284·9	1995	98·6	1994	25·2	123·8	43·45
Saudi Arabia	1992	17 018·0	1995	714·0	1992	217·0	931·0	5·47
Somalia	1987	810·0	1990	0·1		—	0·1	0·01
Sudan	1995	17 800·0	1990	0·4		—	0·4	0·00
Syria	1993	14 410·0		—	1993	370·0	370·0	2·57
Tajikistan	1989	12 600·0		—		—	—	—
Tunisia	1990	3 075·0	1990	8·3	1993	20·0	28·3	0·92
Turkey	1992	31 600·0	1990	0·5		—	0·5	0·00
Turkmei-n-stan	1989	22 800·0		—		—	—	—
United Arab Emirates	1995	2 108·0	1995	385·0	1995	108·0	493·0	23·39
Yemen	1990	2 932·0	1989	10·0	1992	—	10·0	0·34
<b>Near East Region</b>		<b>512 444·3</b>		<b>1 726·5</b>		<b>1 200·1</b>	<b>2 926·6</b>	<b>0·57</b>

\*The figure for total water withdrawal refers to the government controlled area; other figures refer to the whole island.

### 5.7. Salinization, drainage and environment

The Near East is a region subject to salinization and the problem has been known and recognized for a long time. Over-extraction of groundwater leads to a lowering of the groundwater table and a deterioration of the groundwater quality due to seawater intrusion and/or the upward diffusion of deeper saline water. Using saline groundwater for irrigation may increase soil salinity. All the countries of the Arabian Peninsula are facing this problem as are the islands of Cyprus and Malta and the coastal zones of countries such as Libya and Egypt. Also

in Tunisia and Djibouti, the groundwater used for irrigation is reported to be rather saline.

### 5.8. The Aral Sea Basin

The Aral Sea is not included in the Near East region. However, since most of the countries of the Aral Sea basin are part of the Near East Region, special attention has been paid to the Aral Sea basin, in view of its particular environmental problems related to water resources and irrigation. Due to the increasing need for water for



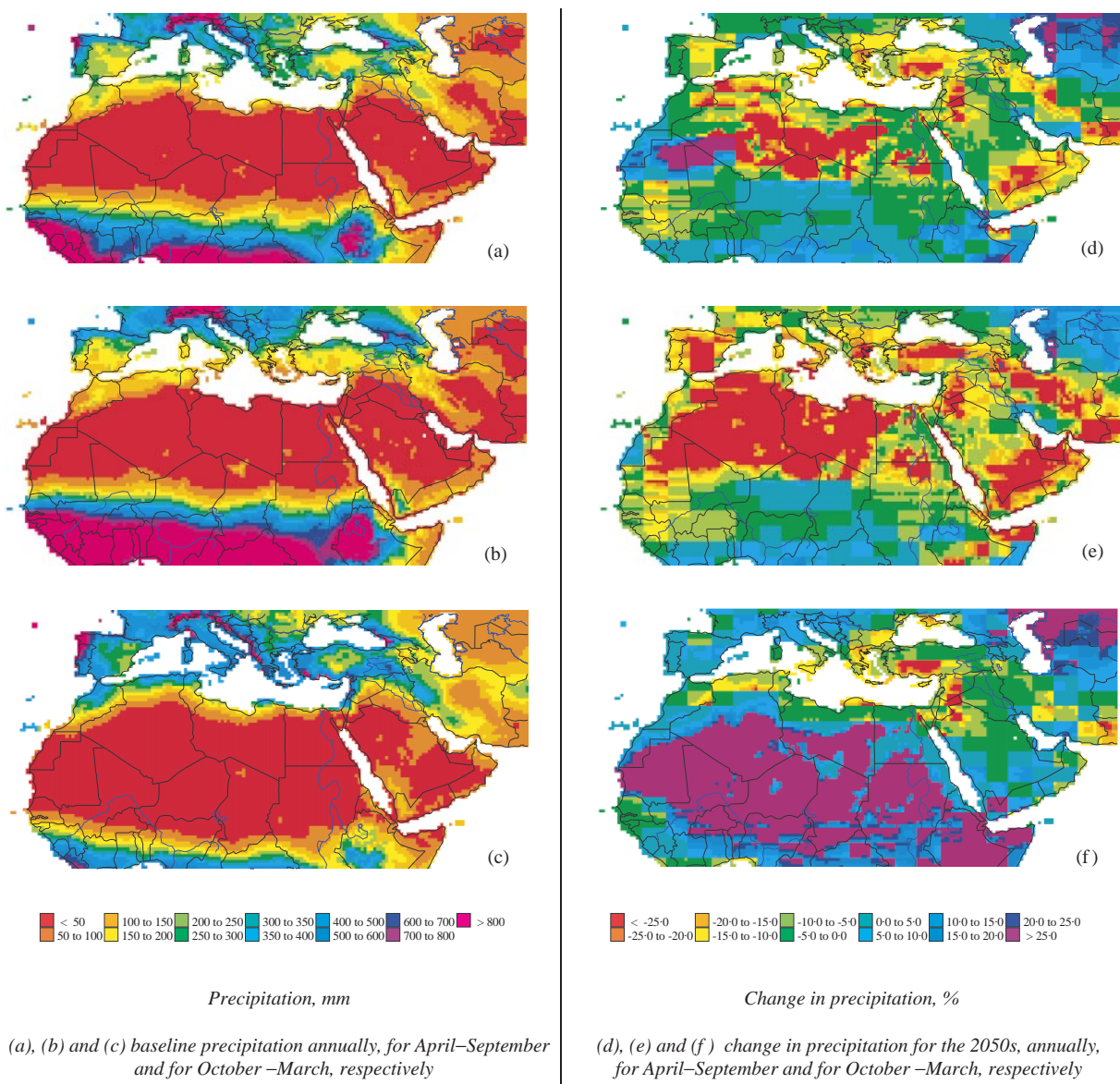


Fig. 5 — (Continued.)

irrigation in the Aral Sea basin, mainly from the 1950s onwards, the sea level continually fell as more water was diverted from its two major effluents, the Amu Darya and the Syr Darya. Between 1960 and 1965, its surface area shrank by more than half, from 64 500 km<sup>2</sup> to less than 30 000 km<sup>2</sup>. At the same time, the level fell by 19 m and its salinity tripled. Once the world’s fourth largest lake, the Aral Sea has now lost so much of its water volume that what remains is contained in three separate highly saline lakes. The dry seabed exposed to weathering has increased soil salinization and desertification around the sea. It is estimated that since the 1970s dust storms yearly spread tens of millions of tonnes of dust and salt, polluted with pesticides, over the whole region. Traces have been found

at a distance of more than 1000 km. Water logging is reported in large areas due to inefficient irrigation combined with insufficient or no drainage. In 1993, all five Aral Sea basin countries (Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan) signed an agreement to improve the situation in the basin, but so far progress has been slow due to the region’s political and economic situation.

5.9. Climate change in Mediterranean, countries north Africa and the Middle East

There has been a decrease in rainfall throughout the Mediterranean region, southern Africa and the Sahel, the

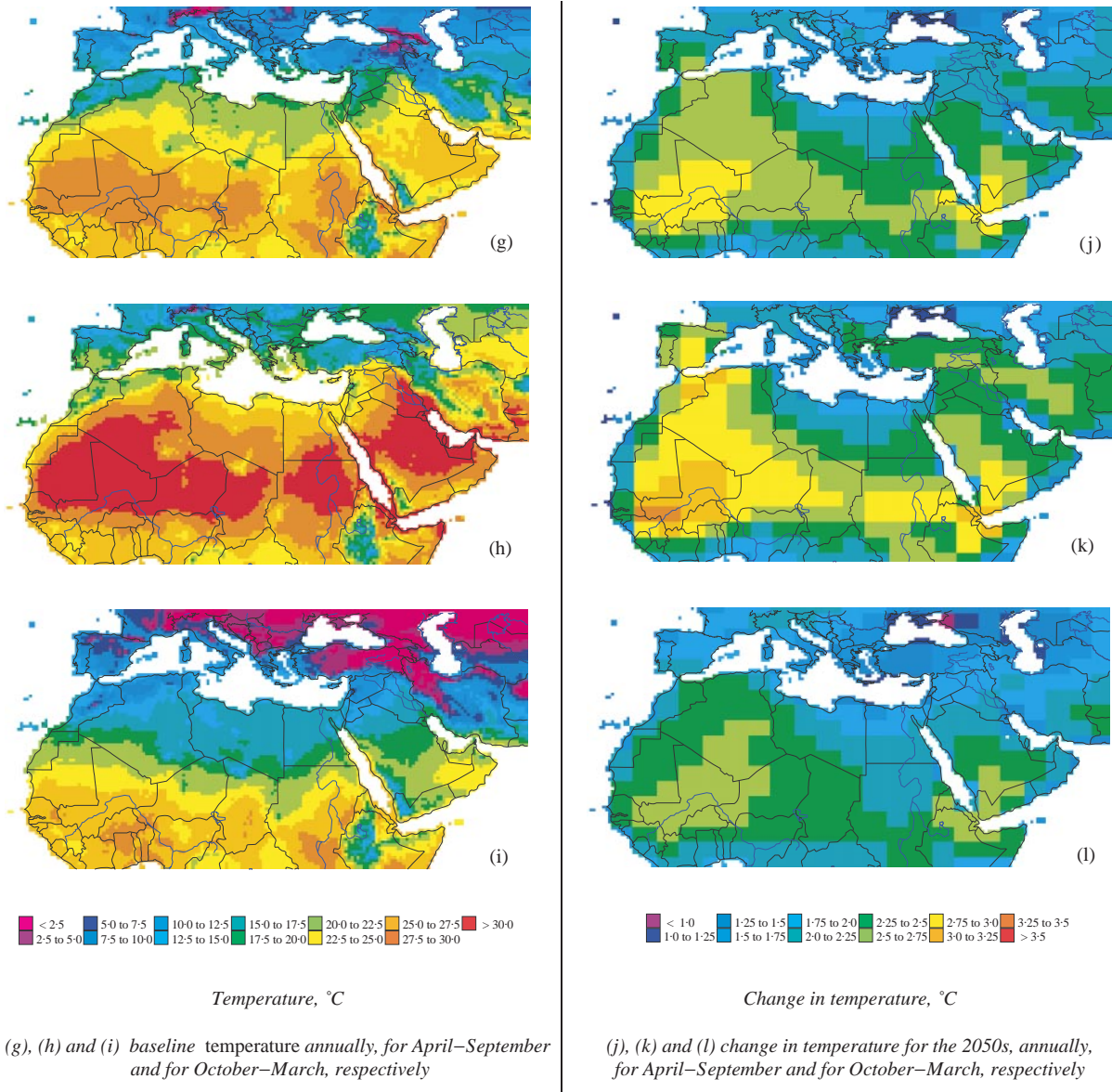


Fig. 5. Mean annual precipitation in mm and temperature in °C from the Climate Research Unit 1961–1990 and the global climate model HadCM2 prediction for the 2050s for precipitation in percentage and temperature in absolute value for the Middle East and Northern Africa (MENA)

Aral Sea basin and Australia over the past century. In the Mediterranean region for example, summer rainfall is now 20% less than at the end of the 19th century. In Tangiers, rainfall has dropped by 100 mm in 40 years and at Ifrane, in the Moyen-Atlas mountains in Morocco, by 400 mm in 30 years. Such changes create uncertainty and cast some doubt on the validity of the long-term averages of rainfall or river flow as a basis for planning water resources use.

At present, there is overexploitation of water in several countries. The water exploitation index taken as a percentage of renewable annual water resources is: 83% for

Tunisia; 92% for Egypt; 140% for Israel; 169% for Gaza; 644% for Libya (because 84% comes from non-renewable fossil water from beneath the Sahara); 50% for Syria; 25% for Lebanon; 20% for Algeria and 40% for Morocco (Acreman, 2000; Pearce, 1996).

Results from the HadCM2 model suggest that for the 2050s, rainfall is expected to be reduced annually in north Africa and some parts of Egypt, Saudi Arabia, Iran, Syria, Jordan and Israel by 20–25% less than the present mean values [Fig. 5(d)–(f)]. This decrease in rainfall should be accompanied by temperature rise in those areas between 2 and 2.75°C, while nearer the coast, the

rise should be lower (around  $1.5^{\circ}\text{C}$ ). In wintertime (October–March), rainfall should decrease by about 10–15% but would increase over the Sahara by about 25%. However, given the low rainfall rate over the Sahara, this increase does not correspond to any significant amount of rain to the region. Temperature in the coastal areas is shown to also increase but by only  $1.5^{\circ}\text{C}$  on average while inside the region it will increase by  $1.75\text{--}2.5^{\circ}\text{C}$  [Fig. 5(j)–(l)].

## 6. Water resources and climate change in Asia

Asian countries have been grouped into five regions: Indian subcontinent, Eastern Asia, Far East, Southeast and Islands.

*Indian subcontinent.* The Indian subcontinent with an area of  $3\,961\,680\text{ km}^2$  represents about 18% of the total area of the region. It is made up of India, Bangladesh, Bhutan, Nepal, Sri Lanka and Maldives.

*Eastern Asia.* The Eastern Asia region includes China, Mongolia and the Democratic People's Republic of Korea (DPR Korea).

*Far East.* The Far East region includes Japan and the Republic of Korea.

*Southeast.* The Southeast region with an area of  $1\,939\,230\text{ km}^2$  or 9.5% of the total area of the region, is composed of Myanmar and the four riparian countries of the lower Mekong basin (Cambodia, Thailand, Viet Nam and Lao PDR).

*Islands.* This region includes the countries of the Indian and North Pacific oceans from Malaysia to Papua New Guinea. The total area of the region is about 20.4 million  $\text{km}^2$ , which is 15% of the total land area of the world. China and India together represent about 63% of this area. The total population of the region was estimated in 1996 at 3030900920 inhabitants, about 53% of the world's population. The population of Asia is predominantly rural: about 67% of the total, compared to 54% for the world as a whole. This reflects the importance of agriculture in the Asian countries.

### 6.1. Water resources

The large range of climates encountered in the region generates a variety of hydrological regimes. The region is host to some of the most humid climates (with annual precipitation above 10 m in places) giving rise to major rivers, while in other parts it has a very arid climate, with

closed hydrologic systems. As a result, the region shows a very uneven distribution of its water resources and of its water use conditions. In the humid areas, water management concerns have mostly been dominated by considerations related to flood control. This is the case in the Mekong, Brahmaputra and Ganges basins. In the arid areas, such as in central China, where water is scarce, hydrological studies have been oriented much more towards water resources assessment.

The total area of the region represents 15% of the world's land surface, it receives 22% of its precipitation and produces 28% of its water resources. The region is home to 53% of the world's population, the amount of water resources per inhabitant is only slightly above half the world's average. The relative aridity of the countries of Eastern Asia is shown by the precipitation, which is between two and five times less than the average of the other regions. The figure of  $2000\text{ m}^3$  per inhabitant yr is usually used as an indicator of water scarcity: India and China are reaching this limit, while the Republic of Korea is already below it, at  $1538\text{ m}^3$  per inhabitant yr and the Maldives have a chronic water scarcity, with  $114\text{ m}^3$  per inhabitant yr. Furthermore, in the case of India, 34% of the water flows from neighbouring countries, the country's internal water resources being only  $1334\text{ m}^3$  per inhabitant yr.

### 6.2. Water withdrawal

In Asia, almost 84% of the water withdrawal is used for agricultural purposes, compared to 71% for the world. The Indian subcontinent and Eastern Asia have the highest level of water withdrawal for agriculture with 92 and 77%, respectively. Water withdrawal expressed as a percentage of TRWR, which takes into account the incoming or border flows and the existing agreements, is a good indicator of the pressure on water resources. Roughly, it can be considered that pressure on water resources is high when this value is above 25%, as is the case for India and the Republic of Korea with 34 and 26%, respectively. China, Japan, DPR Korea and Sri Lanka also have high values with 18.57, 21.26, 18.36 and 19.54%, respectively. Industrial water withdrawal is particularly important in Eastern Asia (18%) and the Far East (16%), where the industrial sector is more developed.

In most countries, treatment plants for wastewater are non-existent. Information on re-used treated wastewater exists only for China and Japan, where the re-used treated wastewater is reserved for the industrial sector. In addition, about 40 and  $0.37\text{ Mm}^3$  of water are produced by the desalinization of seawater in Japan and Maldives, respectively.



**Table 2**  
**Wastewater and non-conventional sources of water in selected countries in Asia (FAO, 1999)**

Country	Year	Produced wastewater, km <sup>3</sup>	Treated wastewater, km <sup>3</sup>	Re-used treated wastewater, km <sup>3</sup>	Desalinated water, km <sup>3</sup>
China	1995	37.29	23.33	13.39	—
India	1988	4.91	0.60	—	—
Japan*	1993	32.80	11.37	0.08	0.04
Korea, Rep.	1996	7.95	4.18	—	—
Malaysia	1995	2.69	0.39	—	—
Philippines	1993	0.07	0.01	—	—
Thailand	1995	0.083	0.04	—	—

\*Figure for desalinated water is for 1996.

### 6.3. Irrigation

The irrigation potential for the region was estimated at 235 million ha, taking into account only the countries for which data were available. India and China account for about 76% of this total, with 113.5 million ha in India and 64 million ha in China.

### 6.4. Irrigation techniques

Surface irrigation is by far the most widespread irrigation technique in the region. It includes all paddy rice cultivation and most of the other crops. In most countries, sprinkler or drip irrigation systems are reported not to exist or are in very limited use. Mongolia is the only country where sprinkler irrigation represents a significant part of the area under irrigation.

### 6.5. Non-conventional sources of water

Treated wastewater has become a more attractive source than desalinated water in some Asian countries in the Far East (Table 2) as desalinating water costs more. Moreover, using wastewater would also make use of the existing source.

### 6.6. The arid region of China: the Taklimakan region (Tarim Basin) west of China

*Current climate.* The average annual baseline temperature according to the data of 1961–1990, ranges from 10 to 15°C. The summer range is between 20 and 25°C, while the winter range is between <2.5 and 5°C [Fig. 6(g)–(i)].

The average annual baseline rainfall according to the data of 1961–1990, ranges from <120 to 240 mm [Fig. 6(a)–(c)].

*Climate change estimations.* Mean annual temperature is expected to increase in a range from 1.75 to 2.5°C by the 2050s [Fig. 6(i)–(k)]. Annual average rainfall should increase by between 5 and >25% in most of the region but decrease by between 5 and 10% in some small parts. In the summer, there will be an increase of between 5 and 15% in most of the region and an increase of 25% or more during the winter time [Fig. 6(d)–(f)].

### 6.7. The Thar Desert (India–Pakistan–Afghanistan)

*Current climate.* The average annual baseline temperature according to the data of 1961–1990, ranges from 22.5 to 27.5°C. The summer range is between 25 and >30°C, while the winter range is between 15 and 25°C [Fig. 7(g)–(i)].

The average annual baseline rainfall according to the data of 1961–1990, ranges from <120 to 360 mm. In winter, it ranges between 100 and 250 mm, while in summer it ranges from <50 and 150 mm [Fig. 7(a)–(c)].

*Climate change estimations.* By the 2050s, the mean annual temperature should increase by 1.75–2.5°C, within a range of 1.5–2.25°C in winter and 2–2.5°C in summer [Fig. 7(j)–(l)]. The mean annual rainfall should see a decrease of 5–25% in the region, especially in the summer where most of the region should experience a decrease closer to 25% [Fig. 7(d)–(f)].

## 7. Water resources and climate change in the former Soviet Union

The former Soviet Union (FSU), which covers part of the European and Asian continents, comprises 15 countries. The 15 countries have been grouped in five: Russian Federation; Central Asia—Kazakhstan, Kyrgyz Republic, Tajikistan, Turkmenistan and Uzbekistan; Eastern

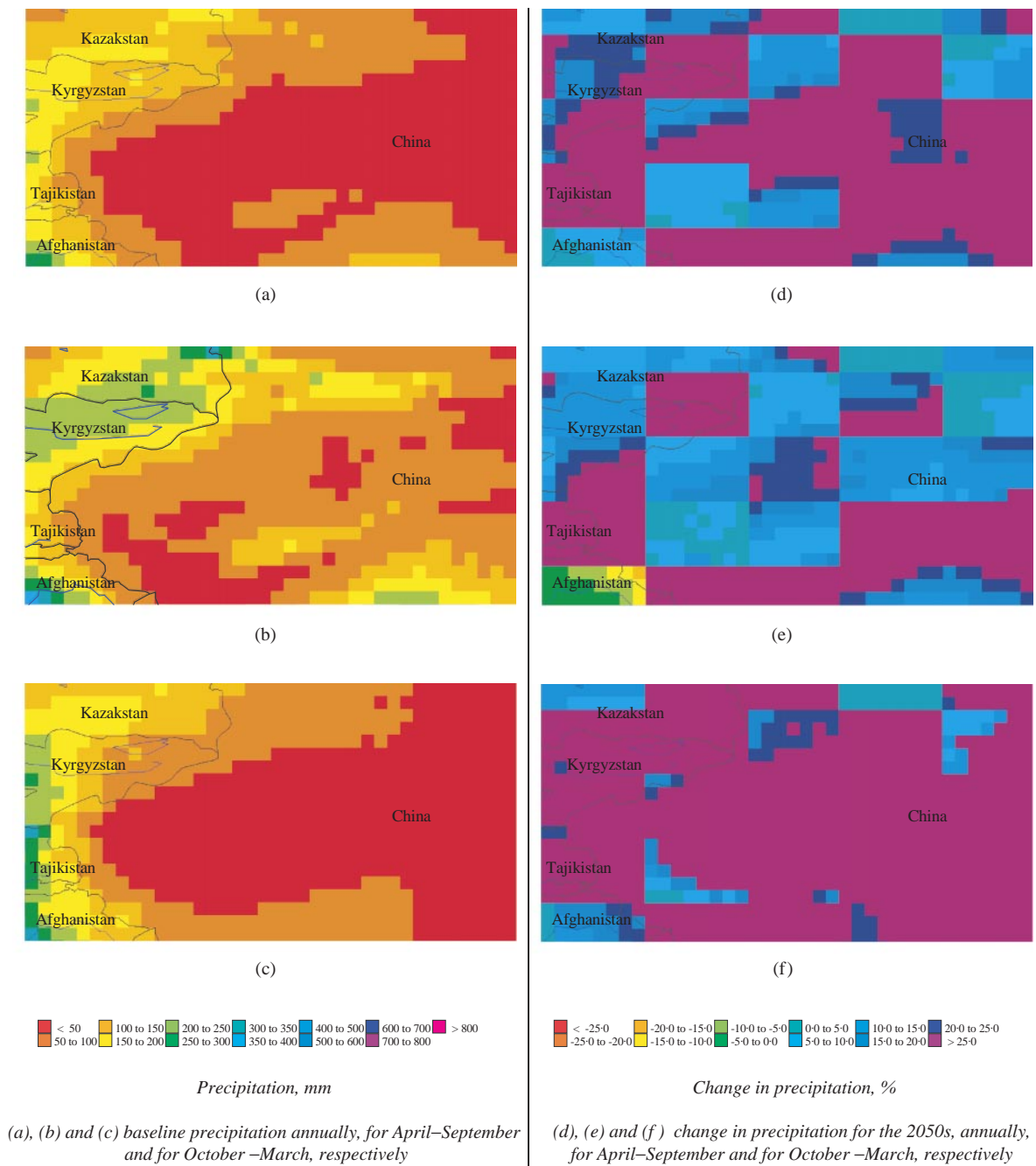


Fig. 6 — (Continued.)

Europe—Belarus, Moldova and Ukraine; Caucasus—Armenia, Azerbaijan and Georgia; and Baltic States—Estonia, Latvia.

The total area of the FSU is about 22.3 million km<sup>2</sup>, which is almost 17% of the total area of the world. The total population of the FSU was about 293 million in 1996, which represents 5% of the world population. About 32% of the total population of the countries of the FSU is rural, compared with 54% for the whole world.

7.1. Water resources

The annual renewable water resources (RWR) for the FSU are 12% of those for the world. However, as the FSU contains only 5% of the world's population, the annual internal renewable water resources (IRWR) per inhabitant, over 16 000 m<sup>3</sup>, are more than twice the world average. There is a wide variation by region: Eastern Europe, with the highest population density, having

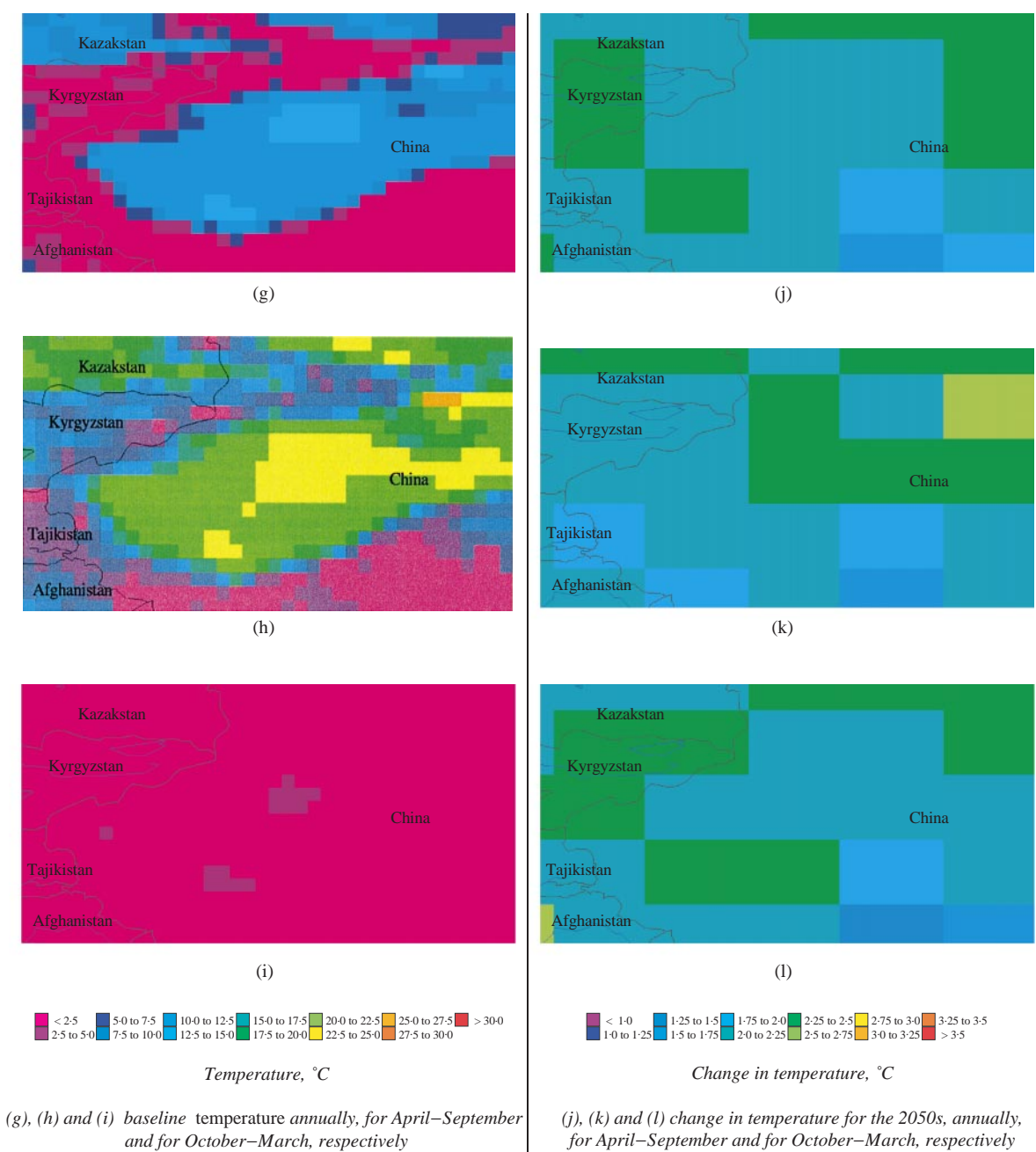


Fig. 6. Mean annual precipitation in mm and temperature in °C from the Climate Research Unit 1961–1990 and the global climate model HadCM2 prediction for the 2050s for precipitation in percentage and temperature in absolute value for Taklimaken region

IRWR of only 1375 m<sup>3</sup> yr<sup>-1</sup> per inhabitant and the Russian Federation, with the lowest population density, having over 29 000 m<sup>3</sup> yr<sup>-1</sup> per inhabitant. In Moldova, the IRWR per inhabitant are only 225 m<sup>3</sup> yr<sup>-1</sup>; in Turkmenistan 327 m<sup>3</sup> yr<sup>-1</sup>. However, looking at the actual renewable water resources (ARWR), these amounts are 2622 and 5949 m<sup>3</sup> yr<sup>-1</sup> per inhabitant, respectively, thanks to the importance of flow coming from neighbouring countries.

7.2. Water withdrawal

In the FSU, 62% of the water withdrawal is directed towards agriculture, compared to 69% for the whole world. Central Asia has, with 91%, the highest level of water withdrawal for agriculture. Industrial water withdrawal is particularly important in the Russian Federation and in Eastern Europe. The water withdrawal per inhabitant varies from less than 70 m<sup>3</sup> yr<sup>-1</sup> in Lithuania

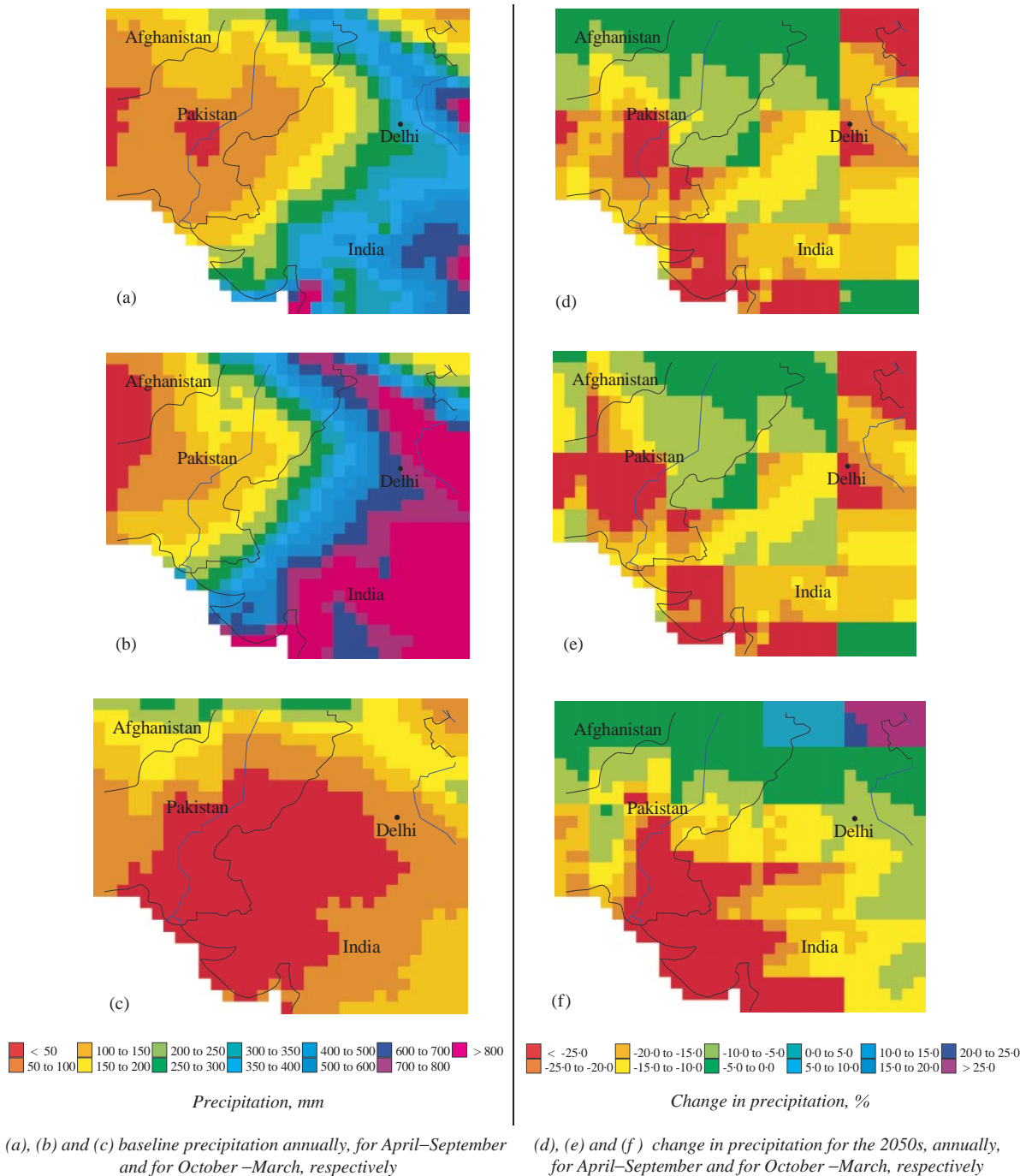


Fig. 7. — (Continued.)

to more than  $5700 \text{ m}^3 \text{ yr}^{-1}$  in Turkmenistan, compared to  $560 \text{ m}^3 \text{ yr}^{-1}$  for the whole world. The water withdrawal per inhabitant in Central Asia is almost 30 times that in the Baltic States. While Central Asia uses almost 67% of its IRWR (the amount would be close to 100% for the Aral Sea basin only, if losses from rivers and canals were included), the Baltic States use only 1.5%. The FSU as

a whole uses less than 6% of its RWR, compared with 8% for the whole world.

7.3. Use of non-conventional sources of water

The total quantity of produced wastewater in the FSU is reported to be about  $48 \text{ km}^3 \text{ yr}^{-1}$ , of which about 25%

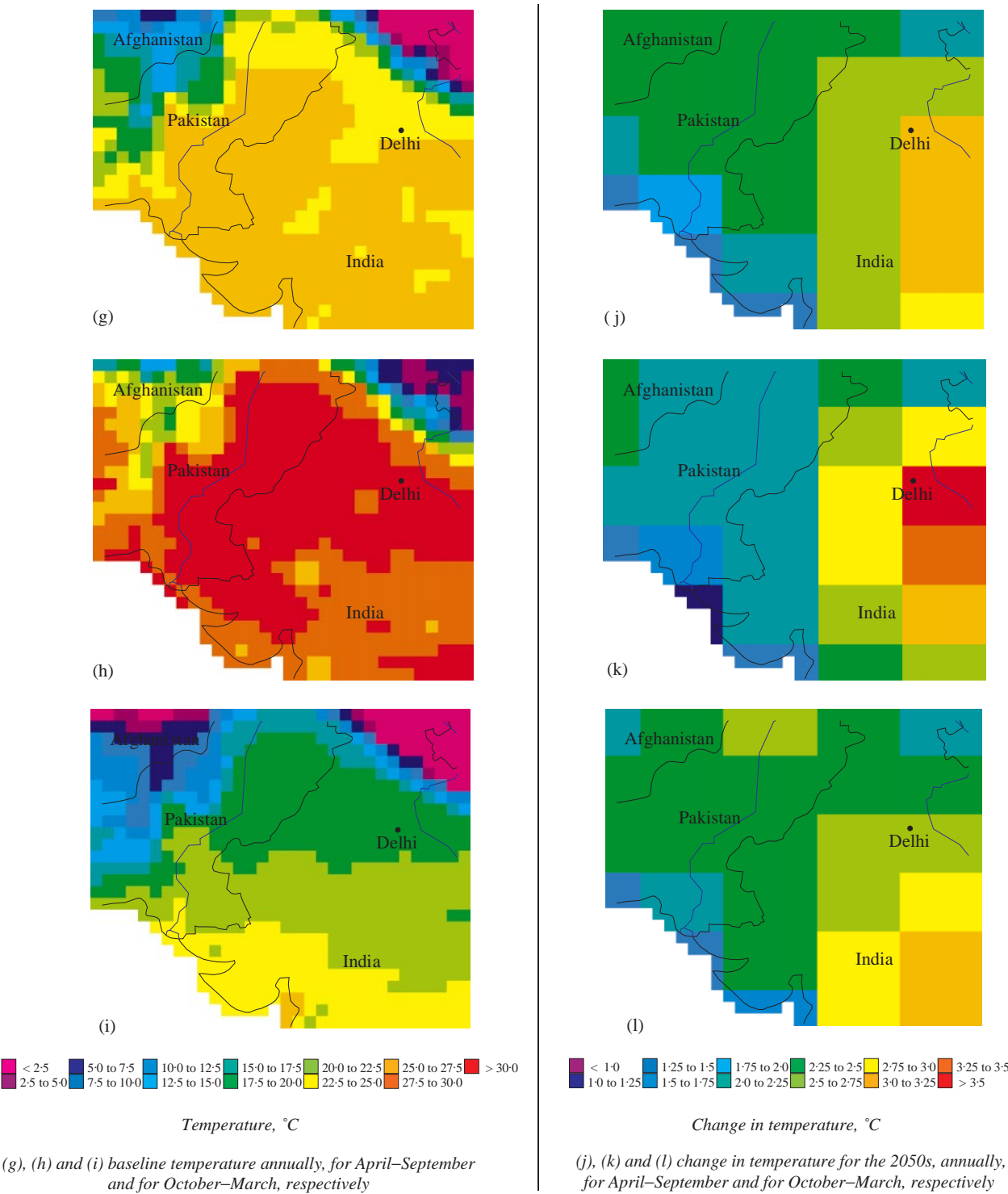


Fig. 7. Mean annual precipitation in mm and temperature in °C from the Climate Research Unit 1961–1990 and the global climate model HadCM2 prediction for the 2050s for precipitation in percentage and temperature in absolute value for the Thar desert

is treated. Information on the re-use of treated wastewater was available for only 6 of the 15 countries: 0.32 km<sup>3</sup> yr<sup>-1</sup>, of which 0.27 km<sup>3</sup> yr<sup>-1</sup> in Kazakhstan. The total quantity

of re-used domestic and industrial wastewater in the Aral Sea basin is reported to be about 3 km<sup>3</sup> yr<sup>-1</sup>, which means that most of the re-used wastewater is untreated.

In general, the re-use of treated or untreated wastewater concerns a relatively low quantity compared to the produced wastewater quantity. This is probably related to the fact that in many countries water is not scarce.

Amounts of agricultural drainage water are only available for the Central Asian countries, where it plays a significant role. In 1993, the total agricultural drainage water was estimated at about  $49 \text{ km}^3 \text{ yr}^{-1}$ , of which  $40 \text{ km}^3 \text{ yr}^{-1}$  in the Aral Sea basin. About 15% was reported to be directly re-used for irrigation in the Aral Sea basin (see the section on the Aral Sea basin).

Irrigation covers almost 23 million ha in the FSU, half of which is located in Central Asia and about one-quarter in the Russian Federation.

#### 7.4. Irrigation techniques

For the FSU as a whole, surface irrigation, with 58.3%, is the most widely used technique, followed by sprinkler irrigation with almost 41.7%. Micro-irrigation is practised on 0.05% of the irrigated area. Surface irrigation predominates in Central Asia and the Caucasus, ranging from 76% in Kazakhstan to 100% in Tajikistan. Sprinkler irrigation is predominant in the Baltic States, the Russian Federation and Eastern Europe, ranging from 80% in Ukraine to 100% in the three Baltic states and Belarus. An exception is Moldova, where surface irrigation predominates.

#### 7.5. The Aral Sea basin

The Aral Sea basin, located in Central Asia, has undergone many changes in the recent past. The Aral Sea, the world's fourth largest lake before 1960, has been progressively drying up. With the end of the Soviet era, the international community has become aware of this problem and focused on what is considered one of the major anthropogenic environmental degradations in the world. The purpose of this section is to present the Aral Sea basin, the causes of the drying up of the lake, the present trends and the solutions being studied by the governments of the countries of the region.

##### 7.5.1. Water resources of the Aral Sea basin

The Aral Sea, located in a depression in the Turan plain, is fed by two major rivers: the Amu Darya in the south, and the Syr Darya in the north, which rise in the southwestern Pamir and Tien Shan mountain ranges, respectively. The combined hydrologic basin of these two rivers has a total area of about  $1.9 \text{ million km}^2$  and extends over six countries. The average annual RSWR in the Aral Sea basin are estimated at  $115.6 \text{ km}^3$ , of which  $78.46 \text{ km}^3$  in the Amu Darya basin and  $37.14 \text{ km}^3$  in the Syr Darya basin. For a 20-yr return period, the values are  $46.9 \text{ km}^3$

for the Amu Darya and  $21.4 \text{ km}^3$  for the Syr Darya. The evaporation over the lake is estimated at about  $60 \text{ km}^3/\text{year}$ . The Aral Sea level was then fluctuating at around 50–53 m above sea level.

##### 7.5.2. Irrigation development in the basin and the drying up of the Aral Sea

The development of irrigation in the Soviet part of the Aral Sea basin was spectacular: from about 4.5 million ha in 1960, it rose to almost 7 million ha in 1980. The population increased from 14 million inhabitants in 1960 to about 27 million inhabitants in 1980. The total water withdrawal increased from  $64.7 \text{ km}^3$  in 1960 to  $120 \text{ km}^3$  in 1980, of which more than 90% was for agricultural purposes. It resulted in the disruption of the prevailing water balance in the basin.

The consequences of this huge irrigation development are numerous.

- (1) Many tributaries have been exploited to such an extent that they no longer contribute directly to the flow of the Amu Darya and Syr Darya rivers.
- (2) The intensification of irrigated agriculture has led to major waterlogging and salinization. In 1995, the irrigated area was almost 8 million ha, compared with 4.5 million ha in 1960. The main causes of this soil deterioration are: the low irrigation efficiencies, due particularly to the small percentage of lined drains and the absence of a drainage network, or its poor state. In 1994, about 40% of the irrigated land in the basin was saline. Agriculture in the Aral Sea basin has been practised with a high level of inputs, particularly fertilizers and pesticides, and this has resulted in the deterioration of surface water and groundwater quality. The salt content of groundwater in the lower reaches of the river basins varies between 1 and  $30 \text{ g l}^{-1}$ .
- (3) The Aral Sea is drying up. Its level has dropped by 17 m, its surface area has fallen by a half and its volume by three-quarters. The mineral content of the water has increased four-fold to  $40 \text{ g l}^{-1}$ , preventing the survival of most of the fish and wild life in the Aral Sea.
- (4) With the reduction of the size of the Aral Sea, its climate modifying function has been lost. The climate around the sea has changed, becoming more continental with shorter, hotter, rainless summers and longer, colder, snowless winters. The growing season has been reduced to an average of 170 days per year. Desert storms are frequent, occurring on more than 90 days a year.

##### 7.5.3. Water supply management

Currently, a proposal to transfer water from the Caspian Sea to the Aral Sea is being studied. Greater use



of agricultural drainage water and wastewater, as well as the introduction of more salt-tolerant crops, have also been envisaged and in part implemented. In 1993, agricultural drainage water was estimated at about  $40 \text{ km}^3 \text{ yr}^{-1}$  and the re-use of industrial and domestic wastewater was about  $3 \text{ km}^3 \text{ yr}^{-1}$ . About  $6 \text{ km}^3 \text{ yr}^{-1}$  of agricultural drainage waters or wastewater are directly re-used for irrigation. Some  $37 \text{ km}^3 \text{ yr}^{-1}$  return to natural depressions or rivers where they are mixed with freshwater and can be re-used for irrigation or other purposes.

#### 7.6. Future prospects

Much progress has already been made since 1990. The total water withdrawal in the basin has now stabilized at about  $110\text{--}120 \text{ km}^3 \text{ yr}^{-1}$ . However, further improvement is needed to meet the increasing demand from new water users. It has been estimated that at least  $73 \text{ km}^3 \text{ yr}^{-1}$  of water would have to be discharged to the Aral Sea for a period of at least 20 yr in order to recover the 1960 level of 53 m above sea level.

As the water resources of the basin are more or less stable, or even slightly decreasing due to the climatic change induced by the Aral Sea drying up, all extra water flowing to the Aral Sea should be saved from upstream existing uses. Major efforts should be made to: reduce losses in the rivers and canals, notably through lining and automation of the distribution; stop irrigation expansion; generalize micro-irrigation and other water saving techniques on existing irrigated areas; redirect drainage water and other spilled reservoir and canal water directly to the sea; return the non-consumed fraction of the water diverted into irrigation schemes to the Aral Sea.

#### 7.7. Current climate of the Aral Sea basin (Kazakhstan, Turkmenistan and Uzbekistan)

The average annual baseline temperature: annual basic temperature according to the data of 1961–1990, ranges from between  $12.5$  and  $15^\circ\text{C}$  in the south to between  $2.5$  and  $5^\circ\text{C}$  in the north. The summer range is between  $22.5$  and  $25^\circ\text{C}$  in the south and between  $20$  and  $25^\circ\text{C}$  in the north, while the winter range is between  $10$  and  $12.5^\circ\text{C}$  in the south and between  $2.5$  and  $5^\circ\text{C}$  in the north [Fig. 8(g)–(i)].

The average annual baseline rainfall according to the data of 1961–1990, ranges from  $<120$  mm in the middle of the basin to between 240 and 360 mm elsewhere. The summer range is between  $<50$  mm in the middle of the basin to 10 mm elsewhere, while the winter range is between 50 and 100 mm in the middle, and between 100 and 150 mm elsewhere [Fig. 8(a)–(c)].

*Climate change estimations for the Aral Sea basin.* By the 2050s, the annual average temperature should increase in a range from  $1.75$  to  $2.25^\circ\text{C}$ . The summer range is between  $2$  and  $2.75^\circ\text{C}$  while the winter range is between  $1.5$  and  $2^\circ\text{C}$  [Fig. 8(j)–(l)]. Rainfall is expected to increase annually by 5–20%, but in the summer, to decrease in the south by up to 5% while the north might see an increase of 5–10%. In wintertime, all the region should experience an increase of the rainfall, ranging from 5–10% in the south and from 20 to 25% in the north [Fig. 8(d)–(f)].

### 8. Australia

In Australia, 57.1% of the  $17\,800 \text{ Mm}^3$  water withdrawn is used for irrigation. In 1902, 1912–1915, 1965–1967, 1972 and 1983, Australia suffered severe drought. There are reports indicating a 10% decline in rainfall in some areas in the southwest, but there is some increase in other areas such as New South Wales.

*Current climate.* The average annual baseline temperature according to the data of 1961–1990, ranges from between  $15.0$  and  $17.5^\circ\text{C}$  in the south to between  $25$  and  $27.5^\circ\text{C}$  in the north. The summer range is between  $17.5$  and  $20^\circ\text{C}$  in the south and increases towards the north to between  $27.5$  and  $30^\circ\text{C}$ , while the winter range is between  $12.5$  and  $15^\circ\text{C}$  in the south, and increases towards the north to between  $27.5$  and  $30^\circ\text{C}$  [Fig. 9(g)–(i)].

The average annual baseline rainfall according to the data of 1961–1990, ranges from between 240 and 360 mm in the south to around 1000 mm in the north. The summer range is between 150 and 200 mm in the south and decreases towards the north to between 50 and 100 mm, while the winter range is between 50 and 100 mm in the south and increases towards the north to over 800 mm [Fig. 9(a)–(c)].

*Climate change estimations.* By the 2050s, mean annual temperature is expected to increase in a range from between 1 and  $1.5^\circ\text{C}$  in the south, to between  $2.5$  and  $2.75^\circ\text{C}$  in the north, with slightly higher changes during the summer than in winter [Fig. 9(j)–(l)]. The mean annual rainfall should decrease by 20–25% in the south and 5–10% in the north [Fig. 9(d)–(f)].

### 9. Uncertainties in climate change predictions

The climate models used to generate estimates of future climate conditions are in need of refinement and improvement in many areas (Gleick, 1998). Gaps in data and basic understanding of fundamental climatological processes hinder definitive assessments. Unexpected large and rapid

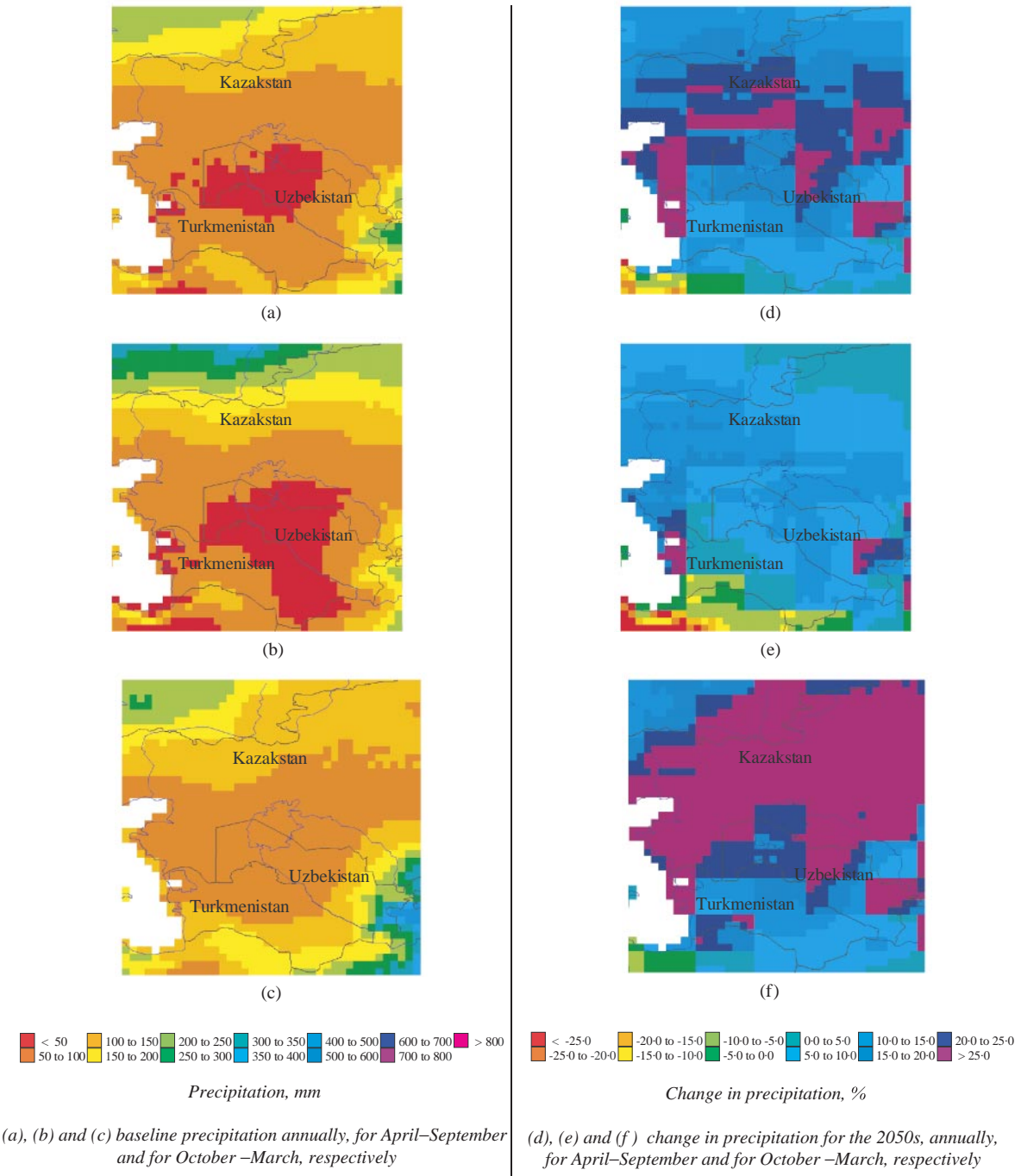


Fig. 8. — (Continued.)

changes in climate in the future as those of the past are difficult to predict. These unpredictable surprises arise from the non-linear nature of the climate system (Gleick, 1998). How much confidence is there in the predictions?

According to Jager and Ferguson (1991), the uncertainties in climate predictions arise from imperfect knowledge of:

- (1) future rates of human-made emissions;
- (2) how these will change the atmospheric concentrations of greenhouse gases; and
- (3) the responses of climate to these changed conditions.

There are many uncertainties associated with timing, direction and extent of these climatic changes as well as about their implications for societies. These uncertainties





Fig. 8. Mean annual precipitation in mm and temperature in °C from the Climate Research Unit 1961–1990 and the global climate model HadCM2 prediction for the 2050s for precipitation in percentage and temperature in absolute value for the Aral Sea basin

have great influence on the rational water-resources planning for the future. These uncertainties should not paralyse policy makers and water managers and stop them from rethinking and re-evaluating current policies.

**10. Impacts of changes in water resources on the society**

The impact of climate change on water resources supply, availability and demand will have direct and indirect

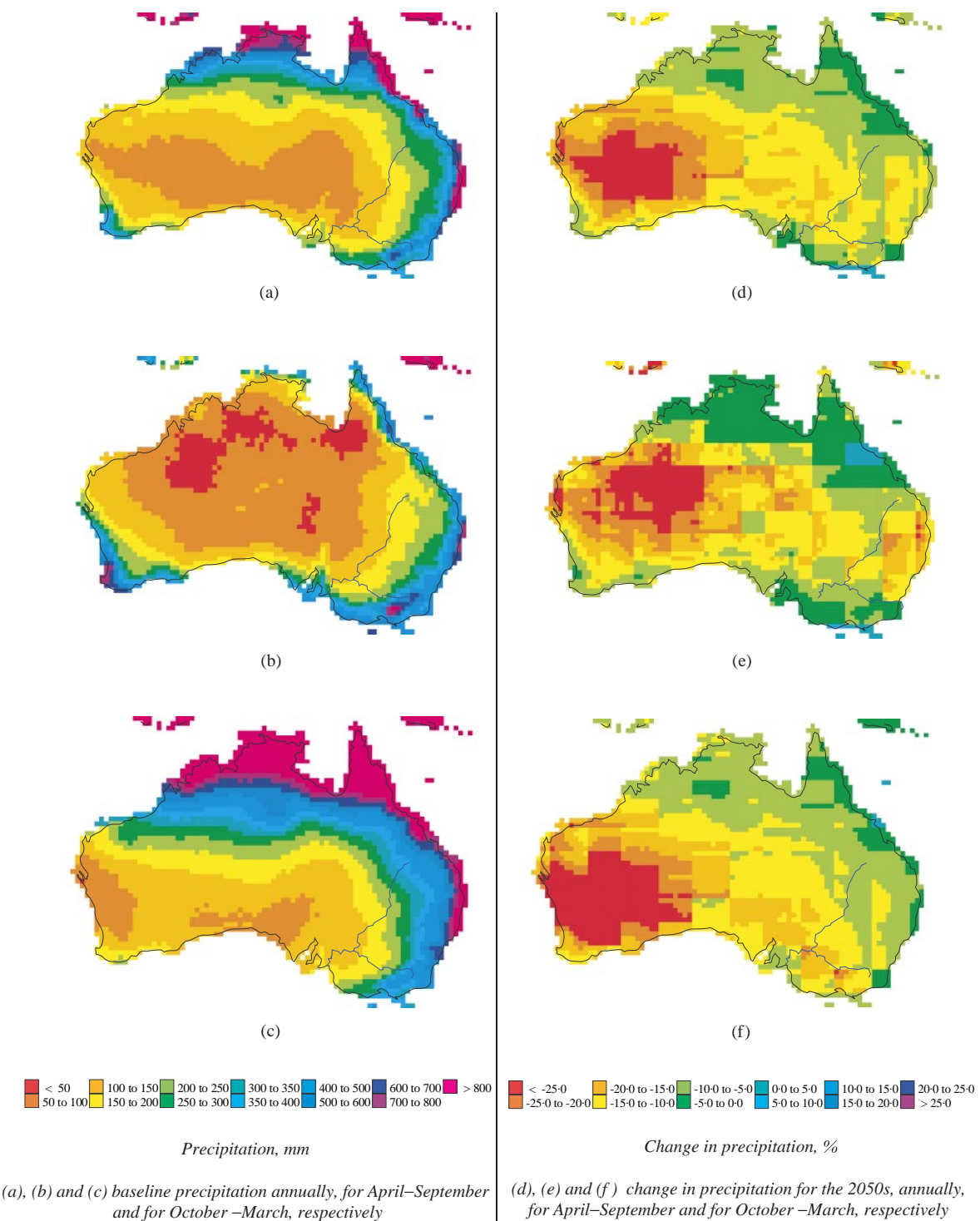


Fig. 9. — (Continued.)

effect on a wide range of institutional, economic and social factors. The ability of the society to adapt and the nature of these effects are not well understood. The cost benefit of reducing greenhouse gas emissions becomes more debatable if water managers and planners can

easily and cheaply adapt to climate change impact using innovative management. Relying only on adaptation could be a dangerous policy (Gleick, 1998) because: (i) the impact of climate change on water sectors is very complicated and partly unpredictable; (ii) many impacts are

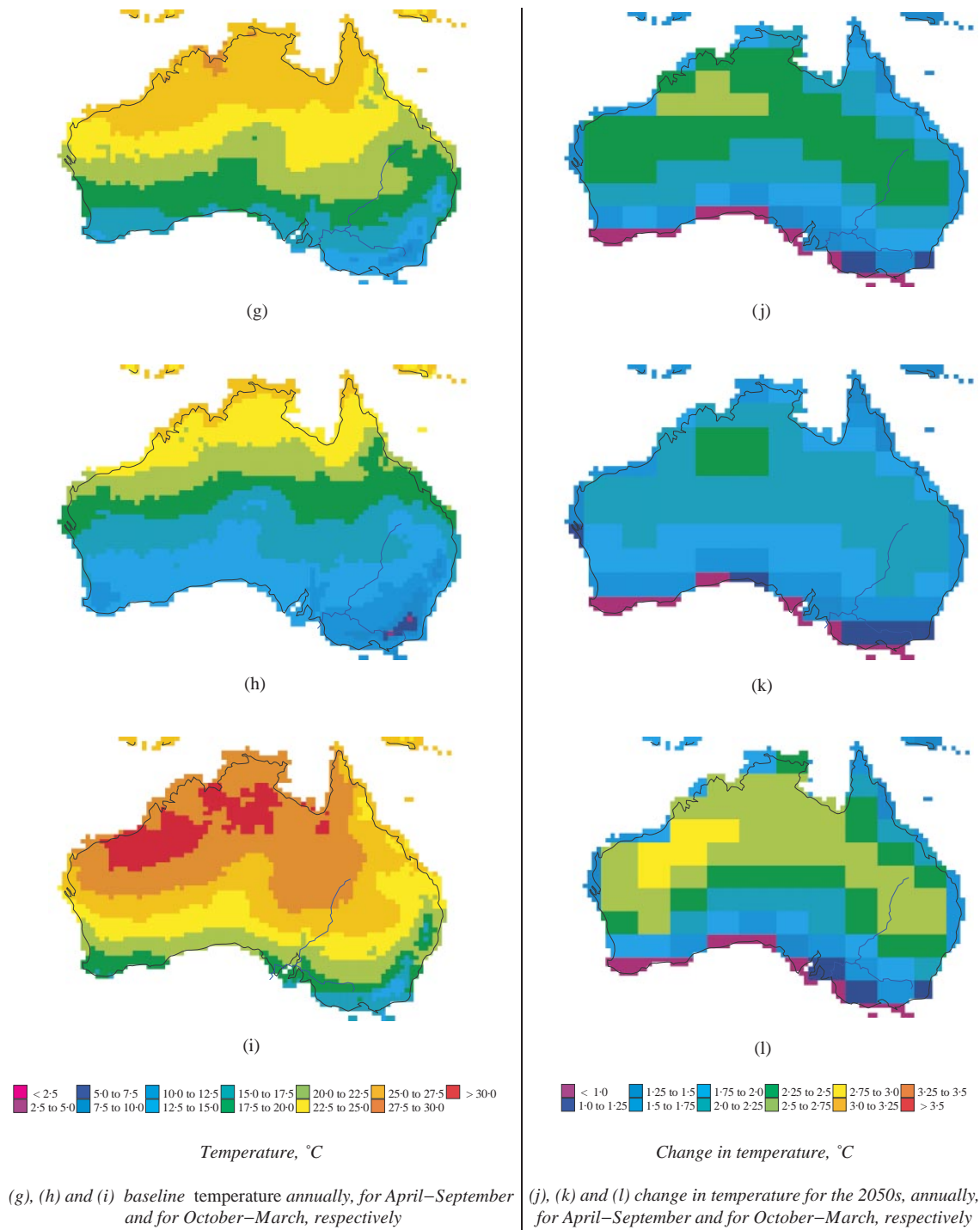


Fig. 9. Mean annual precipitation in mm and temperature in °C from the Climate Research Unit 1961–1990 and the global climate model HadCM2 prediction for the 2050s for precipitation in percentage and temperature in absolute value for Australia

non-linear and chaotic with many surprises and unusual events; (iii) in addition to climate change impact, water resources will be under additional stress due to population growth, competition for financial resources from other sectors, disputes over water allocation and priori-

ties; and (iv) finally the adaptive measures may help mitigate some adverse impacts of climate change while simultaneously worsening others. There is a vast amount of literature on the climate change impact on water systems, reservoir operations,

water quality, hydroelectric generation, navigation and other water management aspects. One of these findings indicated the high sensitivity of the water supply to changes in the inflows and demands. For example, a 10% decrease in average natural flow in the Colorado River basin (expected under future climate change), would result in a 30% reduction in reservoir storage, a 30% reduction in hydroelectricity generation and increase in salinity standards in the lower river in almost all years (Gleick, 1998). One should bear in mind that present water systems are optimally designed to cope with current climatic conditions and therefore are sensitive to any changes in those conditions. In addition, the changes in the operating rules need to be closely examined to see if they can reduce the risks of being associated with a system of a fixed infrastructure and designs.

At present, the high seasonal and inter-annual variability of supply is a major factor affecting the water availability and quality in the arid regions. Inter-annual variations are also greater in arid parts than in the humid parts. Variability has three important implications for water management: (i) it introduces an element of risk in estimating the true opportunity cost; (ii) expensive storage capacity is required for seasonal and inter-annual flows despite the large losses by evaporation (*e.g.* 14% at Aswan), groundwater storage via artificial recharge which could play an important role being at present very limited (few cases in Jordan and Israel); and (iii) variability requires systematic contingency planning to mitigate drought impacts in the region. With few exceptions, irrigation is by far the largest user in the arid regions. Increasing the efficient use of water is a key non-structural approach to water resources management.

#### 10.1. *Conflicts at national level*

Fast-rising water demand inevitably creates conflicts especially when uses are regarded as 'non-essential' or of benefiting only a few people or of being stolen by neighbouring communities or countries.

In Tunisia, there is a conflict between agriculture and tourism in Cap Bon region, where hotels containing beds for more than 100 000 tourists are competing for water from the local aquifer, which is already, seriously over-exploited to meet farmers needs. In Morocco, both tourism and industrial development are putting pressure on water resources currently used for irrigation around Casablanca. This has not stopped the government from formulating a national plan to increase the area of irrigated land to more than 1 million ha by the end of the year 2000 under the programme known as the 'Politique des Barrages' (Pearce, 1996).

#### 10.2. *Conflicts at international level*

Political boundaries often do not follow hydrological boundaries. Instead national boundaries sometimes run down the middle of rivers as on the Danube, or rivers may flow from one country into another. Thus, the Rhone passes from Switzerland into France, and the River Jordan passes through Syria, Israel, Jordan and Palestine territory.

There is an ongoing dispute between Israel and its neighbours since 1964 when Israel diverted most of the water of River Jordan to the Sea of Galilee. It passes now down a 'new' River Jordan, the Israel National Water Carrier that takes water to all major cities and even to the Negev desert in the far south. The West Bank aquifer receives its water from rainfall over the West Bank hills. It extends beneath Israel and drains into the Mediterranean Sea. With a new Palestinian state in sight, how will the two states jointly manage this vital resource to provide an equitable allocation? Palestinian towns and villages currently extract water from springs and shallow wells in the hills. The Israelis extract it from deep boreholes to supply new West Bank settlements and from boreholes on Israeli territory near the coast. Israel take more than  $300 \text{ Mm}^3 \text{ yr}^{-1}$  from the aquifer, with Palestinian villages taking much less, though the exact amount is disputed. In any case, the resource is already over-abstracted by at least  $100 \text{ Mm}^3 \text{ yr}^{-1}$  (Pearce, 1996). This has resulted in a reduction of the size of the irrigated area from 27% before the occupation to 4% by 1990s, whereas Israeli settlers on the West Bank irrigate 70% of their crops. Israeli hydrologists admit that in some areas such as in the village of Jiftlik in the Jordan valley and Barada near Nablus, Israeli boreholes sunk deep into the aquifer have dried up shallow Arab wells, causing local disputes.

Today Egypt, which is using most of the Nile water, is in fear that upstream neighbours such as Ethiopia will begin to harness the water for their own use. The Nile treaty was signed only between Egypt and Sudan in 1959.

The River Jordan provides Israel with 40% of its water resources. Farmers on the east bank suffer a great shortage to irrigate their lands. Also, Syria and Jordan are suffering.

Underground aquifers also frequently cross national boundaries. If anything, the potential for conflict is even greater here because the aquifer, once emptied, might take centuries or even longer to refill. There is a greater room for dispute over the basic data of the resource: how much water it contains, what the recharge rates are, where the recharge comes from, *etc.*

Conflicts can be especially acute over the exploitation by one country of non-renewable 'fossil' reserves that extend beneath the neighbour. By pumping water out from the aquifer beneath its own territory, it could begin

to drain forever the water beneath its neighbour's territory. The great fossil-water-filled aquifers beneath the Sahara desert are a major potential cause of future water conflict. The Eastern Erg artesian aquifer, south of the Atlas Mountains, extends from Algeria into Tunisia. The Nubian aquifer underlies Libya, Egypt and Sudan and contains an estimated 6000 km<sup>3</sup> of water. Only Libya is tapping it so far—but on a massive scale, with the 'Great Man-made River' project. The World Bank says there is a study on the region indicating that there is a fear that this may reduce substantially the groundwater reserves in Egypt and Sudan. There are already claims that the Libyan pumping is drying up Egyptian oases.

## 11. Vulnerability of regions for food security

The vulnerability of the various regions with reference to food security depends in part on the size of the population, the production potential and the consumption pattern. Most of Africa and Asia can be considered vulnerable. The present projection of Africa in 2025 will be 1.62 billion. The per capita consumption of food grains is 257 kg annually, which is the lowest in the world. Even at that rate the consumption will be 416 Mt. Assuming that the consumption will rise to 300 kg per capita annually, similar to Asia, then a total of 486 Mt of food grains or energy and protein equivalent would be needed (Jager & Ferguson, 1991). Are there enough resources in Africa to meet this need? At present there are 166 million ha of arable and 18.6 million ha permanent cropped lands. However, only 100 million ha are actually cultivated. The average productivity (1986) of cereals, pulses, and root and tuber crops was 1077, 591 and 2717 (dry weight) kg ha<sup>-1</sup>, respectively. This leads to a total production of 119 Mt compared with the present requirement of 158 Mt for the present population at the consumption rate of 260 kg per capita annually needed (Jager & Ferguson, 1991).

South and southeast Asia are also described as vulnerable to climate change from the point of view of food security. The population of Asia is 4.54 billion (by 2025), average per capita annual consumption at present is 300 kg and annual food grains requirement by 2025 will be 1362 Mt (Jager & Ferguson, 1991).

Cultivation of roots and tuber crops, particularly cassava, sweet potato and yams have more than double the productivity of cereals and could play an important role in the production of edible calories in the tropics and have the advantage of being less sensitive to temperature as compared to grain crops. Also, productivity of sorghum and millets can be enhanced more than two-fold in large parts in Africa. The alternative is for Africa to receive food aid with prohibitive financial terms or

clear more forests for agriculture. The effect of climate change on livestock is uncertain and more study is needed.

## 12. Climate change impact: what are the choices?

### 12.1. Adoption of the conventional solutions

It seems that the south Mediterranean (SMED) and the Middle East (ME) region are geared primarily to conventional solutions especially in north African countries (Pearce, 1996). Algeria believes it will need another 5.5 km<sup>3</sup> of water a year by 2010, 50% for irrigation and 50% for domestic and industrial uses. It plans 50 more dams and 10 diversions canals and will tap non-renewable fossil water beneath the Sahara.

Tunisia expects by the year 2000 to be using 90% of its surface water in the north and all of its groundwater. It will build new large dams and develop a network of pipes and canals to transfer water between river basins. It will have the capacity to transfer more than 50% of the water captured behind dams in the northern regions.

Morocco intends to double the proportion of its river flow that is controlled by dams and extract more groundwater. It will build 60 large dams, sink boreholes with a total length of 100 km and build 280 km of water-transfer structures.

All this will be very expensive for developing countries. Water infrastructure already accounts for more than 20% of public sector investment in Morocco and Tunisia and 12% in Algeria. Libya is planning to tap more undergroundwater and transport it to the coastal aquifers such as Jefara, which have been destroyed by overabstraction.

### 12.2. Searching for innovative solutions

An innovative search for water resources would include: (i) new solutions to harvest rainwater; (ii) desalination of seawater by evaporation using solar/wind energy (less expensive when compared with reverse osmosis which is energy consuming), the cost of desalination being three to five times the cost of tapping groundwater; (iii) rainfall generation using precipitation enhancement such as cloud seeding; (iv) storing water in surface reservoirs or underground via artificial recharge; and (v) use of brackish water which could be desalinated but a cheaper option is to develop salt-tolerant crops that can be irrigated with this water either mixed with fresh (to dilute) or alone. Desalination can offer limitless fresh water, as salty water represents 97% of the global water resources. In 1997, the global desalination capacity

reached 18 million m<sup>3</sup> per day. Most of this capacity is in the Middle East and the Persian Gulf region where water is scarce but money is not. There are different methods for desalination and there is still a need for a cheap method.

### 12.3. *Applying alternative solutions*

#### 12.3.1. *Reducing water demand*

Water policies can be redirected towards cutting demand, with the technology as a key factor. Present computer systems can monitor flows and pressure, can detect leaks and can prevent water wastage, whether in industrial or urban water-distribution networks. A more market-oriented approach to water can be adopted using price incentives to encourage savings.

Attention to leaks and evaporation, could reduce losses which amount to 60% in some urban areas. It is 30% in Damascus, 65% in Malta and 45% for Greek cities. An evaporation rate in northern Africa is 2 m yr<sup>-1</sup> and losses from surface waters and reservoirs can be great. Evaporation losses from Lake Nasser are 14%.

#### 12.3.2. *Using efficient irrigation systems*

The overall global average of agricultural water use efficiency is 40%, meaning that more than half of the water allocated for agriculture never produces food. Surface irrigation is the common practice in most of the arid regions. However, sprinkler and drip irrigation systems are now in use. Losses due to inefficiency of flood irrigation can be more than 50%. There is no doubt that improving the irrigation efficiency using new technologies such as new sprinkler design with low-energy precision application can increase the efficiency from between 60 and 70 to 90% as high as the drip irrigation. Sensors linked to computer systems can control flow of water in pipes and irrigation can be applied at night to reduce evaporation losses. The capital costs are high but the saving in water is substantial (between 30 and 50%).

Lining canals and preventing leaks from the distribution system can help greatly in increasing the water use efficiency. Water pricing is an important issue. The widespread subsidies encouraged water use inefficiency.

#### 12.3.3. *Recycling*

The alternative supplies such as reclaimed wastewater of urban areas will increasingly be used. There has been a significant increase in the availability and the use of treated water in meeting the industrial and agricultural needs. Treated wastewater of cities and farms can be recycled or re-used for irrigation.

## 13. Sustainable vision for fresh water resources

As world population grows from the present six billion to seven, eight or nine billion, more water will be required to satisfy our basic needs and our social, cultural and economic desires. This water might come at a high financial and ecological price. Planning for the future is difficult as the only certainty for anyone looking ahead is that the future is uncertain, unpredictable and complex. To meet the desires of society, decisions have to be made about economic policies, technological choices and institutional structures. Planning for the future should account for the possible climate change impact on water resources availability, the population growth and what the society wants. Subsequently, goals will have to be established for water use that are both sustainable and achievable within a certain time. These goals could become a recipe for a vision. Then by describing a vision, it becomes possible to craft the policies and institutions and to apply the technological tools that will make it a reality. Naturally, many different dreams and visions can be described but it should be remembered that society needs a positive vision that has some thoughts about what truly sustainable water use means. In an example of a positive vision for 2050 'sustaining our fresh water', Gleick (1998) hoped that by the year 2050, basic human needs for water were finally acknowledged as a top international priority and these needs are largely met.

In a global vision with positive attitude towards water use, sharing and equitability, by year 2050, one would hope to realize the following endeavours.

- (1) All the world population would have access to basic water needs for drinking, cleaning, sanitation and cooking for a more healthier and productive societies.
- (2) Domestic water use in the industrial nations would become more efficient and equitably allocated.
- (3) Large-scale desalination of seawater and brackish groundwater would have advanced towards a cheap and clean source of energy such as the solar desalination systems and would be practised in arid coastal countries where water use efficiency is high and water availability is low.
- (4) Water-related diseases would have been conquered through meeting basic needs of all people for drinking, sanitation, cooking and health care.
- (5) Agricultural water use would have been more efficiently used and allocated. A renewed interest in traditional farming techniques in semi-arid regions combined with inexpensive high-technology water monitoring equipment and new varieties would

have encouraged a rethinking of agricultural aid policies and improved production without additional irrigation requirements.

- (6) On irrigation lands, overall water productivity would have been improved significantly with universal adoption of high-efficiency sprinkler and drip irrigation systems on appropriate crops and lands.
- (7) Water use efficiency would have also been improved due to advances in sensors and computer technology. Farmers would have been able to monitor soil moisture inexpensively and accurately, and able to apply water only when it is needed. Farmers would have links with regional weather forecasting centres that help avoid unnecessary irrigation prior to natural precipitation.
- (8) In many arid countries, limited but efficient agricultural production would have been maintained with high-quality reclaimed urban wastewater. Water experts who pioneered this technology would be in high demand in many parts of the world as countries work to maximize their use of this under-utilized resource.
- (9) Great improvements in food distribution and storage would have been realized.
- (10) Water trading among market sectors would be a common practice.
- (11) A global food sufficiency would be a new focus and would have replaced the national food security, which led many countries in the arid and semi-arid regions to overdraft fossil groundwater and invests in unsustainable irrigation projects during the 20th century.
- (12) Basic ecosystems water needs would have been identified and met.
- (13) Serious water-related conflicts would have been resolved through formal negotiations.
- (14) The Middle East would have become a model of regional co-operation and water sharing via joint basin management commissions. A sharing arrangement would have been established among concerned countries for equitable distribution of water.
- (15) New generation of water managers would have been trained to use flexible operating systems, instead of past trends that account for forecasted future conditions.
- (16) The wide sharing of water data and information on successful management strategies would have led to a wider international co-operation between the world's water community.
- (17) Remote sensing would have been used to monitor water treaties and provide real-time data of surface water conditions all over the world.

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