Vulnerability Assessment of Freshwater Resources to Climate Change:

Implications for Shared Water Resources in the West Asia Region

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THE LEAGUE OF ARAB STATES
THE ARAB CENTER FOR THE STUDIES OF ARID ZONES AND DRY LANDS
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United Nations Environment Programme
(UNEP)

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and Dry Lands (ACSAD)

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EXECUTIVE SUMMARY

West Asia (WA) countries have been experiencing different degrees of natural and anthropogenic water risk affecting the sustainability of their limited water resources and preservation of the ecosystem equilibrium. The fragile arid environment and its resiliency to cope with external natural and anthropogenic activities, including the expected impacts of climate change, present a major challenge to decision-makers who must achieve adequate, safe and dependable water and food supply in the future to improve human well-being in their societies, and to meet the requirements of future generations.

The WA region can be classified according to water resource availability, population growth and economic activities into two distinct sub-regions, the Mashriq and Yemen (Iraq, Jordan, Lebanon, the Occupied Palestinian Territories (OPT), Syria and Yemen) and the Gulf Cooperation Council (GCC) countries (Bahrain, Kuwait, Oman, Qatar, Saudi Arabia and UAE). The whole region, however, is suffering from water scarcity, which is attributed to large temporal and spatial variations in most hydrological parameters, especially precipitation and evaporation rates. The most significant parameter causing environmental stress is the rainfall pattern, which influences the generation and dependability of freshwater availability in terms of volume, frequency and distribution. Climate change will further increase the variability of rainfall, adding more uncertainty and complication to the planning and management processes of the water sector. Rainfall distribution in the two sub-regions shows that 72 per cent of the region receives on average less than 100 mm mainly in the GCC countries, 18 per cent of its area receives 100-300 mm and only 10 per cent receives more than 300 mm.

Understanding the vulnerability of freshwater resources in WA is therefore vital to ensuring sustainable water management in the region. Undertaking a vulnerability assessment of freshwater will highlight gaps in information and identify the most dominant factors that influence vulnerability, in addition to enhancing public awareness. The availability of such an assessment will provide decision-makers with options to evaluate and modify existing policies and implement measures to improve water resources management.

The approach used for this vulnerability assessment was based on the methodological guidelines prepared by UNEP and Peking University. According to these guidelines, a vulnerability assessment must have a precise understanding of four components of the water resource system, namely: total water resources, water resource development and use, ecological health and conflict management.

The pressing concern of freshwater vulnerability in WA facing decision-makers now and in the future requires the development of policies that take into consideration the continuous increase in water demand from a changing environment. Solutions can be mapped along a continuum from those where proven solutions are available, to those where understanding of the problem and its solutions are still emerging. It is clear from the above analysis that the vulnerability of freshwater resources in WA countries is a result of inadequate management levels and will be exacerbated by the effects of climate change.

The main water management challenge facing WA countries is the increasing stresses and deterioration of the region's limited natural water resources by increasing water demands. This has significant implications not only for the future development of these countries, but also for the sustainability of their past socio-economic achievements. The lack of integrated water management policies and adequate legislative frameworks, and institutional weakness, coupled with management practices focusing on 'supply-side' management without giving adequate attention to 'demand-side' management, has contributed to increasing freshwater vulnerability in most of the countries of the region. Policy reforms, with emphasis on demand management, conservation and protection, as well as the improvement of the legal and institutional provisions are keys to efficient development and management of water resources and must be given the utmost attention to reduce the vulnerability of freshwater in the region.

It is expected that climate change will impose further stresses on the limited freshwater resources in WA countries and intensify their vulnerability. This is of particular concern for those countries relying on shared water resources, which in the absence of sharing agreements will increase tensions between riparian countries. The issue of shared water resources should be given high priority by WA countries to finalize water resources sharing agreements according to international water laws. Large water savings opportunities exist in the agricultural sector, which accounts for more than 80 per cent of total water consumption in the region (FAOSTAT, 2009) and where most water wastage occurs. Savings are possible by increasing irrigation efficiency with the introduction of enhanced irrigation and agricultural techniques, reuse of treated wastewater, augmentation by agricultural drainage water, and the implementation of incentive/disincentive systems.

Municipal wastewater has become an increasingly significant source of water with considerable potential for alleviating water scarcity in the region, particularly since the volume available proportionally increases with that of urban consumption. With proper treatment, municipal wastewater can be used to supplement water demands in the agricultural and industrial sectors, as well as in managed aquifer recharge (MAR) schemes. While increasing reliance on desalinated water in the region is inevitable in the future and contributes to decreasing water scarcity, especially for GCC countries, desalination technology has many drawbacks: it is capital and energy intensive, is largely imported, provides limited added value to countries' economies, and has many negative environmental impacts. There is an urgent need for cooperation among WA countries and with other Arab Countries for investment in research and development (R&D) for desalination technologies, with the aim of acquiring and localizing these technologies in the region. This would have many advantages, including reducing costs, increasing the reliability of supply, increasing value for countries' economies and reducing the environmental impacts of desalination.

The issue of water resources management should be high on the national agendas of WA countries. Political action is needed for the sustainable management of water resources and is a necessary prerequisite to reducing freshwater vulnerability in the countries of the region.

In order to cope with water scarcity and lower freshwater vulnerability in the region, a major shift to demand management, water use efficiency and conservation needs to be happen. This should focus on the agricultural sector where most water savings can be achieved. Furthermore, there is an urgent need to strengthen and reinforce the capacity of water institutions to deal effectively with water issues in a holistic approach through legal and institutional frameworks. Vulnerability and adaptation to climate change need to be integrated into future water resources management policies at the national level. A key role for concerned institutions to achieve this goal is to provide knowledge and promote awareness.

CHAPTER ONE

INTRODUCTION

Khaled Mubarak

Key Messages

Water resource availability in arid and semi-arid parts of the world, including the West Asia region, is a major constraint to socio-economic development.

In addition to the prevailing arid climate, freshwater availability is expected to suffer from the impacts of climate change due to expected changes to rainfall and temperature regimes. Understanding the vulnerability of water systems in West Asia, therefore, is vital to sustainable water resource management in the region.

Orontes river, Syria

1.1. BACKGROUND

Countries of the West Asia (WA) region have been experiencing different degrees of natural and anthropogenic risk to the sustainability of their limited water resources and preservation of the ecosystem equilibrium. The fragility of their arid environment and its resiliency to external natural and human activities, including the expected impacts of climate change, present a major challenge for decision-makers, who have to ensure adequate, safe and dependable water and food supply availability to meet the requirements of future generations as well as improve human well-being in their societies.

The West Asia region, as defined by the United Nations Environment Programme (UNEP), can be classified according to water resource availability, population growth and economic activity into two distinct sub-regions: the Gulf Cooperation Council (GCC) countries (Bahrain, Kuwait, Oman, Qatar, Saudi Arabia and UAE), and the Mashriq (Iraq, Jordan, Lebanon, OPT and Syria) and Yemen. The whole region, however, suffers from water scarcity due to large temporal and spatial variations in most hydrological parameters, especially precipitation and evaporation rates. Rainfall patterns cause the most significant environmental stress, influencing the generation and dependability of freshwater availability in terms of volume, frequency and distribution. Rainfall and snow accumulation are the sources of river flow, runoff in major wadis, rain-fed agriculture, recharge to groundwater resources as well as hazardous flooding and drought events. Rainfall seasonality influences the renewable flow of the few major rivers in the Mashriq sub-region, while the extreme random nature of rainfall in the Arabian Peninsula (AP) influences the amount of sporadic drainage through wadis, flash floods and groundwater recharge. Climate change will further increase rainfall variability, contributing to greater uncertainty and difficulty in the planning and management processes of the water sector.

In addition to natural water scarcity, growing demand and pollution due to human activities are contributing to the depletion and deterioration of resources. Rapid population growth, increasing rates of urbanization and economic activities have all placed extensive pressure on already limited water resources. Increases in water demand, especially in the irrigation sector, have contributed to further depletion of surface water and groundwater

Oman

resources, in many places in excess of potential recharge. Pollution from domestic, industrial and agricultural wastes is further contributing to the loss of already limited resources, while efforts to meet the Millennium Development Goals (MDG) for adequate and safe water supply and sanitation services as well as food security, have added additional pressure on these limited resources.

Variation in rainfall amount and frequency will impact the quantity and quality of river flow in the Mashriq sub-region. The expected decrease in rainfall will affect rain-fed areas and groundwater recharge (IPCC, 2007). Furthermore, climate change will increase vulnerability to extreme flooding and drought events with significant impacts on human well-being and environmental conditions.

There are many shared surface and groundwater resources among WA countries and with neighbouring countries. Many of the deep aquifers are shared among countries of the Arabian Peninsula and also with Jordan, while substantial portions of surface water originate from outside the region, with no binding agreement for sharing water resources between riparian countries, or implementation and monitoring of existing agreements. The control of shared surface and groundwater flows from up- and downstream countries has increased water disputes and could affect regional stability. These factors have increased the sensitivity of the region's communities to socio-environmental conditions (biophysical, socio-economic or geopolitical factors). Furthermore, they affect the ability of water resource systems to effectively and efficiently function, thereby making these water resources vulnerable in terms of quantity (overexploitation, depletion, etc.) and quality (pollution, ecological degradation, etc.).

1.2. OBJECTIVES

Freshwater vulnerability assessment is a tool for identifying potential risks to resources, providing decision-makers with an early warning signal about the need to monitor potential variation over time. This is important in detecting threats early as well as formulating and implementing measures to reduce negative impacts. Vulnerability assessment of freshwater resources will also identify gaps in existing information and the appropriate indicators and management measures required for the government to gather such information. Moreover, the assessment enhances public awareness about potential threats.

The overall objective of this study is to carry out a national and regional vulnerability assessment of freshwater resources to better understand the existing status of water under the prevailing conditions and to ascertain the most dominant factors that influence vulnerability. The availability of such an assessment will provide decision-makers with options to evaluate and modify existing policies and to implement measures to improve water resource management. Specifically, the study aims to:

- Assess the vulnerability of freshwater resources to threats, and its impact on development options, human well-being and the environment;

- Identify the potential impacts of climate change on water resources and ecosystems, and assess the current adaptive capacity of the national water sector;
- Create a knowledge base of scientific data and information on available surface and groundwater sources and the water demand of each sector;
- Evaluate the impacts of environmental change in terms of water resource stress and identify management challenges;
- Develop the knowledge, policy options, and understanding necessary for forward-looking cooperation among riparian countries with regard to shared water resources;
- Identify gaps in data and research and recommend needs for further studies; and
- Examine water issues and functions in selected surface and groundwater basins.

1.3. APPROACH

The approach used for this vulnerability assessment, based on the methodological guidelines prepared by UNEP and Peking University (UNEP, 2009), is briefly discussed in Chapter 3. The vulnerability of freshwater resources is explored by isolating strategically important issues related to different functions (uses) of freshwater systems in a drainage basin, marking a considerable departure from the preconceived notion of "water crisis" being synonymously linked to vulnerability. In fact, vulnerability, mainly in arid and semi-arid zones, has always been linked to water crises, since any variation in precipitation will have a direct negative impact on the limited water resources in these areas. Thus, the vulnerability assessment must be based on a precise understanding of four components of the water resource system, including their states and relationships, namely:

- Total water resources,
- Water resource development and use,
- Ecological health, and
- Management.

This assessment approach recognizes that a sustainable freshwater system can only function within an integrative operational framework that combines both the natural system and the management system. The fundamental components of this vulnerability assessment are able to account for three different aspects related to the natural resource base (total water resources, water resources development and use and ecological health), and how external factors (climate change, biophysical conditions, policy and management practices, etc.) influence the processes that can make a natural system vulnerable. Evaluation of these components is based on the related indicators and considers a number of constraints related to data and information, including lack of access to some official data, and wide seasonal and spatial variations in hydrological parameters.

The methodology is based on the Drivers, Pressures, State, Impacts and Responses (DPSIR) framework to estimate a vulnerability index influenced by four indicators: resources stress (RS); development pressure (DP); ecological health (EH); and management capacity (MC). The degree to which stress is being placed on the water sector by water scarcity, increasing water demand and the requirements of socio-economic activities and ecological conditions, will be evaluated by the vulnerability assessment.

Although such studies require advanced modelling work to improve the accuracy of the results, this study is intended to complement such an analysis and can thus be considered a starting point for the recommended detailed study. This assessment is not a substitute for a rigorous quantitative analysis at the sub-regional and national levels.

CHAPTER TWO

WATER RESOURCES IN WEST ASIA: AN OVERVIEW

2

Khaled Mubarak

Key Messages

It is expected that climate change will exacerbate existing water stress in the region by affecting precipitation, temperature, evaporation, relative humidity and solar radiation.

These impacts are expected to reduce the availability of renewable resources, increase the variability and frequency of extreme events (flooding and drought) and increase agricultural and domestic water consumption.

Climate change will threaten food security in the region due to the projected decrease in available water resources and agricultural productivity. Moreover, under these unfavourable and uncertain conditions, it is expected that food self-sufficiency will decrease with time, resulting in the failure of adopted agricultural policies being implemented by a number of countries. It is therefore necessary to prepare and appropriately respond to the potential negative impacts of climate change.

Shat el Arab, Iraq
Source: UNEP, 2009

2.1. INTRODUCTION

Water is one of the most valuable resources on Earth. It is an important factor in both socio-economic development and ecosystem health. In WA, the importance and value of water is even more pronounced because the region is located within an arid to semi-arid zone. The region itself is considered one of the world's most water-stressed (UN-ESCWA, 2007). Rainfall scarcity and variability coupled with high evaporation rates have characterized this part of the world as having a limited availability of renewable freshwater. The Mashriq sub-region is mostly arid and semi-arid, with about 70 per cent of the sub-region receiving less than 250 mm of rain per year (UNEP, 2007). The region has two shared rivers originating outside it (the Euphrates and Tigris) and many smaller ones. The Arabian Peninsula (AP) sub-region is characterized by an arid climate with annual rainfall of less than 100 mm, with no reliable surface water supplies, and depends entirely on groundwater and desalinated water to meet its water requirements (UNEP, 2007). Water scarcity in the region is further aggravated by continuous deterioration in surface and groundwater quality due to industrial, domestic, and agricultural effluent discharges, which also affect human health (UNEP, LAS and CEDARE, 2010). The two sub-regions have different levels of natural resource capacity and reserve, income disparities and different rates of socio-economic development; however, in both sub-regions, water availability is essential for achieving the desired socio-economic development. Both sub-regions are also highly vulnerable to external natural and human-made stresses, such as rainfall amount and variability, population growth, pollution levels and water management practices (UN-ESCWA, 2006).

In the last three decades, most countries in WA have undergone dramatic demographic and socio-economic transformation, resulting in a substantial increase in water demand. These demands have been driven mainly by the implementation of agricultural policies aimed at achieving national food security and escalating urbanization and industrialization, leading to immense pressures on the limited water resources in the region (UNEP, LAS and CEDARE, 2010).

Another major challenge facing the countries of the region is the management of shared water resources among them as well as those shared with countries outside the region. As more than

60 per cent of surface water resources originate from outside the region, this issue remains a major concern threatening stability, food security and water resource plans in the region (UNEP, LAS and CEDARE, 2010; ACSAD 2009). Conventions and agreements on equitable sharing and management of water resources have been signed by riparian countries for some shared rivers, such as the Orontes, but not for others, such as the Euphrates and Tigris. Furthermore, some of the countries of the region (OPT, Syria, and Lebanon) lack access to some of their water resources due to the Israeli occupation of parts of their territories, another major constraint to development in the region (ACSAD, 2009; UNEP, LAS and CEDARE, 2010).

The critical nature of the current water situation in the region is expected to be further aggravated by the impacts of climate change. Water scarcity and quality deterioration in the region are expected to increase due to the reduction of precipitation, increase of domestic and agricultural water demands and seawater intrusion into groundwater resources due to sea level rise (ACSAD, 2009).

2.2. PHYSICAL CHARACTERISTICS

The arid and semi-arid ecosystem of the WA region makes it very sensitive to external pressures. The region is characterized by sparse vegetation, shallow under-developed top soil and calcareous soil prone to degradation (UNDP, 2006). About 79.3 per cent of the total area (estimated at 3.95 million km^2) is classified as dry desert, of which 16.3 per cent is vulnerable to desertification and only 4.4 per cent is suitable for agriculture (UNEP, 1999). The percentage of land covered by deserts varies among countries. A large proportion of the GCC is covered by desert, with only small areas of land considered as having a reasonable natural resource base endowment. In the Mashriq sub-region, 50.6 per cent of land is covered by deserts, with 36.4 per cent covered by areas vulnerable to desertification and just 13 per cent considered arable. In the AP, about 88.8 per cent is desert, 8.8 per cent is vulnerable to desertification and only 2.4 per cent is arable (UNEP, 2002). The desertification process is influenced by the temporal and spatial distribution of rainfall patterns and the frequency of drought cycles. The large percentage of arid and semi-arid lands in WA is attributed to the extreme random nature of rainfall, which influences water availability and vegetation cover.

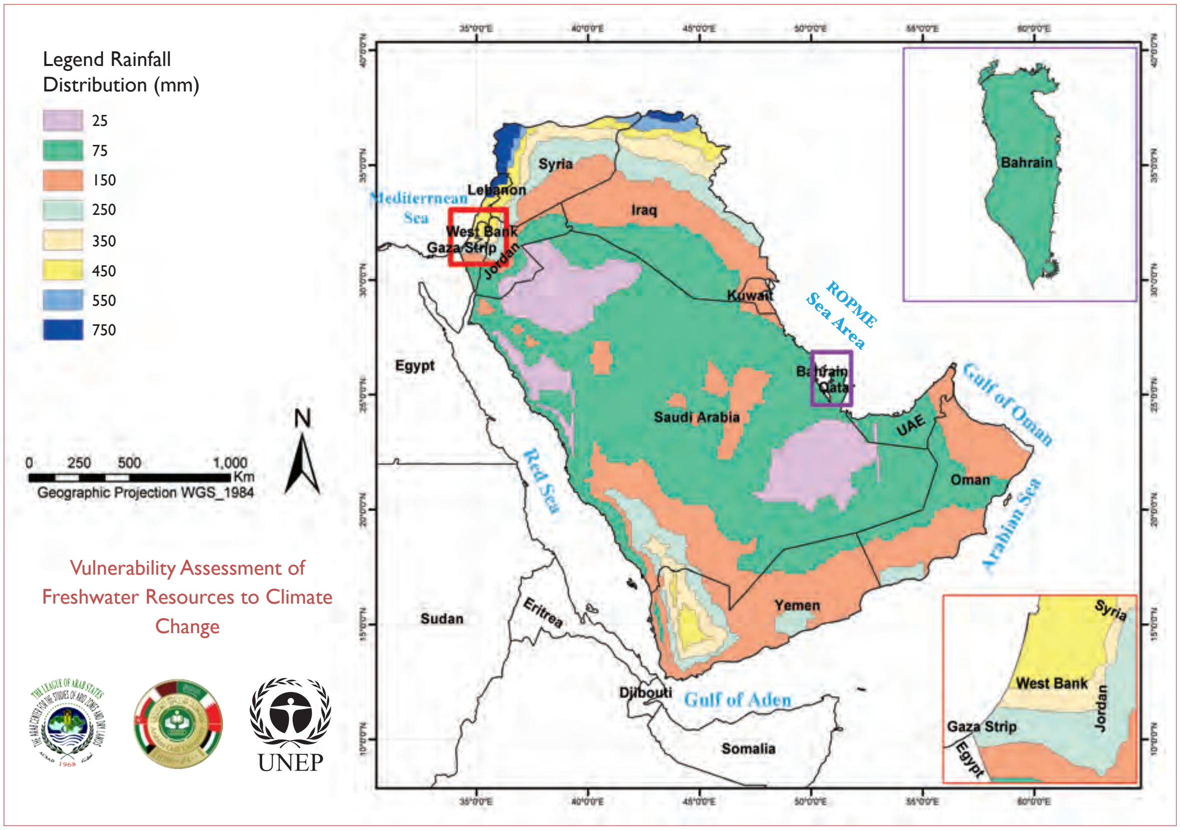
2.2.1. Rainfall

The rainfall pattern in the desert ecosystem influences, to a large extent, natural water resource availability and consumption patterns. Rainfall scarcity and variability coupled with high evaporation rates, typical of arid regions, are characteristic of this part of the world. Rainfall distribution in the region is highly varied in amount and frequency, with 72 per cent of the region receiving on average less than 100 mm per year mainly in GCC countries, 18 per cent receiving 100-300 mm and only 10 per cent receiving more than 300 mm per year (analysis in present study). Annual rainfall distribution in WA is shown in Figure 1. The relatively high rainfall rates of more than 300 mm a year are limited to locations with high elevations in Iraq, Jordan, Lebanon, Syria, Oman, Saudi Arabia and Yemen. Rainfall and snow accumulation in Lebanon and northern Iraq, Jordan, Syria and some parts of the Arabian Peninsula are the main water sources for rivers, springs and wadi flows and also the main sources of renewable groundwater in the region.

2.2.2. Water Resources

The WA region's renewable water resources consist mainly of surface water and shallow and deep groundwater resources, supplemented by non-traditional desalinated water as well as the reuse of treated wastewater. Surface water resources, mainly

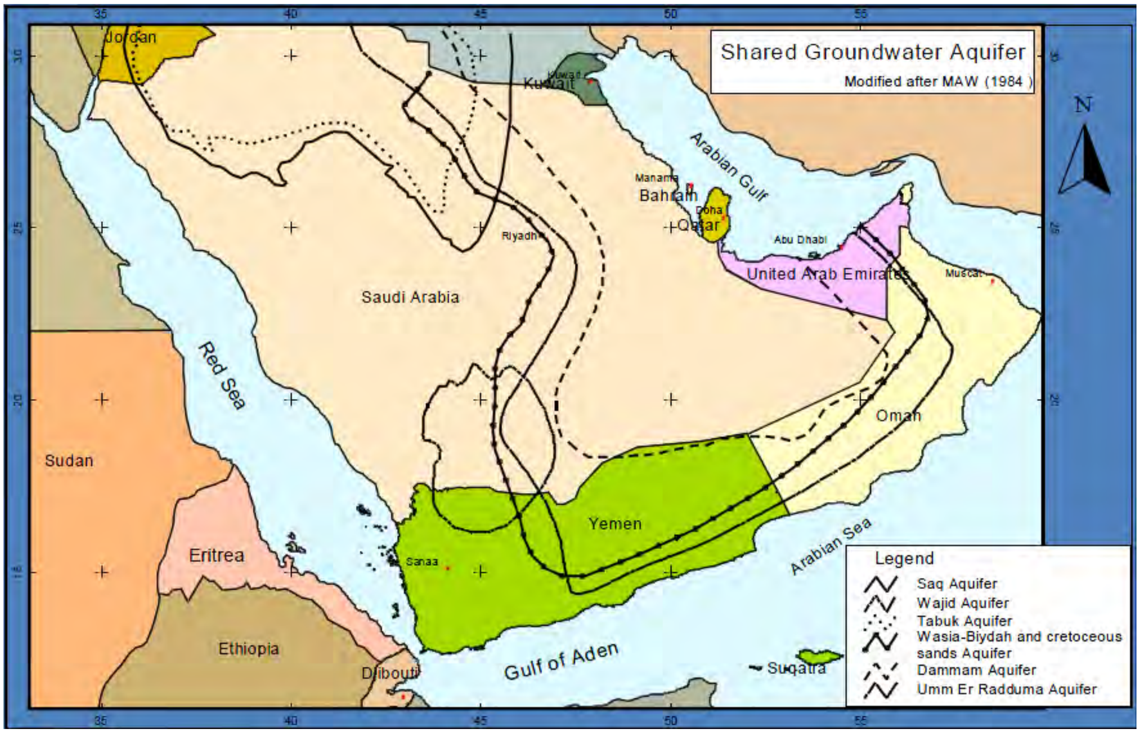
Figure 1: Rainfall distribution in West Asia



river flows, are estimated at 93 100 million cubic meters (mcm) concentrated mainly in the Mashriq sub-region with 80 100 mcm available from the major shared rivers and the remaining 13 000 mcm from small rivers, springs and intermittent wadi flow (UN-ESCWA, 2007). The Mashriq countries, such as Iraq, Lebanon and Syria, rely on river flows supplemented by limited groundwater sources, while the remaining countries rely on flood and shallow and deep groundwater sources. Total annual internal renewable water resources account for only 6.3 per cent of their average annual precipitation, against a world average of 40.6 per cent, due to the high rate of evaporation (Dabour, 2006). While renewable water resources are the main dependable sources for the countries of the region, resource renewal is expected to experience uncertainty due to climate change.

Renewable groundwater in the region generally takes the form of shallow alluvial aquifers recharged by main rivers and wadi flow, especially during major flooding events, and directly from rainfall at aquifer outcrop areas. Renewable groundwater, or the amount of groundwater recharge, is estimated at 15 500 mcm (UN-ESCWA, 2007). In the Mashriq sub-region, the amount and frequency of recharge is much greater than in the AP, due to the higher volume and frequency of rainfall. The degree of groundwater exploitation in most countries of WA is much higher than the amount of recharge leading to continuous and sharp declines in groundwater levels, extensive depletion of groundwater reserves and increased salinity (UNEP, LAS and CEDARE, 2010). There are shared surface and non-renewable groundwater resources lying within and beyond

Figure 2: Shared groundwater aquifers in the Arabian Peninsula



■ Source: MAW, 1984

many countries of the region (Figure 2 shows the shared aquifers in the AP). There are extensive groundwater reserves of varying quality available in shared deep non-renewable aquifers covering most countries of the AP, Jordan and Syria. The major shared deep groundwater sources are the Eastern Arabian Aquifers (Um Err Raduma, Dammam, and Wajeed), located in the AP, the Shaq aquifer between Saudi Arabia and Jordan, and the Basalt aquifer between Jordan and Syria.

A large portion of shared surface water, estimated at 56 000 mcm of total flow, originates outside the region (UN-ESCWA, 2007; UNEP, 2007). Shared surface water resources are:

- The Tigris and Euphrates Rivers shared between Iraq, Syria, Iran and Turkey,
- The Yarmouk River shared between Syria and Jordan,
- Al-Kabeer and Orontes Rivers shared between Syria and Lebanon, and
- The Jordan River shared between Syria, Jordan, Lebanon, the OPT and Israel.

The water dependency ratio indicates the proportion of renewable freshwater resources that originate outside any given country. The high dependency ratio of Syria, Iraq and Bahrain for example shows how highly dependent they are on other countries for their freshwater resources (Figure 3).

Countries such as Iraq, Syria and the OPT have been experiencing reduced surface water flow resulting from disputes about water sharing. Currently, the

Figure 3: Water dependency ratio by country

■ Source: SFG, 2009

majority of shared water resources in the region have no binding agreements to regulate their utilization and management (UNEP, LAS and CEDARE, 2010). Cooperation among countries is affected by the prevailing political situation. Political tensions in the past has resulted in reduction of upstream releases. Increased competition for the limited water resources to meet the demand of socio-economic activities could lead to regional instability; however, it could also become a catalyst motivating countries to agree on fair allocation and improve management measures, especially from non-renewable groundwater sources. The current extensive pumping practices from shared aquifers could potentially lead to further deterioration of the quantity and quality of water with high technical and financial implications to restore sustainability. In addition, neglecting the issue will not make the problem disappear, but will further exacerbate the situation and increase tensions among the countries of the region as well as with neighbouring countries.

Other complimentary water sources are available from desalination of seawater and brackish water and treated wastewater. Desalinated water with very low total dissolved solids has become the main source of water for the domestic sector in most GCC countries (World Bank, 2005). Desalinated water is combined with groundwater from the limited amount available to bring its quality up to drinking water standards. The total capacity of current desalination production as well as that under construction in the region is more than 3 300 mcm per year, or more than 56 per cent of the domestic water supply share (World Bank, 2005). The region, especially the GCC countries, accounts for approximately 44 per cent of global desalination capacity (UN-ESCWA, 2009).

Roman water reservoir, Bosra, Syria

Desalination plant, Ras al-KAhaimah, U.A.E.

Ryan Lackey/www.flickr.com

Treated wastewater at desirable standards represents a potential non-conventional source of water to augment the supply of irrigation water. Countries of the AP, as well as Jordan and Syria, have initiated the reuse of treated wastewater for landscaping and agriculture, estimated at 640 mcm/year (UN-ESCWA, 2007). Of the treated wastewater, less than 6 per cent is used as domestic water supply, 60 per cent is used in agriculture and landscaping and the remainder is discharged into rivers, wadi channels, open sea or injected into ground reservoirs (UNEP, LAS and CEDARE, 2010).

2.3. SOCIO-ECONOMIC CONTEXT

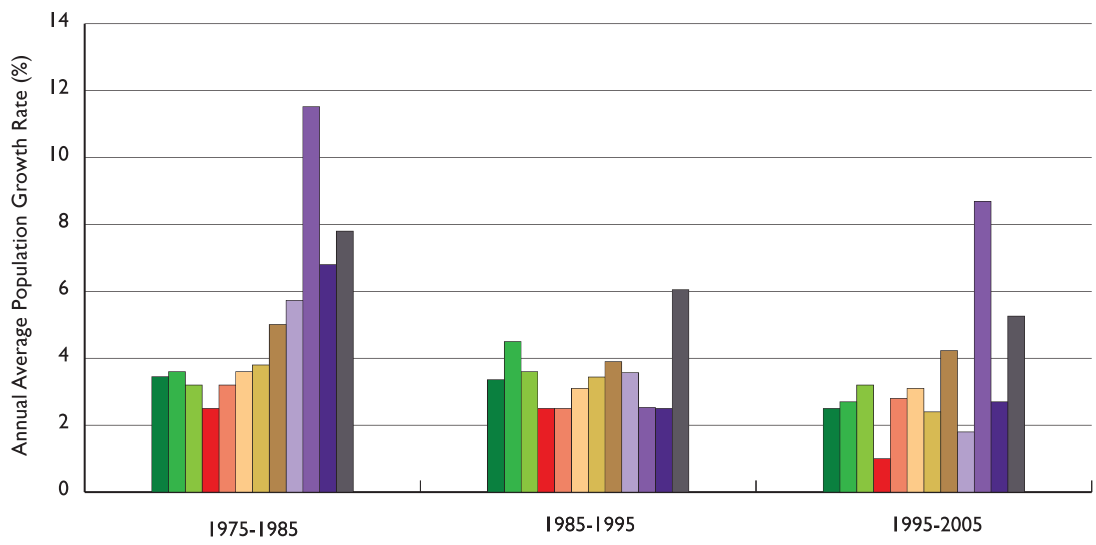
Social, economic and environmental factors influence the well-being of society. Countries of the region have been formulating and implementing policies to improve their standards of living through the provision of improved water supply and sanitation coverage and services and promoting economic activities to generate higher income. In the past, their economies relied on a mixture of mostly regulatory mechanisms; however, in the last two decades, there has been increasing trade liberalization and privatization in order to further integrate into the global economy.

2.3.1. Population Growth

Population pressure represents a major challenge for decision-makers in the region as the limited renewable water resources will not be enough to meet domestic and irrigation demand if prevailing practices continue. Over the last two decades, demographic changes and socio-economic development, especially in the GCC countries, have led to increasing domestic water demands in the region. Rapid population growth and urbanization increase water demand, while population growth increases the pressures on water supply to meet the MDGs for providing adequate drinking water and sanitation services on the one hand, and for achieving food security on the other. The populations of all countries of WA have been growing at a faster pace than the development of services (UN-ESCWA, 2009).

Especially in GCC countries, rapid population growth can be attributed to improved health care, large family size and changing lifestyles. The total population of WA increased from less than 20 million in 1950 to 98 million in 2000, a fivefold increase, reaching 116 million in 2005 and is projected to reach 146 million in 2015 (UNDP,

Figure 4: Population growth for West Asia countries 1975-2005



Bars show the average population growth per annum for the decades preceding 1885, 1995 and 2005

■ Source: this study, data from ACSAD, 1998; LAS and others, 2005.

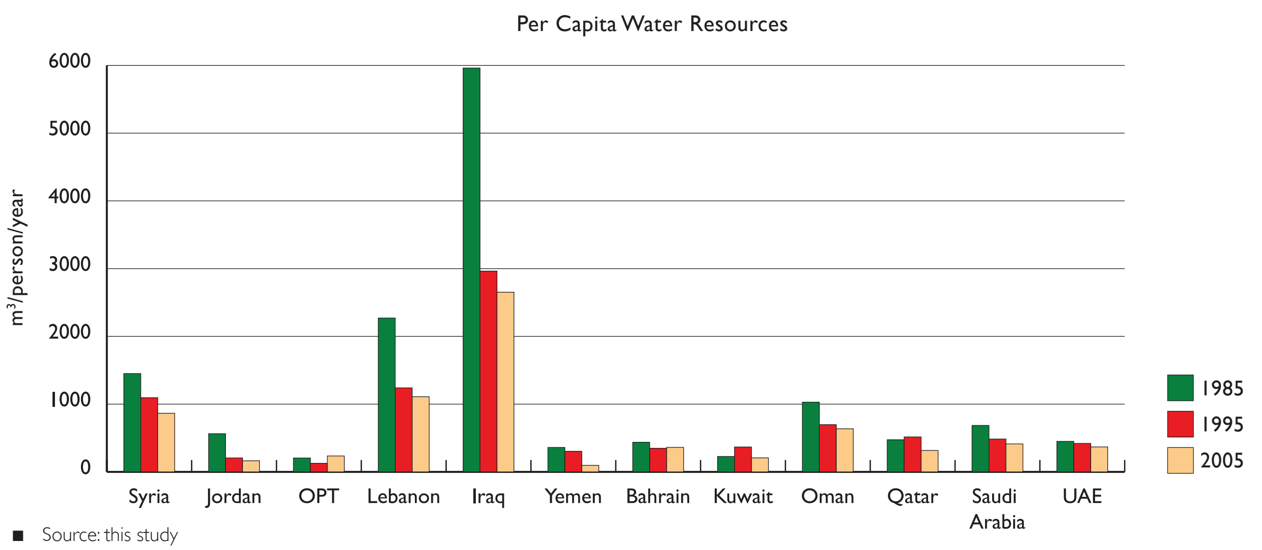
2009). During the period 1985-2005, population size varied among the two WA sub-regions: In the Mashriq sub-region, the population grew from 25.4 million in 1975 to 82 million in 2005 and is projected to reach 159 million in 2040; while for the GCC, it grew from 7.1 million in 1975 to 35 million in 2005 and is expected to reach about 61 million in 2040. Figure 4 illustrates the difference in population growth rates between WA countries (this study).

Due to this rapid population growth, per capita share of water resources has decreased (Figure 5), with some countries falling below the water poverty threshold and showing severe water stress. Expressed in cubic meters (m^3) of renewable water resource per capita, the annual per capita share of renewable sources provides an indication of the vulnerability of freshwater resources to natural and human-made activities. The WA region's annual per capita freshwater share fell from 1 700 m^3 in 1985, to 907 m^3 in 2005 (UNEP, 2007). The region's

Syria River

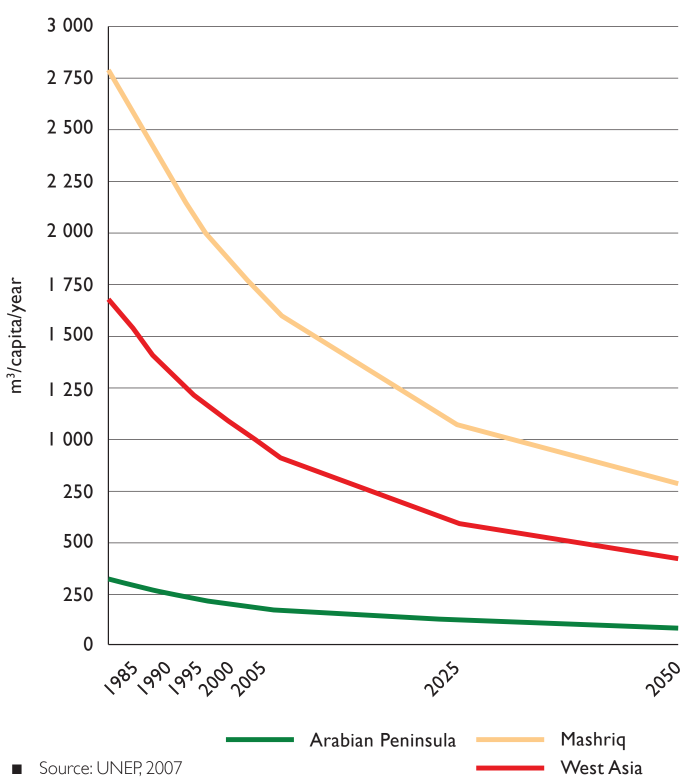
annual per capita freshwater availability (Figure 5) is very low compared to the world average of 7 243 m^3 (CEDARE and AWC, 2004). Sub-regionally, per capita water availability for the Mashriq fell from 2 844 m^3 in 1985 to 1 608 m^3 in 2005, while for the AP it fell from 313 m^3 in 1985 to 156 m^3 in 2005. Currently, the Mashriq sub-region per capita is estimated at 1 500 m^3 while for the AP it is estimated at 125 m^3 (UN-ESCWA, 2007). Future per capita share of renewable water in WA is expected to fall to 650 m^3 in 2025 and 420 m^3 in 2050 due to anticipated population increase (Figure 6).

Figure 5: Per capita freshwater availability trend



■ Source: this study

Figure 6: Trends and projections of per capita share of renewable freshwater sources in West Asia "Asia"



■ Source: UNEP, 2007

2.3.2. Urbanization

The increase in population growth rates in the region was accompanied by high urbanization rates resulting from increased economic activities, migration from rural areas and an influx of foreign labour. Push factors from rural areas include: decreases in water availability due to depletion, and frequent droughts, land degradation due to salinization, deterioration of range capacity and frequent drought cycles (UNDP, 2006; UN-ESCWA, 2009). The high urbanization rate is over-stretching the urban water infrastructure, creating water shortages and unhealthy living conditions, mainly in Mashriq countries (UN-ESCWA, 2009). The urban population in WA accounted for 23.7 per cent of the total population in 1950, rising to 55 per cent in 1980, and reaching 66.5 per cent in 1995 and 69 per cent in 2000 (UNEP, 1999). In 2005, it accounted for 85 per cent of the general population in the GCC sub-region and 71.6

Sand washing plant, Qatar

per cent in the Mashriq (UNDP, 2009). Moreover, the change in consumption patterns has resulted in increased per capita water consumption and the generation of more waste.

This urbanization has created many urban centres home to more than one million people, putting more pressure on government budgets to meet the water supply and sanitation infrastructure needs of these newly built areas. Domestic water shortages have become a problem in key cities in the region. The city of Sana'a, Yemen, faces severe water shortages (WEC, 2001), while in Amman, Jordan, severe shortages forced the government to pipe water to the city from the Disi aquifer, some 325 km away. Damascus, Syria, had an abundant water supply in the past; however, as the population grew to 3.8 million in 2000, water shortages started to be felt, leading to the implementation of water rationing. Water shortages are also experienced in the OPT and some cities in Saudi Arabia (UNEP, 2007).

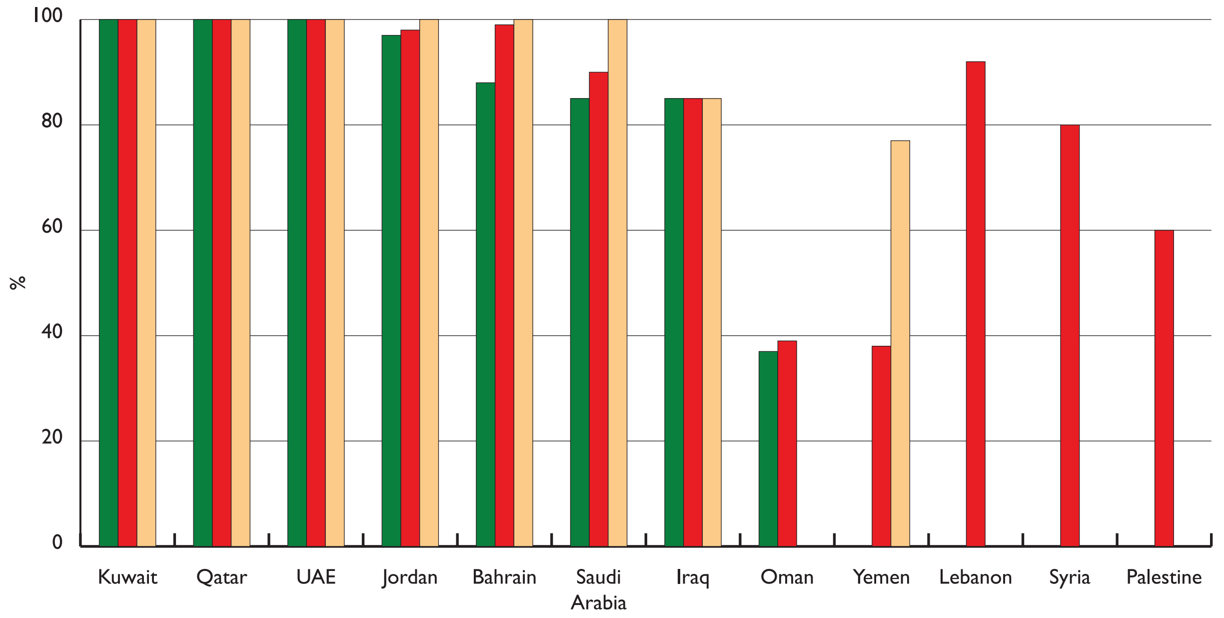
The expansion of the housing sector in newly developed areas is taking place at a faster rate than the installation of water and sanitation infrastructures, and many newly built areas lack water supply and wastewater collection systems. Informal settlements have been on the rise in the last decade, reaching 15, 25 and 31 per cent in Jordan, Syria and Lebanon respectively, and doubling in Yemen (UN-HABITAT, 2003). Furthermore, current urbanization practices are contributing to the loss of fertile agricultural lands, because of encroachment and sensitive coastal shorelines around some major cities due to land reclamation.

2.3.3. Water Related MDGs

In general, the last two decades have witnessed major progress in expanding access to water supply and sanitation services in WA, despite the financial limitations of some countries in the region. These efforts were undertaken not only to achieve the MDGs, but also because the provision of water and sanitation services moved to the top of many of the countries' agendas as important components of development and human well-being. However, while several WA countries have achieved commendable progress in providing safe drinking water and sanitation to their populations, many are still lagging behind (Figures 7 and 8).

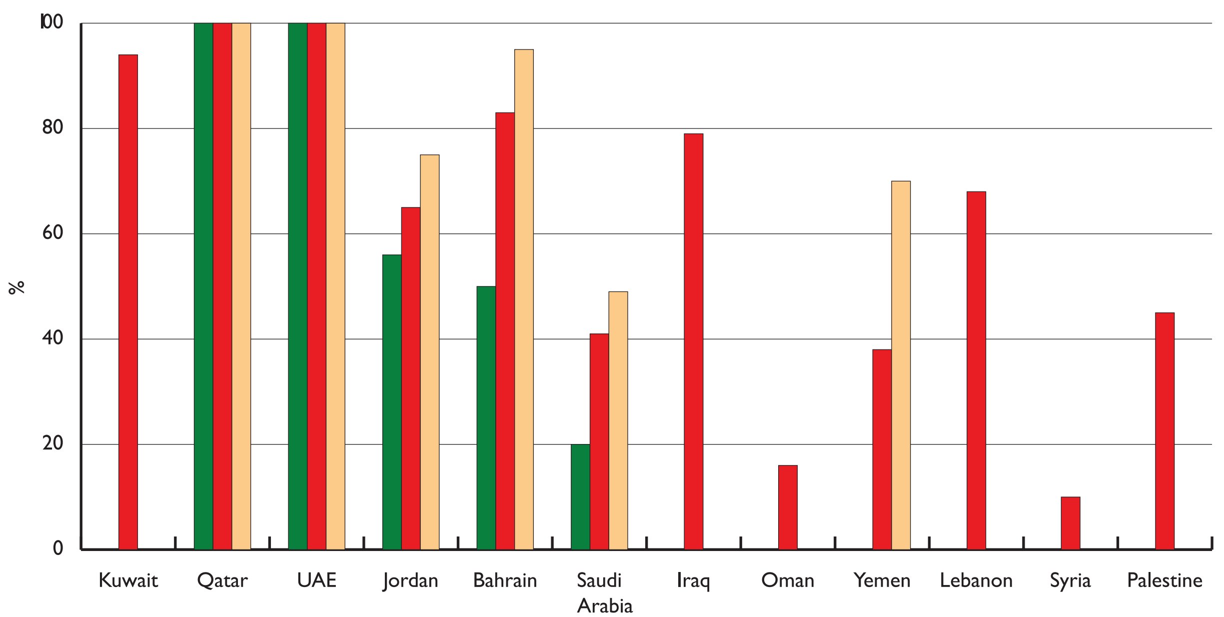
In the WA region, there are approximately 37 million people without access to safe drinking water and about 40 million people that need access to sanitation services (CEDARE and AWC, 2004). This is largely because these people live in

Figure 7: Population with access to safe drinking water, 1990, 2005 and 2015



■ Source: CEDARE and AWC, 2005

Figure 8: Population with access to sanitation, 1990, 2005 and 2015



■ Source: CEDARE and AWC, 2005

countries with a lower income, under occupation or riddled by war and conflict. It is estimated that the total financial cost of providing water supply and sanitation services required to halve the proportion of the population without sustainable access to safe drinking water and sanitation by the year 2015, thereby attaining MDG7, would be about US$100 000 million and US$62 000 million, respectively (CEDARE and AWC, 2004). At this point, lower income countries lack the financial resources for this sort of investment, although investment in providing clean water supply has the potential to generate a high return in reducing healthcare costs. If current practices and trends continue, large investments in water and sanitation treatment facilities will be required for the protection of general public health, particularly given high population growth rates and the associated urban expansion.

An added benefit to improving sanitation measures is the potential use of treated wastewater in the irrigation sector to alleviate water shortages. However, social barriers, such as farmers' personal and religious beliefs, in many countries in the region hinder increased reuse, even where wastewater treatment meets well recognized standards (third-degree treatment) that allow for its use in the irrigation sector.

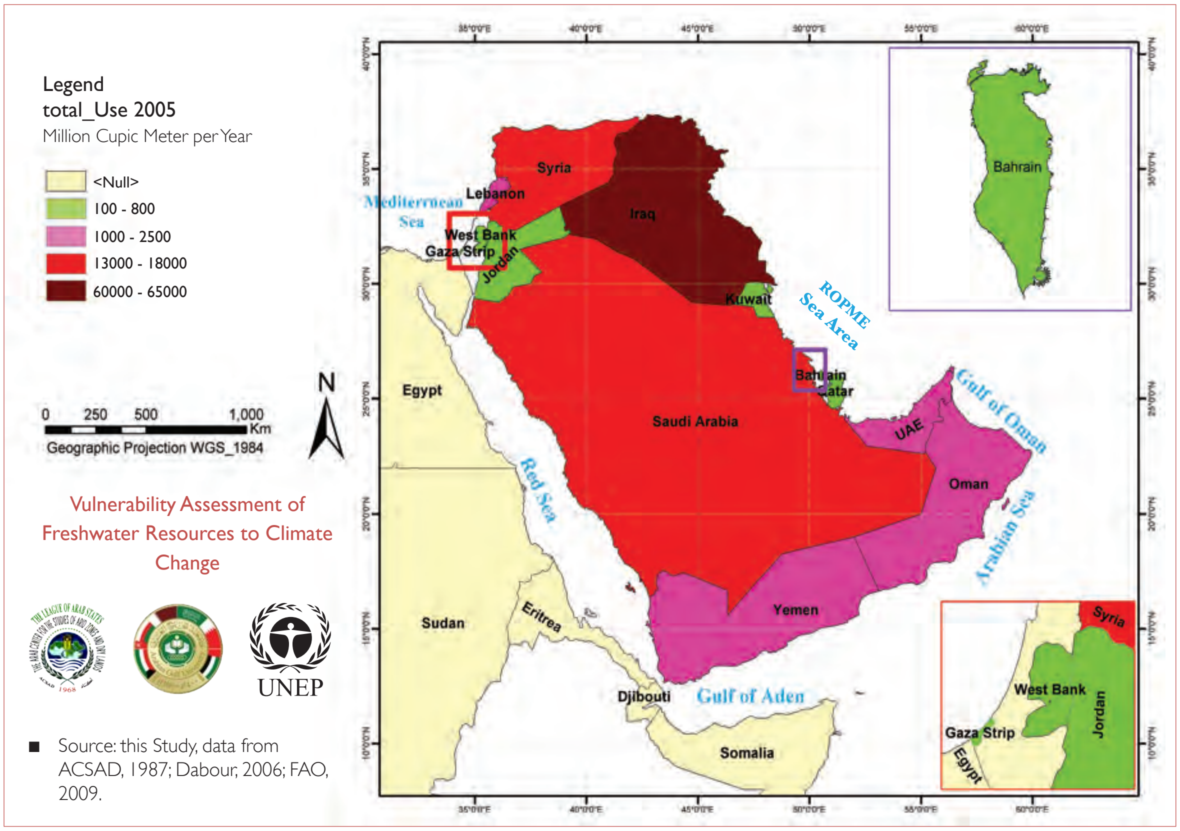
2.3.4. Economic Activities and Water Demands

The oil, agricultural and industrial sectors provide a diverse source of income for the countries of the region and contribute by varying degrees to their gross domestic product (GDP). The main source of income for GCC countries is oil and the associated petrochemical industries, while for the Mashriq sub-region, it is a mixture of agriculture, industry and labour remittance contributions (UNDP, 2009). In the Mashriq sub-region and Yemen, agriculture is the main economic activity, contributing 20-30 per cent of GDP and employing more than 40 per cent of the work force (UN-ESCWA and API, 2002). Currently, most countries in WA are experiencing different degrees of water stress in order to meet increasing water demands, especially for irrigation purposes. Rising water consumption rates in the domestic and irrigation sectors are attributed to population growth, improved standard of living, improved water supply and sanitation infrastructures, increased irrigated areas and increased industrial activities overall. Municipal water consumption rose from 7 800 mcm in 1990 to about 11 000 mcm in 2000, and is currently estimated at approximately 13 000 mcm, a trend expected to persist in the region (Figure 9) (UN-ESCWA, 2003).

Although urban demand is high, the agricultural sector consumes the most water, accounting for more than 80 per cent of total water use (Figure 10). During the past few decades, economic policies favouring food self-sufficiency and socio-economic development in many countries in the region have prioritized the development and expansion of irrigated agriculture. Agricultural water use

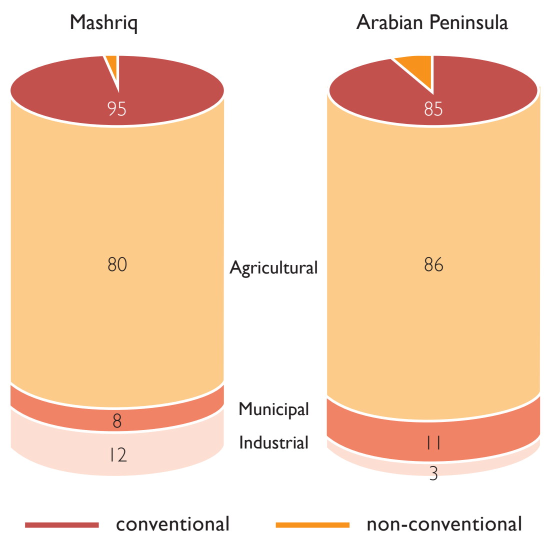
Traditional irrigation

Figure 9: Total water use in West Asia countries



■ Source: this Study, data from ACSAD, 1987; Dabour, 2006; FAO, 2009.

Figure 10: Water resources in West Asia by origin and use

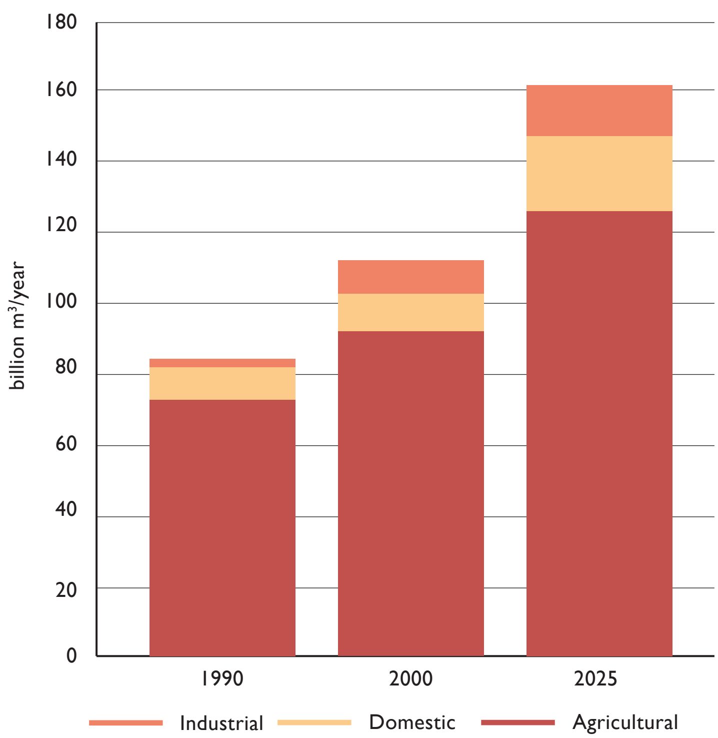


■ Source: UNEP, 2002, adapted from Khouri, 2000

increased from approximately 73 000 mcm in 1990 to more than 85 000 mcm by 2002 (UN-ESCWA, 2003), and reached about 87 000 mcm in 2007 (UN-ESCWA, 2007), placing immense pressure on the region's limited water resources. Although many countries recently abandoned such policies, agricultural water consumption is expected to increase, and problems in allocating water among agricultural, domestic and industrial sectors will worsen (Figure 11).

Meeting future demand in WA, mainly in the irrigation sector, will lead to major depletion of groundwater resources especially from non-renewable aquifers, and will also require significant investment in desalination and wastewater treatment and distribution networks. Such

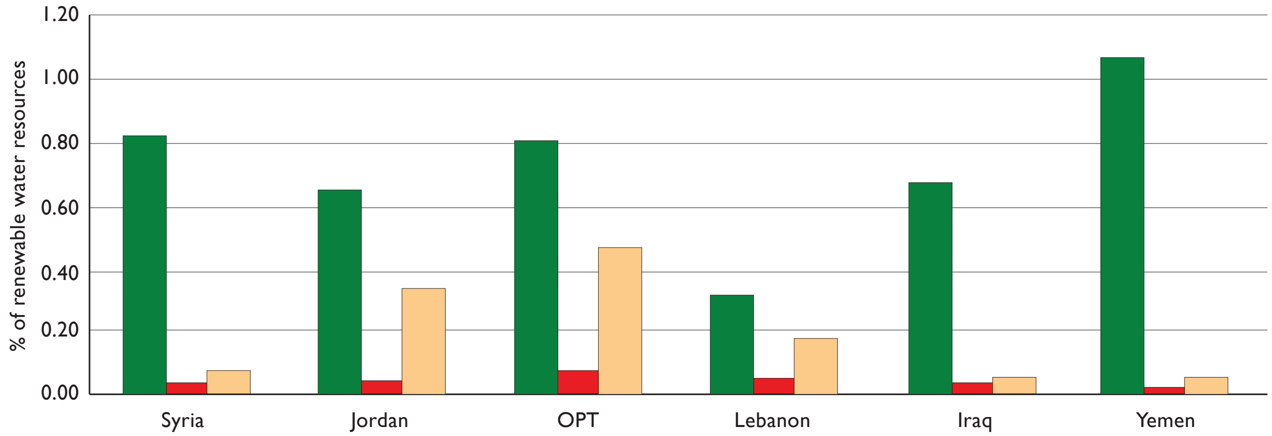
Figure 11: Trends and projections in water demand in West Asia



■ Source: UNEP, 2007

Freshwater spring, Wadi Hawqayn, Oman

Figure 12: Percentage of water use in different sectors in the Mashriq sub-region



■ Source: this study, data from ACSAD, 1987; Dabour, 2006; FAO, 2009 investment could be beyond the financial capacity of most countries of the Mashriq sub-region. The percentage of renewable water consumption of the different sectors for the Mashriq sub-region is shown in Figure 12.

2.3.5. Water Sector Financing and Contribution

The development and management of the water sector is largely funded by government budgets, which in turn are influenced by the magnitude of their GDP. Annual budget allocation to the water sector varies among the countries of the region, with higher allocation rates in the GCC; while some countries, mostly in the Mashriq sub-region, depend on Arab and international lending institutions to finance their water supply and sanitation sector. Achievements vary among countries based on their policies and priorities among the various sectors, namely water supply and sanitation coverage, increases in food production, allocation of sufficient funds to invest in infrastructure and the provision of financial support to increase agriculture and industrial productivity.

The region's total GDP has risen with the volatile price of oil, reaching US$258 000 million in 1995 and US$693 000 million in 2005, contributing to higher investments in the water sector and social welfare (UNDP, 2009). The GDP of the GCC sub-region reached US$600 000 million in 2005, mainly from oil revenues, while the GDP of the rest of WA countries was estimated at US$92 600 million. Between 2004 and 2008, GDP growth rates in the GCC fluctuated from as low as 5.3 per cent in Saudi Arabia to 20.8 per cent in Qatar in 2004, and 4.1 per cent in Saudi Arabia to 9.7 per cent in Qatar in 2008 (UN-ESCWA, 2009). For the rest of the WA region, it ranged between 2 per cent in the OPT and 23 per cent in Iraq in 2004, compared to 1 per cent in the OPT and 7 per cent in Iraq in 2008 (UN-ESCWA, 2009). High GDP growth, especially in the GCC countries, due to increased economic activities, resulted in an influx of foreign labourers, putting more pressure on the water supply sector. The growth in tourism also contributed to a small increase in water demand. This sector employed 20-30 per cent of the total population, contributing 8-15 per cent of total GDP (UN-ESCWA, 2009).

The irrigation sector has contributed a lower relative value to the GDP than the industrial and oil sectors. In 2005, agriculture accounted for 20-30 per cent of GDP in the Mashriq sub-region and Yemen, and 2 per cent in the GCC countries (UNDP, 2005). During the period 1995-2005, the sector employed 16-54 per cent of the labour force in Yemen, Syria, and the OPT, and only 5 per cent in GCC countries (UNDP, 2009). Nonetheless, agriculture has contributed somewhat to the economies of some WA countries, such as Lebanon, Syria, Iraq, Oman, Saudi Arabia and Yemen. In many countries, though, agricultural production has not kept pace with the rapidly increasing demand for food, resulting in a widening food gap that is filled by imports (UNEP, LAS and CEDARE, 2010).

GDP per capita data indicates that most countries experienced improvements to their standard of living with the GDP growth, resulting in higher water consumption, estimated at 350-600 l/day for most GCC countries (UNEP, LAS and CEDARE, 2010). Furthermore, increases in commodity prices, especially the recent food price spikes, have eroded individual incomes, especially for the poor, leading to continued government subsidies on the water supply and irrigation sectors. High inflation rates during the last five years in particular have forced many governments in the region to maintain subsidies to establish a safety net for human well-being.

Subsidies have long been justified in the region on equity grounds as social safety nets, especially for the poor, to enhance water provision in all countries of the region. Water supply provision in all countries has been subsidized through low water tariffs estimated at much less than production and distribution costs. Production of desalinated water is generally much costlier than that from surface and groundwater sources. Significant financial subsidies are being provided by GCC countries for the provision of excellent water supply quality and adequate quantities, where the cost of desalinated water production is estimated at US$1-2 per m^3 (World Bank, 2005) compared to a very low water tariff rate in the local currency. Extensive agricultural subsidies were provided by GCC countries, Syria, Iraq and Yemen, while the remaining countries provide different types of subsidies to the agriculture sector to enhance farm income and increase productivity (UNEP, LAS and CEDARE, 2010).

2.3.6. Social Benefits

Water supply availability, dependability and quality has implications for enhancing human well-being and human health, as well as to the attainment of the human right to adequate and clean water supply and appropriate sanitation coverage. The most important social dimension is to provide a real opportunity for people to improve their living conditions, achieve human security, good health and material needs. The principle of water as a human right entitles each individual to sufficient, safe, acceptable, physically accessible and affordable water for domestic use (UNDP, 2009). To satisfy this principal, the countries of the region have been committed to improving social well-being across all segments of society through the provision of adequate and safe water supply, and the collection and treatment of domestic waste.

The availability of clean water supply and sanitation (both collection and treatment) has social and environmental implications. Clean water, essential for sustaining life, has major health implications especially for the poor, due to their low capacity to cope with risks. Increased pollution levels being experienced in many parts of the region, especially the Mashriq sub-region, poses high health risks to communities, reducing water supplies and damaging fragile ecosystems. As the quality of water resources deteriorates, health risk levels rise and the costs of health care and the treatment of highly polluted

Palmyra Bishri, Syria

water increases. Pollution sources are taking place from either over-exploitation of shallow groundwater leading to water quality deterioration, or direct pollution from the disposal of domestic and industrial wastes and irrigation return flows contaminated with pesticides and fertilizers.

Many rivers, springs and shallow groundwater sources have shown symptoms of pollution as a result of the dumping of raw or partially treated wastewater along river courses and wadi beds (Hamad and others, 1996). The percolation of such wastes into shallow aquifers represents a major health risk, particularly from nitrate, faecal coliforms, undetected viruses and heavy metals. This contamination poses a significant health risk and can cause malaria, malnutrition, waterborne diseases such as Giardiasis and Cryptosporidiosis, and respiratory illnesses. Nitrate contamination of groundwater sources in the Mashriq countries poses a serious risk to infant health. Nitrates can cause methemoglobin (blue baby syndrome) in infants, a condition that can result in brain injury, mental dysfunction or death (UNU, 2002). Air pollution from emitted oxides, high brine reject concentration and residual metals emitted during the production of desalinated water also pose health risks to the surrounding marine environment. Besides the health cost of pollution, rehabilitation of polluted surface and groundwater sources incurs high cost, with a low likelihood of success for groundwater rehabilitation.

Despite generous subsidies, agricultural policies adopted in many countries have not fulfilled their goals, as the sector performance indicators are very low with regards to achieving food security, with major negative impacts during the period 1995-2008 concerning the depletion and deterioration of already limited water resources. Agricultural performance and food production in the region remains unsatisfactory (Dabour, 2006; UNEP, LAS and CEDARE, 2010). The GCC sub-region still imports more than 50 per cent of its food. The subsidization policy has exerted additional pressure on their limited water resources by creating an incentive for irrigated agriculture, leading to increased water consumption in the irrigation sector with extensive mining of groundwater and cultivation of water-intensive crops, as well as increased pollution from pesticide and domestic wastes. Over the last two decades, the net irrigated area tripled across all GCC countries (UNEP, LAS and CEDARE, 2010).

2.4. WATER GOVERNANCE

During the past few decades, economic policies favouring socio-economic development and security were adopted in many countries without due consideration to water scarcity and adequate water availability. Even though these policies have contributed to increases in income level, improved education and healthcare systems, it has had some adverse environmental effects related to urban and irrigated agricultural expansion. Such considerations were not placed high on the political and economic agenda. Availability of financial resources was looked at as a vehicle to resolve any water shortage problem without addressing future challenges and constraints. The current situation reveals that depletion of water resources and deterioration of their quality is a human security challenge for future generations.

Current water issues are associated with the absence of holistic planning in line with the integrated water resources management (IWRM) framework in many countries. Integrated Water Resources Management (IWRM) requires the application of good water governance that emphasizes the implementation of effective institutional and legal frameworks. Whilst senior water professionals and managers need to understand and communicate the issue, responsibility for action lies with government ministers, policymakers, politicians and community leaders. These stakeholders constitute the water governance system. Good water governance includes an enabling environment (integrating policy), water legislation (a legal framework) to set the implementation of policy, water institutions and capacity building, stakeholder participation and a financing structure. Indicators of governance consist of accountability, effectiveness, regulatory quality, rule of law, control of corruption and institutional competence (UN-ESCWA, BGR and GTZ, 2004).

Currently, the water sector in many countries lacks appropriate governance owing to the difficulty of implementing the required reforms and integration of water policies into socio-economic development, as well as inadequate institutional arrangements. As a result, existing water policies are fragmented and focus on the issue of water development to increase water resources with little attention to an integrated management approach. Past practices neglected addressing the institutional arrangements to delineate overlapping functions, jurisdiction in water and water-related sectors and legal enforcement for the implementation of water policies (UNEP, LAS and CEDARE, 2010). Lack of coordination has contributed to waste of financial resources, depletion of natural resources (especially water) and degradation of the environment. Such losses have occurred despite some countries updating their water legislation, and this can be attributed to a lack of provision of the adequate financial and human resources necessary for their enforcement.

The achievements of enhanced water resources management, economic efficiency, social equity and environmental justice call for better governance practices. The linkages between these issues mean that economic, social and administrative mechanisms can all contribute to improved water governance. The following measures can contribute to improved water governance in WA:

- Application of strong water governance measures to support policy integration,
- Enhanced institutional arrangements,
- Improved legal frameworks and enforcement,
- Increased coordination,
- Transparency and accountability,
- Financial efficiency,
- Decentralized decision making,
- Encouragement of public participation,
- Protection of individual rights,
- Exchange of expertise, and
- Promotion of riparian cooperation.

Evaluation of the current state of these indicators in the water sector in the region is difficult; however, the prevailing trends vary from country to country. There is evidence of better performance on the rule of law, institutional set up and regulation, but less on accountability for water distribution, cost recovery of water structure and effectiveness in water use and management (Rogers and others, 2003).

2.5. CLIMATE CHANGE AND WATER RESOURCES

Anthropogenic climate change due to increasing greenhouse gas (GHG) emissions from human activities is now an acknowledged reality and the focus of many debates at UN and other international forums, as well as the scientific community. The main causes are increased GHG emissions from fossil fuel combustion due to increased socio-economic development, coupled with mismanagement of natural resource, such as overgrazing and accelerated development of urbanization centres. Other emissions include nitrous oxides, methane, ozone and chlorofluorocarbons. The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) indicated that average global surface temperatures have increased by 0.74ºC during the last century (IPCC, 2007). The change in temperature regimes during the 19th century was an increase in the range of 0.3-0.6ºC, while for the past 40 years (since 1970) the increase was between 0.2 and 0.3ºC (IPCC, 2007). This temperature change was accompanied, depending on the emissions scenario, by increases or decreases in rainfall with heavy amounts in some regions of the world, increased evapotranspiration rates, and a sea level rise of 0.17 m during the same period. Projections indicate that by 2100, global temperatures are expected to increase by 3-4°C and sea level may rise by about 0.18-0.58 m. In addition, an increase in temperature of 1-2°C could decrease rainfall globally by 5-10 per cent (IPCC, 2007).

2.5.1. Global Impacts

Climate change is expected to have impacts on the well-being of different segments of society with a higher impact on the most vulnerable, women and children, the poor and the disadvantaged, as well as on natural systems. The impacts are expected to vary in space and time. Climate change could have major implications for human health. There are emerging diseases in many regions of the world that may be attributed to changing weather patterns (UNDP, 2009). Climate change could impact plant and animal growth, nutrient cycles and increases in incidence of different pests and diseases. The impact could affect natural vegetation species in shifting their belt up to higher elevations. Low-lying coastal zones, especially along the ROPME Sea Area and small islands, will be exposed to sea level rise, and the increased temperature and changing wave patterns could threaten tourism activities and ecosystems, including coral reefs, sea grass and the fishing industry.

Climate change could be the cause of the current rise in incidents of weather-related disasters. In 2000, 500 events were reported, compared to 120 events in 1980, with a six-fold increase in flooding events (UNEP, 2007). Extreme events such as flooding will increase surface runoff with increases in sediment load, nutrients, pesticides and heavy metals in rivers or wadi courses. Increases in drought frequency and intensity can lead to accumulation of sediment, reduced areas of arable land and soil erosion from reduced soil moisture, reduced upstream inflow of shared rivers and reduced recharge due to decreased rainfall amounts at the outcrop of the shared aquifers. This could lead to increased competition for natural resources and intensification of disputes over water allocation and political tensions.

The agriculture sector, being a major water consumer and faced with the challenge of producing enough food, is expected to be impacted by these changes in temperature and precipitation patterns. The impacts may vary at the basin, sub-basin, national and regional levels. Climate change could have positive or negative impacts on the agriculture sector productivity. In broad terms, climate change could boost productivity in developed countries and decrease it in developing countries (UNDP, 2009). According to the recent Human Development Report (UNDP, 2009), different model projections indicated that by 2080, agricultural potential could be boosted by 8 per cent in developed countries resulting from a longer growing season, while developing countries could see a decrease of 9 per cent. Food shortage has forced many countries to focus on food security instead of food sufficiency due to, among other factors, shortage of water resources.

Food security achievement will force many countries to assess their requirements by focusing on food availability, accessibility, utilization and system stability, thus intensifying food production. Food shortages will force many countries to depend on foreign imports. Climate change could impact production from rain-fed agriculture and decrease productivity per hectare due to variable and reduced rainfall and soil moisture.

2.5.2. Potential Impacts on West Asia

Although the Arab region as a whole does not contribute more than 5 per cent of total GHG emissions, the impact of climate change on the region is substantial (AFED, 2010), with GCC countries shouldering the biggest share. Recent studies indicated that the degree of expected impacts will vary among countries of WA, and GCC countries will be particularly affected. The climate change global index study developed by Maplecroft classified countries in different parts of the world according to the degree of exposure to climate change (Abdel Hamid, 2009). The study indicates that some WA countries may experience different degrees of vulnerability to impacts of climate change ranging from extreme to significant to highly vulnerable. This index classified Iraq globally as the fifth most vulnerable country to decreased water and food availability and extreme temperatures and their associated health problems. Bahrain and Qatar were ranked eleven and are projected to suffer significant impacts because of their small area and low elevation with their coastal zones exposed to sea level rise. The rest of the GCC counties are rated as highly vulnerable and Yemen as extremely vulnerable (Abdel Hamid, 2009). Reduced water availability due to climate change and environmental degradation coupled with high population growth could threaten the progress made towards achieving the MDGs. Studies on the impacts of climate change on WA are very limited due to poor data availability coverage and dissemination.

The change in precipitation patterns (amount, intensity, duration, distribution and seasonality) will influence the availability and dependability of water resources due to the unpredictability of weather events. Future projections suggest a decrease in rainfall in the region according to most global climate models (Meslemani, 2008). Rainfall is projected to decrease by 20 per cent over the next 50 years (Khordagui, 2007). In the Mashriq sub-region, rainfall may decrease by 25 per cent at the regional level and at some locations by 40 per cent (Shindell, 2007). Results from a European Union project on the Mediterranean region supported these projections and indicated that there will be general and continuous drought conditions with increases in water deficits in the Mediterranean region (Hanson and others, 2007). The project also suggested that Lebanon, Syria, Jordan and the OPT may experience significant reduction in rainfall due to the expected changes in the general weather system pattern (Hanson and others, 2007).

Temperature increases could influence the quality of surface water in terms of dissolved oxygen, stratification, mixing ratio, self-purification and biological content and growth especially algal bloom, bacterial content and fungal levels (Khordagui, 2007). Increases in temperature may result in heat waves with impacts on health, higher water and energy consumptions and increased incidence of disease (Figure 13).

A decrease in rainfall and an increase in temperature are projected to contribute to increased evaporation and decreased surface water and associated groundwater recharge. The increase in temperatures and the associated sea level rise will result in seawater intrusion into the groundwater aquifers along coastal zones especially in the AP sub-region as many wadis drain into the long coastal zones. Intake of desalination may be impacted with the potential of additional engineering

Oman

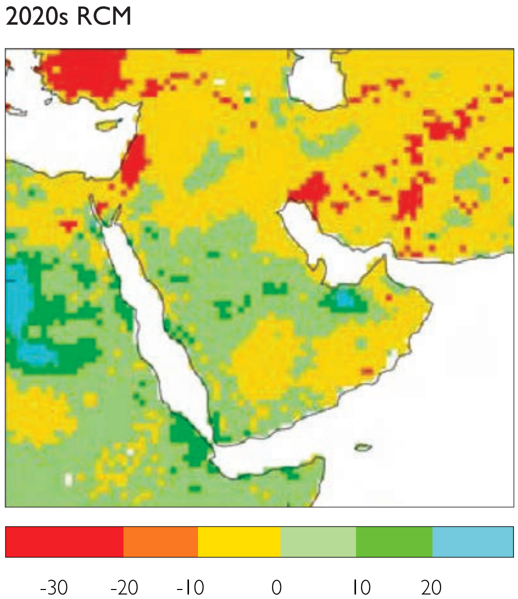
redesign works and environmental assessment to accommodate the expected increase in seawater temperature and salinity concentration.

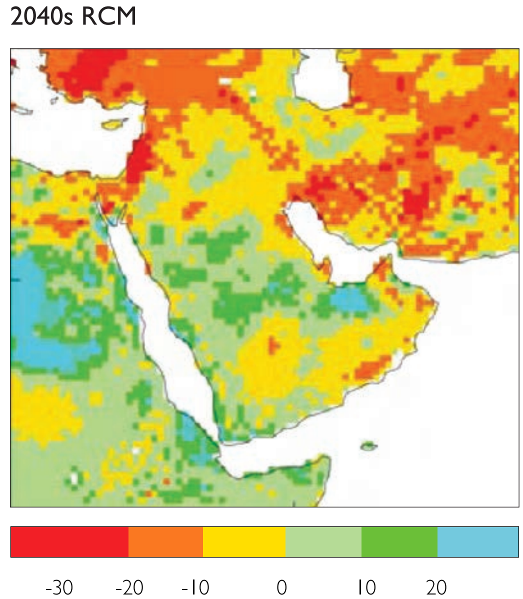
With regards to shared water resources, it was predicted that the Tigris and Euphrates River flows could experience a flow reduction of 29-73 per cent as well as variation of quality as most of the winter precipitation may be in the form of rain instead of snow (Kitoh, 2008). Reduced water availability will increase competition and disputes in the absence of final sharing agreements (UNEP, LAS and CEDARE, 2010).

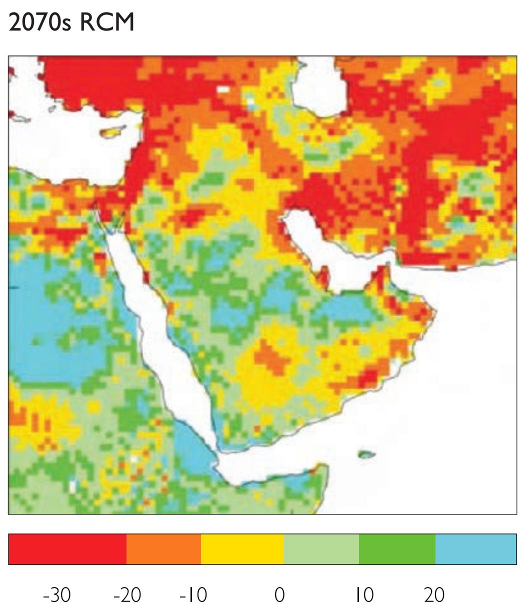
Weather events experienced during the last five years in the region such as the Gonu floods in Oman in 2007, Yemen and UAE in2008 could be attributed to climate change. Cyclone Gonu caused major flooding with significant increases in recharge rates to shallow groundwater sources, damage to infrastructure (housing, road, water distribution and wastewater collection system, dams, dikes) and loss of biodiversity. In the Mediterranean, there is consensus that climate change and the increased frequency of extreme weather events will likely cause more flooding and drought; Syria, Jordan and Lebanon will experience extended droughts.

The impact of climate change needs to be assessed through the evaluation of the prevailing two weather systems in the region. The two major climate zones that affect rainfall regimes are the Mediterranean winter system affecting Lebanon, Syria, Jordan and the OPT on the one hand, and the Indian monsoon affecting south-western parts of Saudi Arabia, Yemen and eastern Oman on the other.

Figure 13: Regional climate model projections of precipitation changes (%) for 2020, 2040 and 2070 relative to 1990



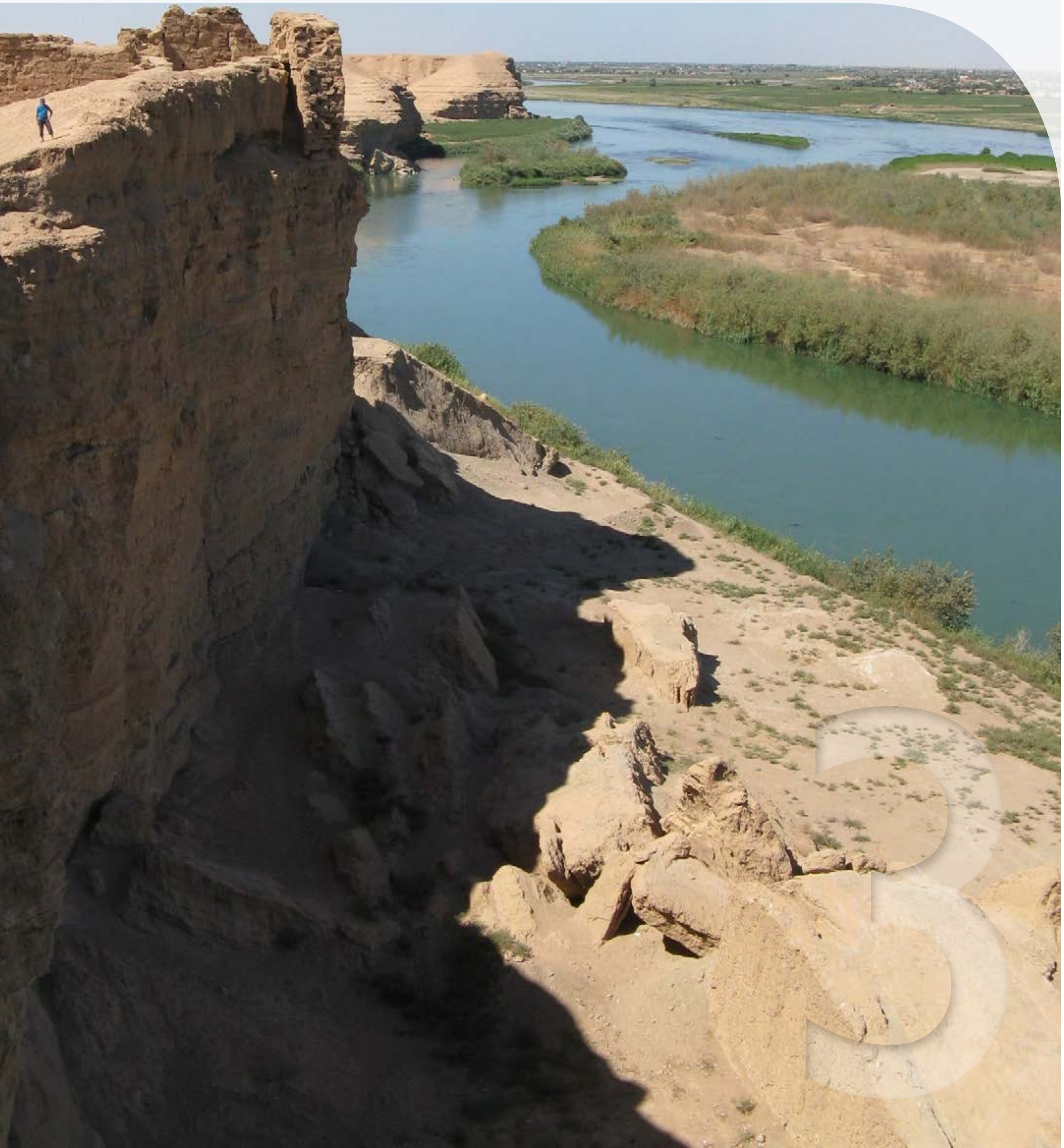




- Source: Hemming, Betts and Ryall, 2007 as cited in AFED, 2009

CHAPTER THREE

METHODOLOGY



Alen Ištoković/www.panoramio.com

Key Messages

The aim of this freshwater vulnerability assessment is to inform decision-makers of vulnerability at different scales.

Data was collected through an intensive literature review that provided a general trend of the different parameters of the vulnerability index. A conceptual framework of analysis was formulated to facilitate the development of a detailed work plan.

The methodology is based on the DPSIR framework. Drivers include population growth and urbanization, water resource availability or deficit and pollution. Impacts include the changes in water sector performance and adaptability as a result of climate change, in addition to other socio-economic activities. Responses were estimated by the adaptive capacity of the ecosystem and humans to potential threats.

Vulnerability is a function of resource stress, water development pressures, ecological health and capacity. Based on these parameters, the vulnerability index (VI) provides an estimated value for a given year ranging from zero (non vulnerable) to one (most vulnerable) to determine the severity of the stress being experienced by the water sector.

Floods in Saudi Arabia

3.1. INTRODUCTION

An appropriate tool to assess freshwater vulnerability is the simplified approach developed by UNEP (2009) that utilizes the available data and its coverage at the national and regional levels. Its objectives are to provide a vulnerability assessment at different scales (basin, sub-basin, national and regional) for generating timely and adequate information for decision-makers. It also allows for the analysis of the state, trends and interrelationship between the following components: water resources availability from natural hydrological systems; resource development and utilization for human well-being, meeting MDG goals and socio-economic development; water availability for the maintenance of ecosystem equilibrium; and the existing management capacity.

According to the guidelines, the assessment of freshwater resource vulnerability will carry out:

I. Desk study to evaluate existing literature and collect the water-related data and information needed to define the most influential parameters that can define potential threats and evaluate their impact.

II. Analysis of the status of water resource availability from the prevailing natural conditions, development, use and management practices as well as identification of key issues that influence resource vulnerability.

III. DPSIR analysis of the water sector in order to identify and evaluate the impact of the main drivers and pressures, evaluate the current state, expected trends and expected responses to existing and future stresses.

IV. Estimation of the integrated vulnerability index defined in the assessment guidelines (UNEP, 2009) taking into consideration the DPSIR parameters and preparation of maps showing the degree and coverage of threats including hot spots at basin, national or regional levels.

V. Draw a general conclusion on freshwater vulnerability that may result from natural phenomena and anthropogenic activities such as improper resource utilization, pollution, climate change impacts and, finally, present conclusions and recommendations to cope with future vulnerability.

3.2. DATA ACQUISITION AND ASSESSMENT PROCESS

In accordance with the vulnerability assessment guidelines developed by UNEP and Peking University (UNEP, 2009), two research teams from AGU and ACSAD were formed to conduct an assessment of the WA region. A desk study was undertaken, involving an intensive review of relevant literature and the collection of extensive data on water resources, water pollution and economic information from government reports, research centres, UN and international organizations' databases, research papers, policy reports, maps, etc. These data were sometimes insufficient, incomplete and contradictory. Thus, the present analysis will provide a general trend rather than an accurate estimation of the different parameters of the vulnerability index. However, tremendous efforts were made to filter, evaluate and ensure the consistency of the data. The data was extrapolated to account for gaps in information and to make future projections. From these pools of data and information, a conceptual framework of analysis was formulated and a detailed work plan was developed. Continuous consultation and exchange of information between teams ensured consistency of information.

3.3. APPROACH

The fresh water vulnerability methodology (UNEP, 2009) uses the DPSIR framework to evaluate the integrated effect of the most dominant factors in order to determine the system performance and adaptability that may take place as a result of the modification of natural processes and socio-economic activities and institutional aspects. Thus, the methodology evaluates the main drivers, including population growth and the associated urbanization; the pressure parameters including water resource availability and deficit due to natural and anthropogenic activities, as well as pollution from different sources, especially wastewater. The impacts would include the change in the state of water sector performance and adaptability resulting from climate change and other socio-economic activities; while the response parameter is estimated by the adaptive capacity of the ecosystem and population to potential threats.

The level of detail attainable is dictated by data availability in terms of scale, coverage and the temporal extent of historic records. The smaller the scale of the analysis (e.g., sub basin, basin or part of the country), the more details will be available on the variation of freshwater vulnerability influenced by hydrological systems, degree of socio-economic activities and environmental conditions. This study, undertaken at the national scale, can be a baseline for more detailed vulnerability assessments at smaller scales (basin; sub-basin or regions of a given country), as well provide many policy options.

The fresh water vulnerability index (VI) for each country in WA was calculated for ten-year intervals starting 1985, 1995 and 2005, and was then projected for the years 2020 and 2040.

The expected environmental impacts from water depletion, pollution and climate change were evaluated for two case studies in shared water resources in WA: the shared surface water of the Euphrates River, and the shared non-renewable Dammam groundwater aquifer. Future vulnerability indices for the four main associated parameters were assessed for two scenarios (up to the year 2040), with and without the impacts of climate change:

Scenario (1) Normal population growth

This scenario assumed that population growth rates will match United Nations population projections for the countries of the region[1]

1. According to UN, 2011.

Scenario (2) Normal population growth and reduced water resources

In this scenario, the impact of climate change is imposed on the previous scenario, manifested by a decrease/increase in water availability due to changes in rainfall amount and snow accumulation. The findings of these two scenarios are presented in Chapter 6.

3.4. Vulnerability Index (VI)

According to the UNEP methodology, vulnerability is a function of water availability, use and management parameters (UNEP, 2009). The vulnerability index can be assessed from the application of a number of governing equations to estimate the four parameters, as follows:

3.4.1. The Resource Stress (RS) parameter

The water stress indicator is influenced by the availability of renewable water resources and the consumption patterns of the growing population (RSs) and water variation parameter resulting from long term rainfall variability (RSv).

3.4.2. Water Development Pressures (DP) parameter

Freshwater resource availability in the region depends on rainfall and recharge distribution patterns. Higher frequency of occurrence and higher amounts led to enhanced water availability and dependability. Supply potential is diminished by growing demand from different sectors and from pollution from different sources, placing pressure of varying degrees on water resources development.

3.4.3. Ecological Health (EH) Parameter

The water ecological health parameter is a measure of the impacts of pollution from different sources on ecosystem equilibrium and protection. An arid ecosystem with low resiliency requires more time to regenerate or adjust to a reasonable stage of sustainability. Water pollution in WA represents a major threat to future water availability and poses a major threat to health.

3.4.4. Management Capacity (MC) Parameter

Freshwater vulnerability is improved by the implementation of effective management practices that contribute to water sustainability. Evaluation of the management capacity provides a means to evaluate how effectively the water sector is being managed.

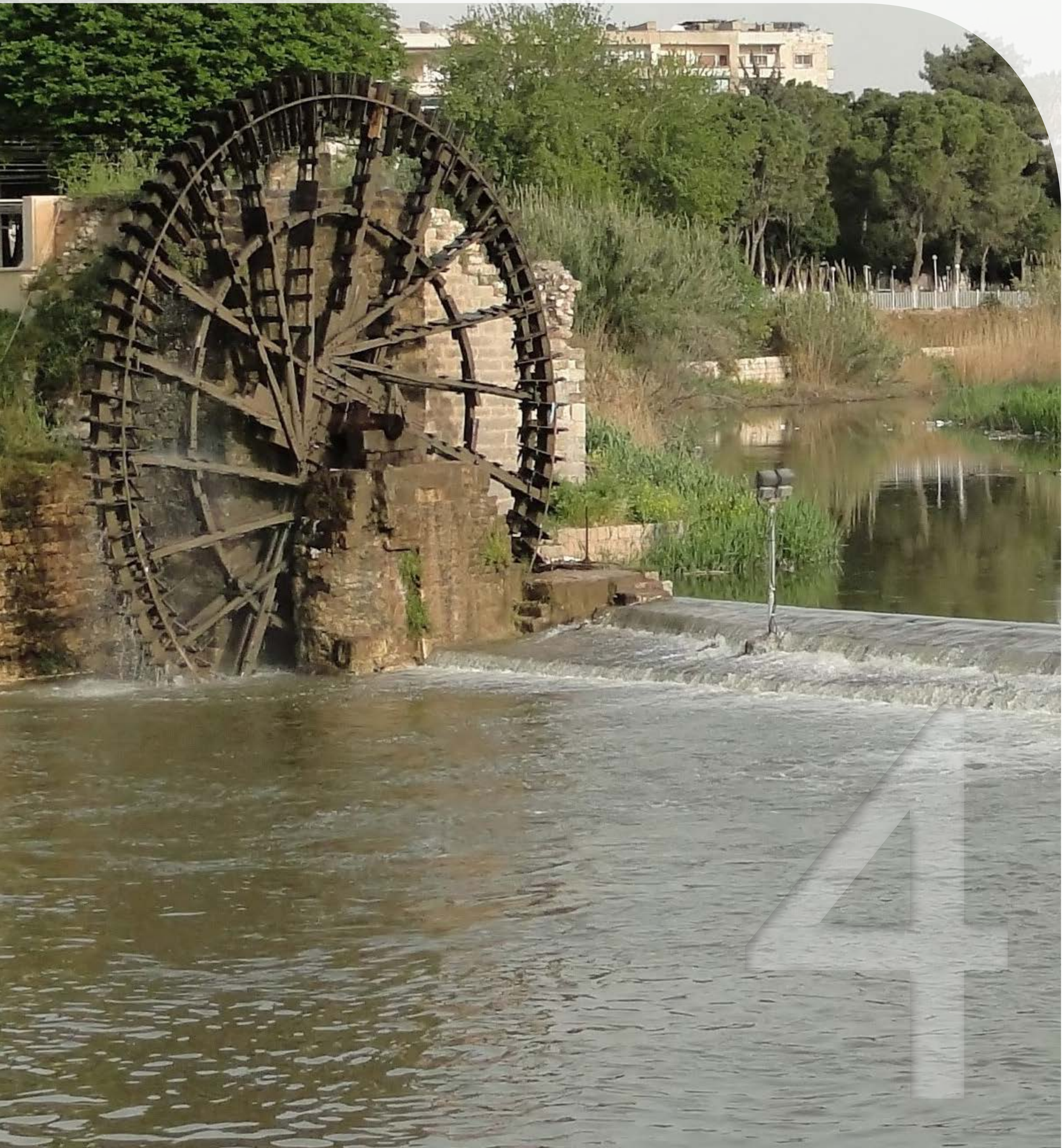
3.5. FRESHWATER VI ESTIMATION

The Vulnerability Index (VI) is estimated based on the consolidation of the values of the four main parameters mentioned above as follows: VI = f (RS, DP, EH, and MC) and can be assessed from two perspectives: Firstly, the main threats to the availability of water resources, their development and water utilization dynamics; and secondly, capacity to cope with the potential national and regional threats to water availability.

The vulnerability index (VI) provides the estimated value for a given year ranging from zero (non vulnerable) to one (most vulnerable) to determine the severity of the stress being experienced by the water sector. All the governing equations for the above mentioned parameters are presented in the Annex.

CHAPTER FOUR

ASSESSMENT OF FRESHWATER VULNERABILITY TO CLIMATE CHANGE



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Key Messages

All countries of West Asia, with the exception of Syria, have large water variation, due to their arid and semi-arid climate. The countries will therefore be very vulnerable to climate change impacts. It is expected that all the countries will be affected by climate change.

Water pollution from domestic and industrial wastes will reduce the availability of usable freshwater.

Levels of access to clean safe water are increasing with time, reflecting improved management of resources.

For the Mashriq sub-region, vulnerability is increasing in all countries. Most countries have been experiencing different degrees of water stress depending on the availability of dependable flows from major rivers, especially shared ones. Countries such as Jordan and Yemen are under severe stress while the remaining countries have adequate surface water sources.

Additional effort is needed for improving water use efficiency in most Mashriq countries as well since any variation in precipitation will affect available water resources. All countries are very vulnerable to climate change. This reflects an urgent need for mitigation and adaptation plans to be adopted by all the countries of the region.

There is a need for technical support and policy backup plans to mitigate these pressures. A longer-term and appropriate strategic development plan should be adopted, with a focus on enhancing management capacity to deal with major threats.

Old irrigation system (Nouria) on Orontes River – Hama, Syria

4.1. INTRODUCTION

The freshwater VI for each country in WA was calculated for a ten year period at intervals starting 1985, 1995 and 2005, and was estimated for the years 2020 and 2040. The VI was estimated according to the methodology and equations presented in Chapter 3 dealing with the four parameters of:

- Water Stress (RS) based on water renewability and water variation,
- Water Development Pressure (DP) based on exploitation and safe drinking water inaccessibility,
- Ecological Health (EH) based on water pollution and ecological deterioration,
- Management Capacity (MC) based on three aspects: water use inefficiency, sanitation inaccessibility and conflict management.

The evaluation of each of the four parameters is based on a range from zero to one; with one representing a high severity of freshwater vulnerability to threats such as climate change, depletion and pollution (i.e., the given country is under high water stress), while zero represents no freshwater vulnerability from such threats.

4.2. RESULTS OF THE ASSESSMENT

4.2.1. Resources Stress (RS) parameter

The vulnerability of freshwater resources to external threats either, natural or man-made or both, may impact water quantity and quality thus contributing to stress about water availability and distribution variation across temporal and geographical scales.

Water Resources stress (RSs)

Water stress was estimated for each country based on per capita water resources. Water availability stress was calculated for three different years (1985, 1995 and 2005), as shown in Table 1. These calculations take into account the amount of desalinated water as part of the renewable water resources in GCC since it has become a main source of supply for the domestic sector. There is a general increase in water stress with time for all countries of the region (Figure 14). Based on 2005 figures, critical water stress in the range of 0.7-0.95 is being experienced by Yemen, Jordan and the OPT, while high water stress is being experienced by all GCC countries except Oman. Lower values were found for the remaining countries as they have large volumes of surface water (generated outside their boundaries) and also relatively higher rainfall rates and snow accumulation. Iraq displays the lowest water stress value due to relatively abundant river flow from its two major rivers. A map showing freshwater stress parameters for each country for the year 2005 is shown in Figure 15.

Water Variation (RSv)

Water variation can be estimated by the coefficient of variation (CV) of long-term average precipitation over a long period of observation, preferably covering 50 years. The higher the rainfall coefficient of variation, the less the dependability of water availability, resulting in high vulnerability to climate change as a result of increased variability in rainfall regimes. The coefficient of rainfall variation for a number of rainfall stations in the WA region is shown in Figure 16.

Table 1: Water resources Stress (RSs) parameters for West Asia

Values of 1 indicate high stress and 0 indicate least stress

Country	RSs		
	1985	1995	2005
Syria	0.15	0.36	0.49
Jordan	0.67	0.88	0.90
OPT	0.88	0.93	
Lebanon	0.00	0.27	0.35
Iraq	0.00	0.00	0.00
Yemen	0.79	0.82	0.94
Bahrain	0.56	0.65	0.67
Kuwait	0.77	0.78	0.84
Oman	0.00	0.30	0.36
Qatar	0.53	0.54	0.68
Saudi Arabia	0.31	0.52	0.59
UAE	0.55	0.58	0.63

Figure 14: Trends of water stress parameters (RSs) for different countries

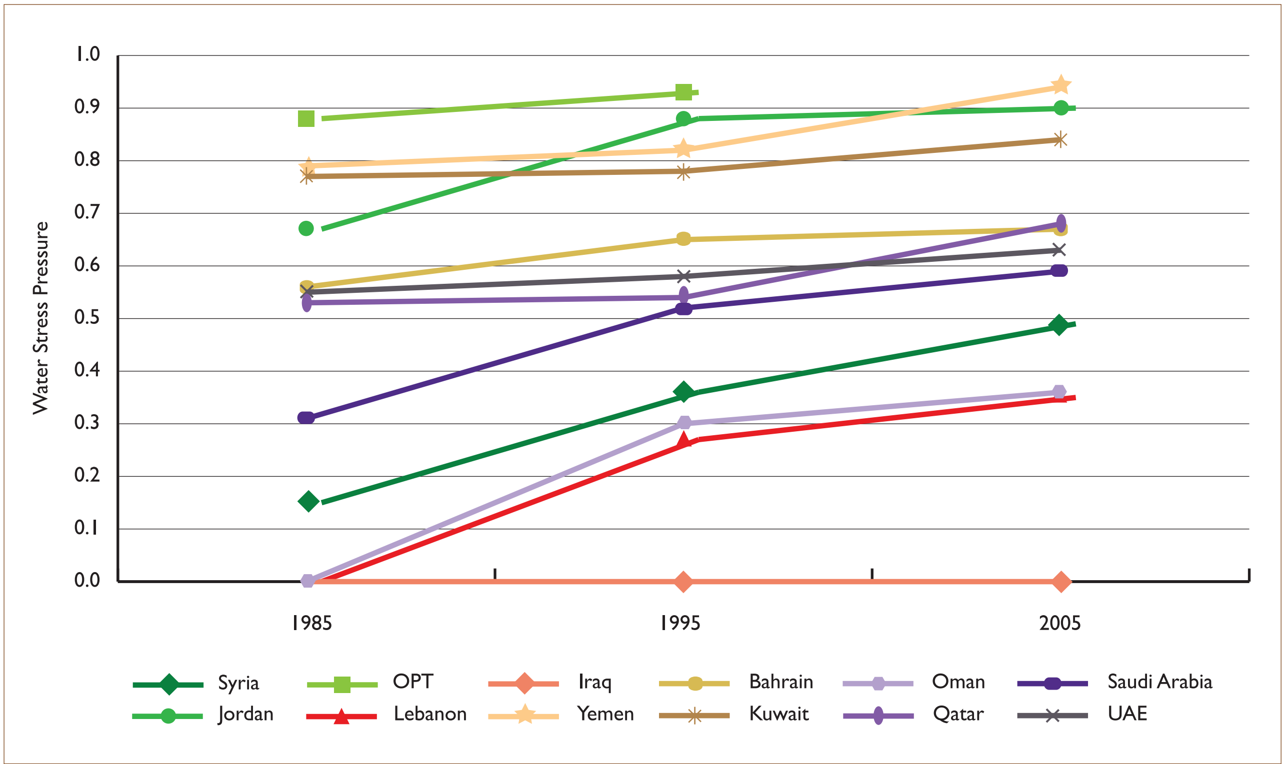


Figure 15: Water stress parameter (RSs) for the year 2005

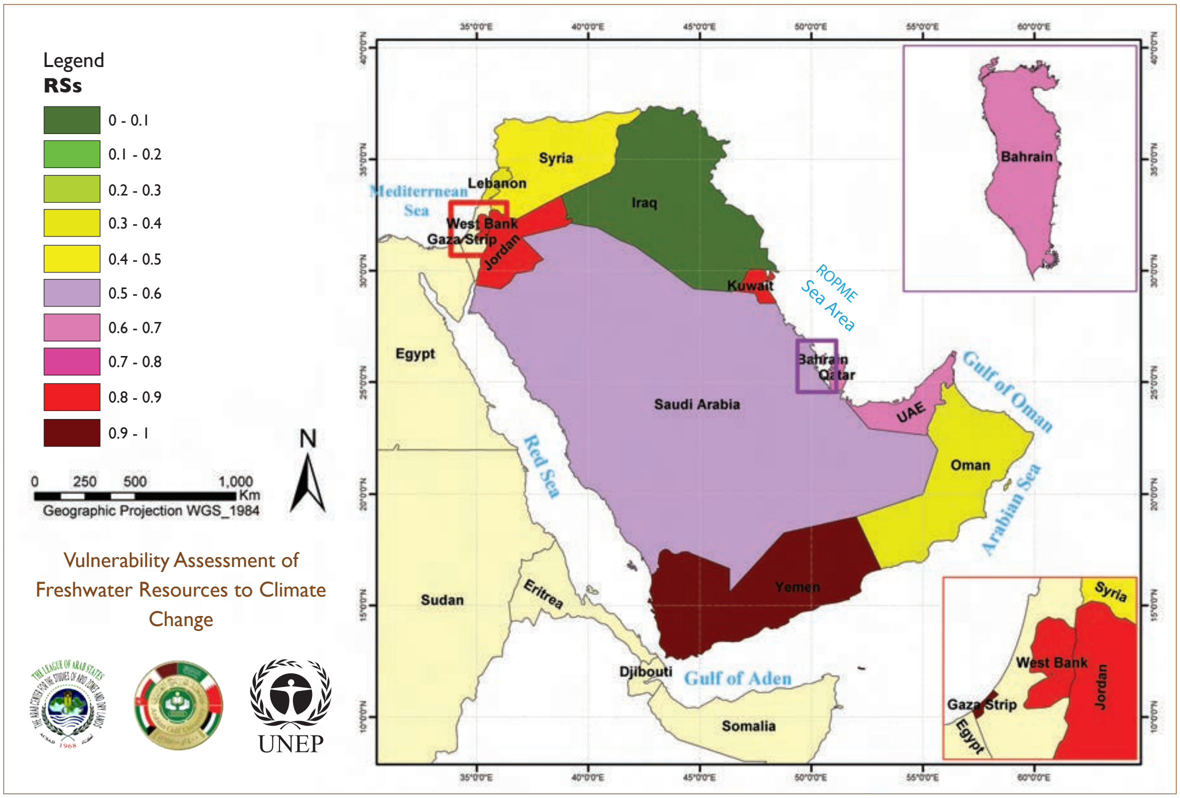
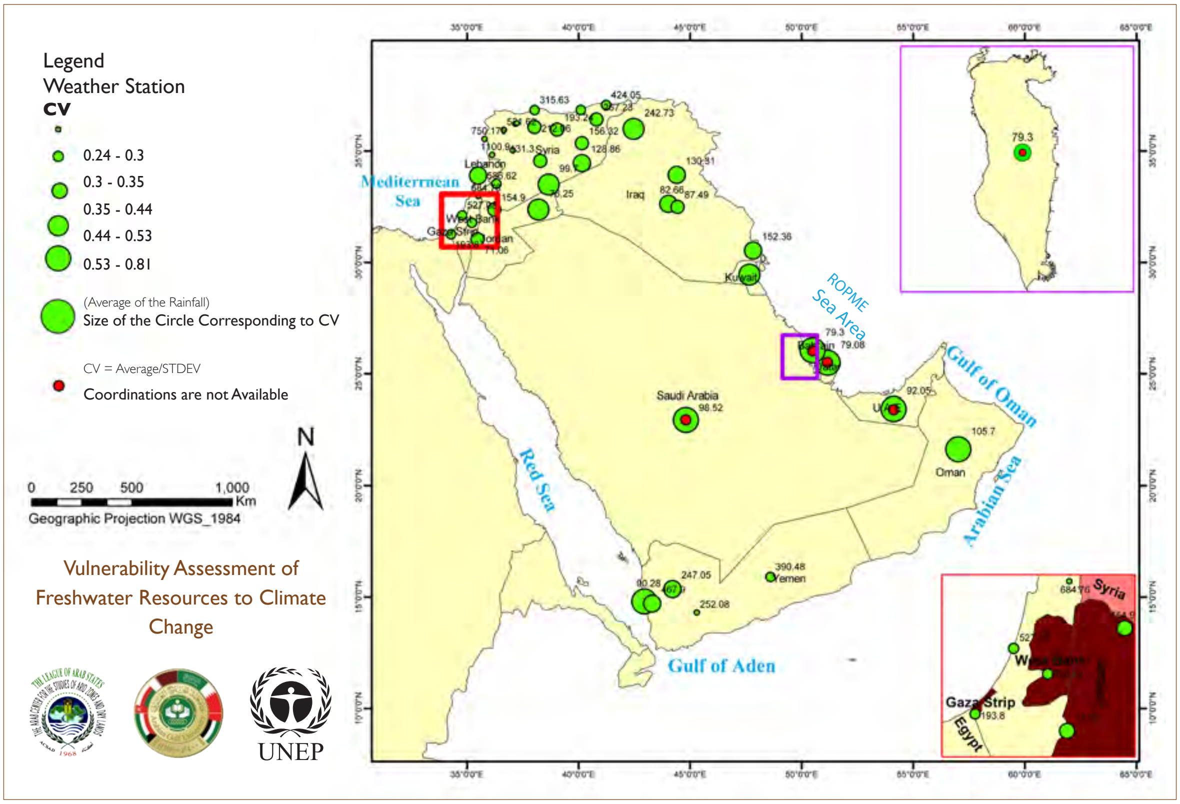


Figure 16: Coefficient of Variation (CV) of precipitation for West Asia



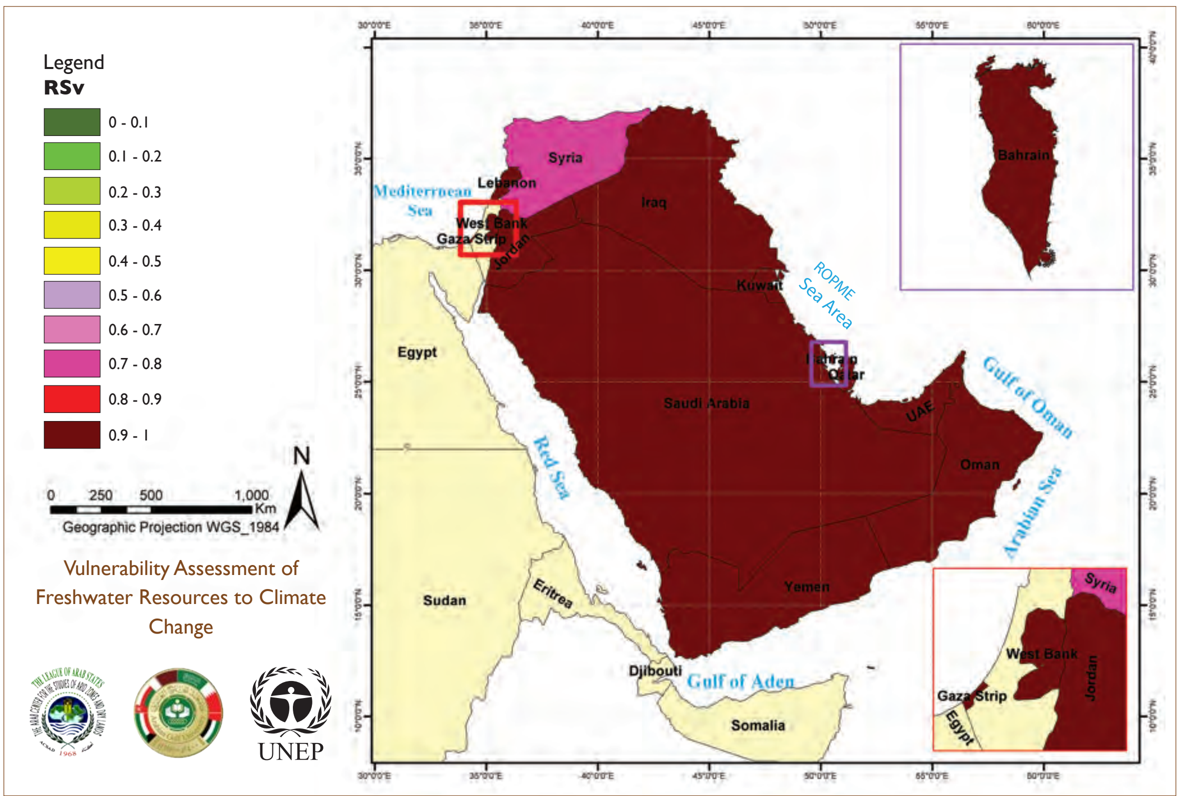
A higher CV of precipitation indicates a higher vulnerability to climate change

Table 2: Water variation parameter (RSv) for West Asia countries

RSv					
Country	CV	S	ρ̇	RSv	equation
Syria	0.23	504.20	116.91	0.77	RSv=CV/0.3
Jordan	0.33	104.30	34.29	1.00	RSv=CV/0.3
OPT	0.42	454.58	190.47	1.00	RSv=CV/0.3
Lebanon	0.43	586.62	252.12	1.00	RSv=CV/0.3
Iraq	0.37	135.56	50.36	1.00	RSv=CV/0.3
Yemen	0.33	404.54	132.62	1.00	RSv=CV/0.3
Bahrain	0.69	79.30	54.50	1.00	RSv=CV/0.3
Kuwait	0.49	112.70	55.13	1.00	RSv=CV/0.3
Oman	0.74	105.70	78.50	1.00	RSv=CV/0.3
Qatar	0.85	79.80	67.90	1.00	RSv=CV/0.3
Saudi Arabia	0.58	98.52	56.75	1.00	RSv=CV/0.3
UAE	0.91	92.05	83.44	1.00	RSv=CV/0.3

S: *mean rainfall*, ρ: *standard deviation*

Figure 17: Water variation parameter (RSv) for West Asia



These results indicate that all countries, with the exception of Syria, have large water variation, due to their arid and semi-arid climate. Analysis of these results concludes that the countries of WA will therefore be very vulnerable to climate change impacts as presented in Table 2 and Figure 17. It is expected that all WA countries will be affected by climate change. Variation in rainfall and snowfall will impact the flow of shared river and shared aquifer resources creating potential disputes among some countries of the region and with neighbouring countries.


Khaled Mubarak

Oman

4.2.2. Water development pressure (DP) parameter

This parameter accounts for the overexploitation of water resources (DPs) and the provision and accessibility of safe drinking water supply. Overexploitation of renewable water resources results from the utilization of water in excess of the amount of replenishment from rainfall and snowmelt. Overexploitation will result in a decrease in surface water flow and spring discharge and a decline in groundwater levels. The provision of adequate drinking water supplies to meet basic needs for the well-being of society is a further factor in calculating this parameter. It represents social adaptation to the degree of freshwater shortage, in terms of how development facilities address population needs (UNEP, 2009). Water development pressure can be estimated from available renewable freshwater sources, total water requirement, water supply coverage and total population.

Water exploitation (DPs)

The analysis indicates that Jordan, the OPT, Yemen and most of the GCC suffer from critical conditions in water resources development since water demand exceeds available water resources. Other countries are approaching this stage, with Syria displaying a significant increasing trend. In the GCC, water demand from the domestic sector relies on investments in desalination facilities. The expected increase in population growth for the region will lead to higher water demand in the absence of adequate demand management measures. The variation in water exploitation for the periods 1985, 1995 and 2005 is shown in Table 3 and Figure 18. A map displaying this variation is shown in Figure 19.

Table 3: Variation of water exploitation (DPs) in West Asia countries (1985-2005)

Values of 1 indicate high stress and 0 indicate least stress

DPs			
Country	1985	1995	2005
Syria	0.36	0.64	0.94
Jordan	0.82	1.00	1.00
OPT	0.45	1.00	1.00
Lebanon	0.31	0.36	0.55
Iraq	0.53	0.64	0.77
Yemen	0.83	1.00	1.00
Bahrain	1.00	1.00	1.00
Kuwait	0.96	0.97	1.00
Oman	0.82	0.87	0.92
Qatar	0.94	0.96	1.00
Saudi Arabia	1.00	1.00	1.00
UAE	1.00	1.00	1.00

Figure 18: Trends of water exploitation pressure (DPs) in West Asia, 1985-2005

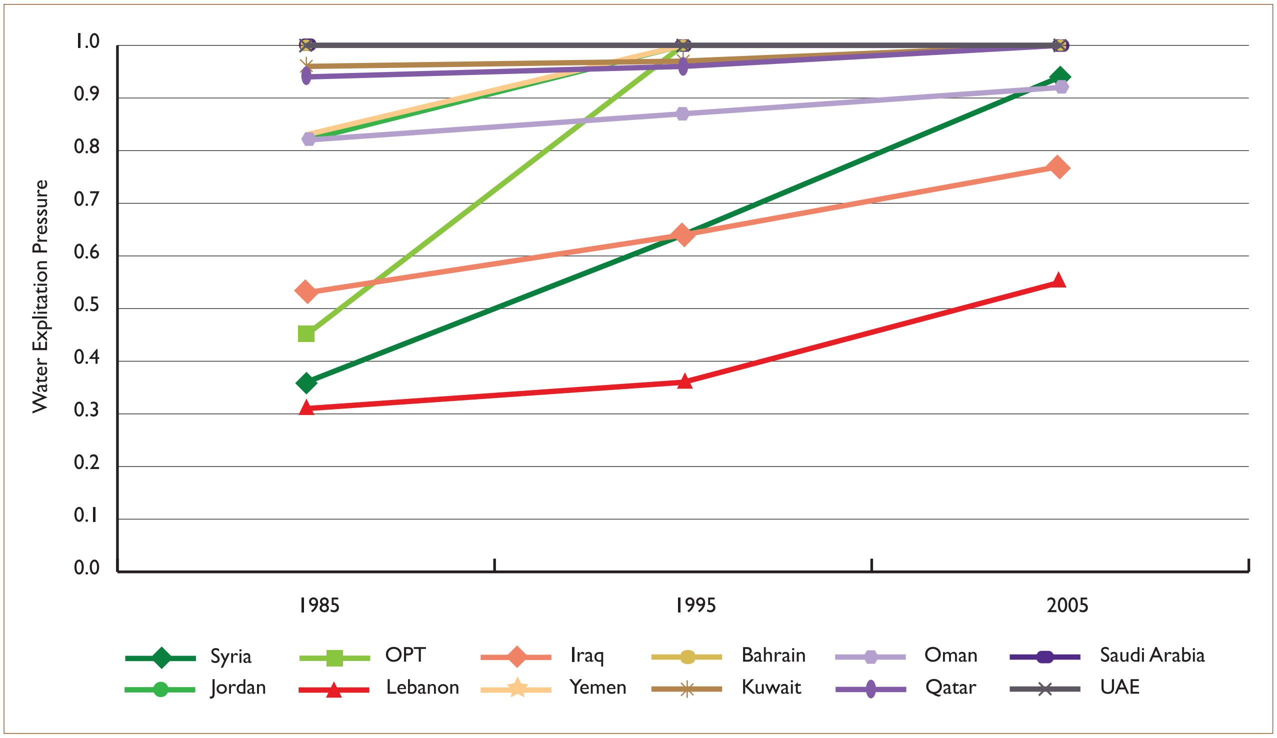
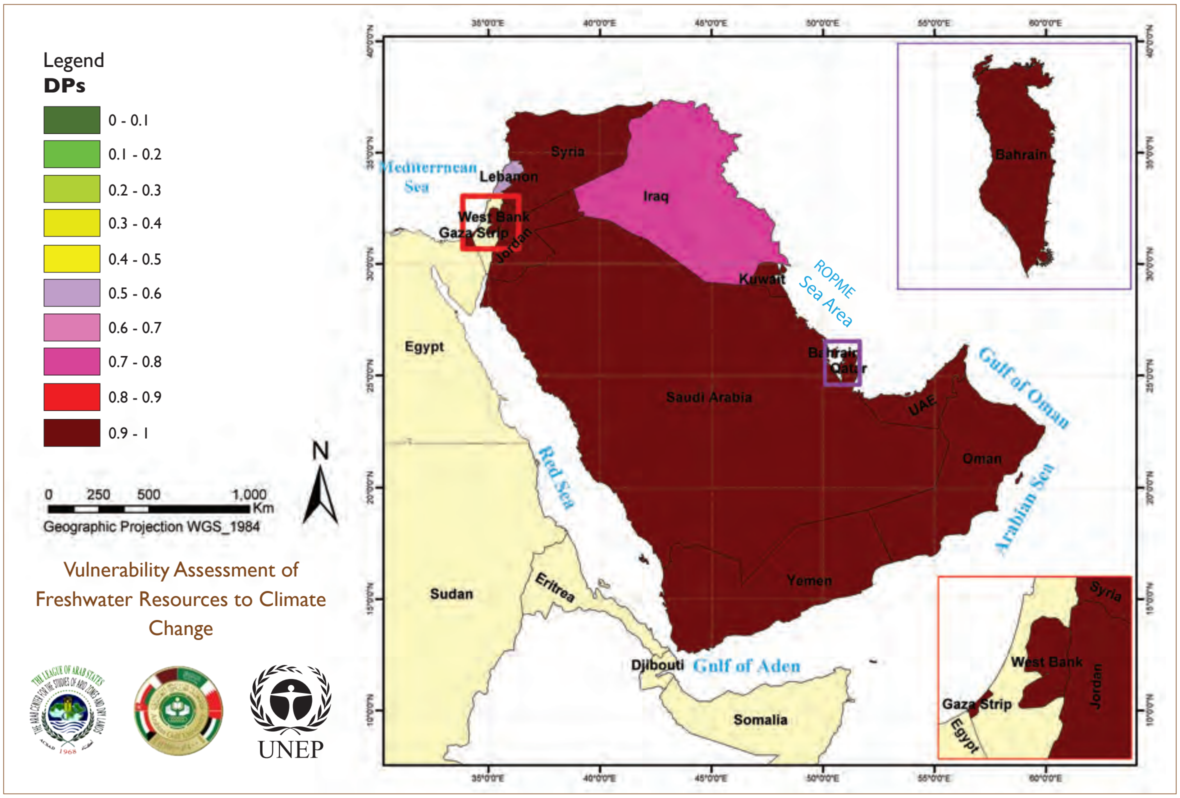


Figure 19: Aerial coverage of water exploitation pressure (DPs)



Safe Drinking Water Inaccessibility (DPd)

This parameter represents the percentage of the population without access to safe drinking water resources (Figure 20). In the last decade, most countries in WA improved their potable water services; however, Oman and Yemen still rank relatively high on the DPd value and are in need of more projects and improved networks to advance their progress.

The OPT has shown a negative trend in the last decade and this can be accounted for by the Israeli occupation and lack of financial capacity. The slightly higher DPd observed in Iraq, can be attributed to the gradual failure in drinking networks and pumping stations as a result of war. Areal coverage variation is shown in Figure 21.

Table 4: Safe drinking water inaccessibility (DPd)

values of 0 indicate least inaccessible while values of 1 indicate most inaccessible

DPd			
Country	1985	1995	2005
Syria	0.21	0.21	0.07
Jordan	0.01	0.02	0.03
OPT		0.06	0.08
Lebanon	0.02	0.00	0.00
Iraq	0.07	0.17	0.15
Yemen	0.37	0.31	0.30
Bahrain	0.00	0.00	0.00
Kuwait	0.00	0.00	0.00
Oman	0.43	0.26	0.79
Qatar	0.09	0.00	0.00
Saudi Arabia	0.05	0.05	0.04
UAE	0.00	0.00	0.00

Figure 20: Variation trend of safe drinking water inaccessibility (DPd)

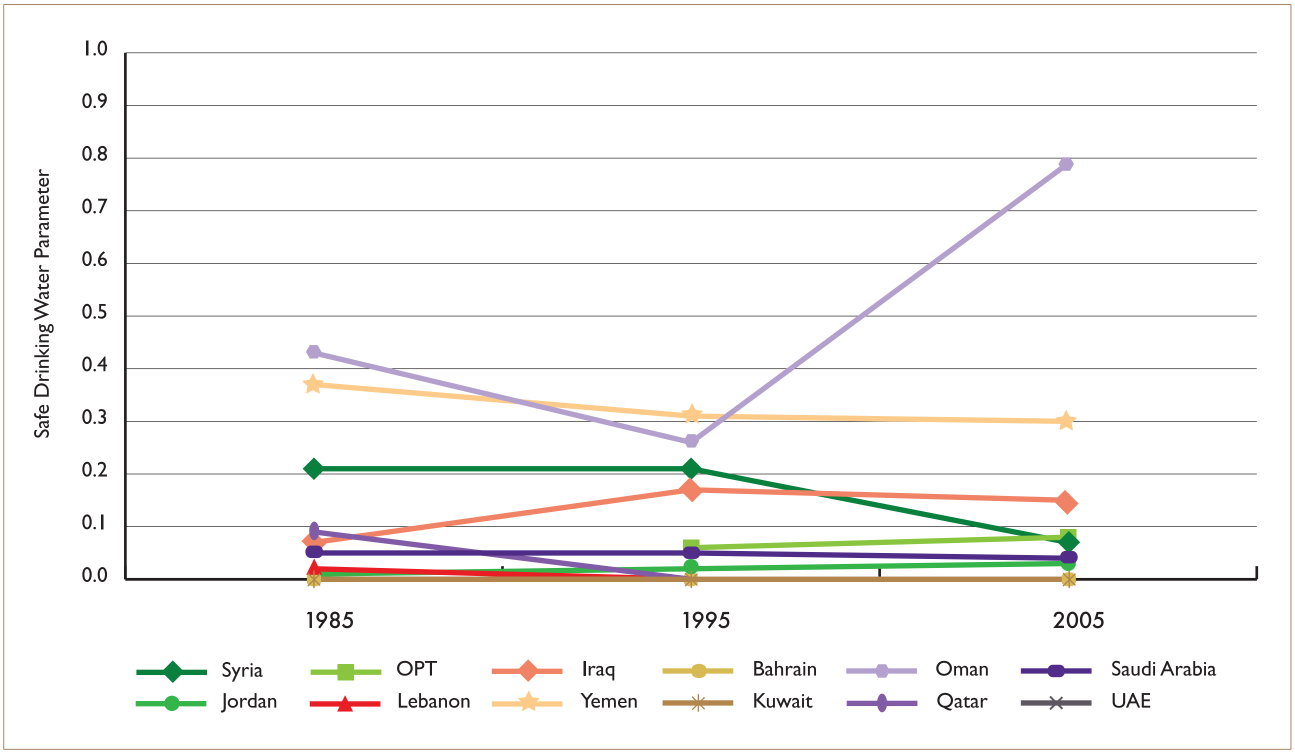
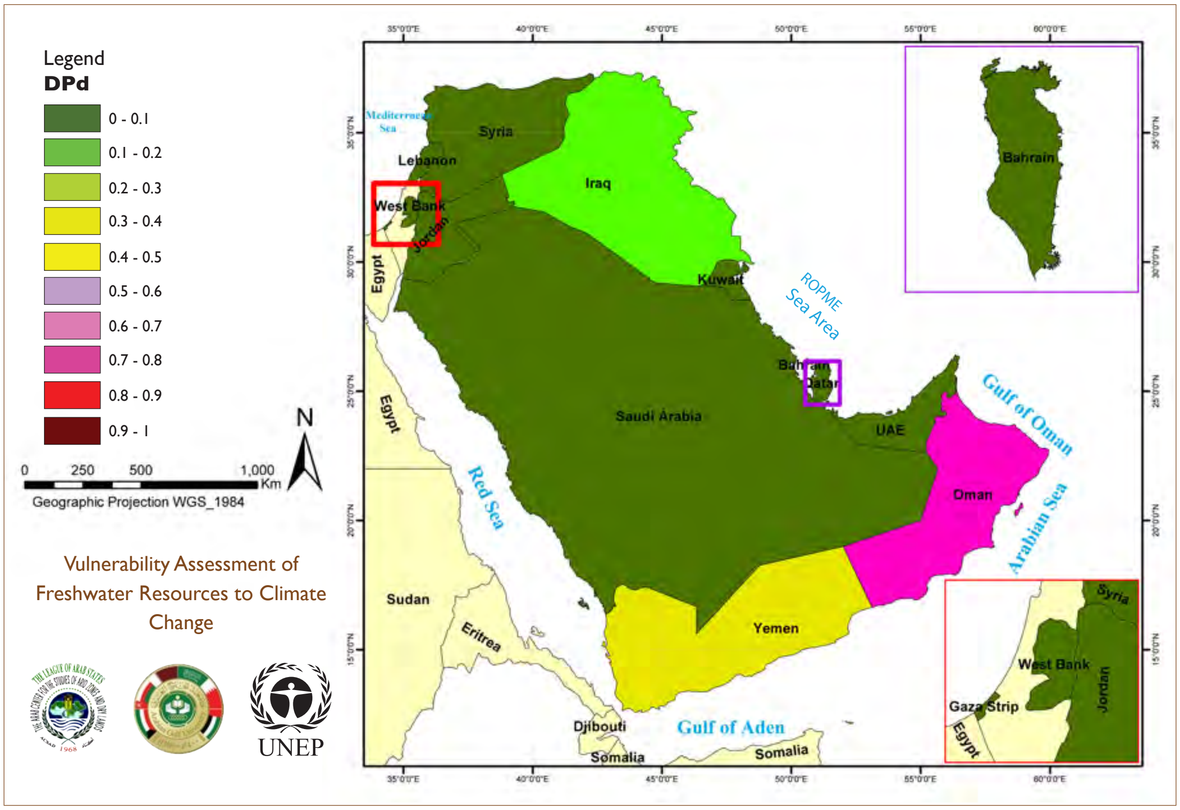


Figure 21: Safe drinking water inaccessibility parameter (DPd) for the year 2005



Oman

4.2.3. Ecological health parameter (EH)

The ecological health of water resources can be affected by natural phenomena in addition to human activities. Ecological health can be measured by two parameters; namely, the water quality/water pollution parameter and the ecosystem deterioration parameter. Water pollution from domestic and industrial wastes reduces the utilization potential of water resources, thus reducing the availability of freshwater. Further degradation of ecosystems and freshwater may occur as the result of various socio-economic development activities such as urbanization, urban expansion, poor land use, removal of vegetation, and over-grazing or desertification.

Water Pollution (EHp)

The level of pollution can be estimated by the ratio of total untreated wastewater discharge into renewable water resources in the country. Water resource pollution due to wastewater discharge is considered one of the major challenges in the region. For the Mashriq sub-region, the annual volume of untreated wastewater was estimated at 8 000 mcm, with only 2 800 mcm receiving varied levels of treatment and the majority discharged untreated directly into the sea or open water courses (UN-ESCWA, 2007). However, limited data availability hinders the evaluation of the impact for most countries of WA; good data was available only for Syria and to a lesser extent, Yemen. Data was extrapolated to provide indicative values of the volume of untreated wastewater in the GCC. This analysis indicates an increase in the pollution levels for Bahrain, Oman, Saudi Arabia, Syria and Yemen during the period 1985-2005 while a decrease in level is observed for Kuwait, Qatar and UAE as shown in Table 5 and Figure 22. A high level of pollution was indicated in 1985 for Qatar, Kuwait and UAE; however, it fell in 2005, which can be attributed to investment in wastewater treatment facilities with advance tertiary treatment levels. Areal variation is shown in Figure 23.

Table 5: Trend in water pollution (EHp) for West Asia countries. Where data were not available, boxes have been left blank.

Values of 0 and 1 indicate least vulnerable and most vulnerable respectively

EHp			
Country	1985	1995	2005
Syria		0.32	0.46
Jordan			0.13
OPT			1.00
Lebanon		0.58	
Iraq			
Yemen		0.07	0.11
Bahrain	0.14	0.18	0.26
Kuwait	0.34	0.25	0.14
Oman	0.39	0.49	0.66
Qatar	0.64	0.53	0.47
Saudi Arabia	0.03	0.11	0.31

Figure 22: Trends in water pollution levels (EHp)

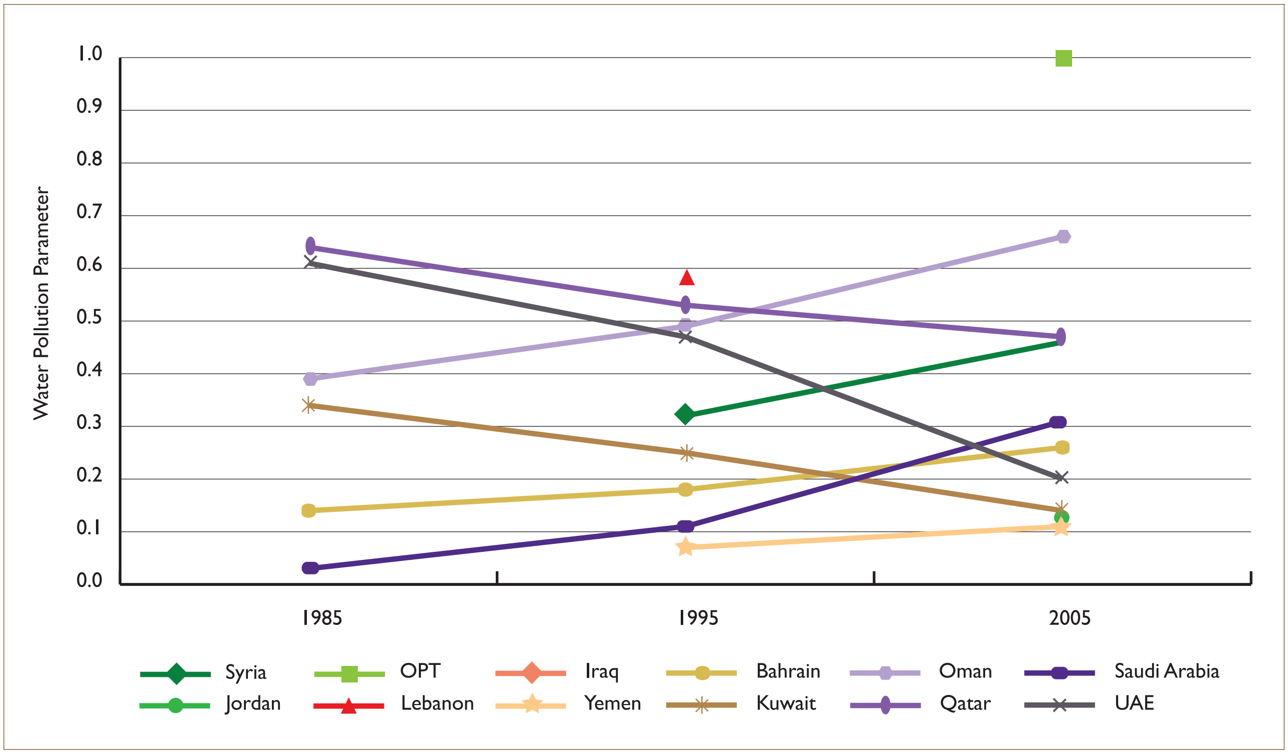
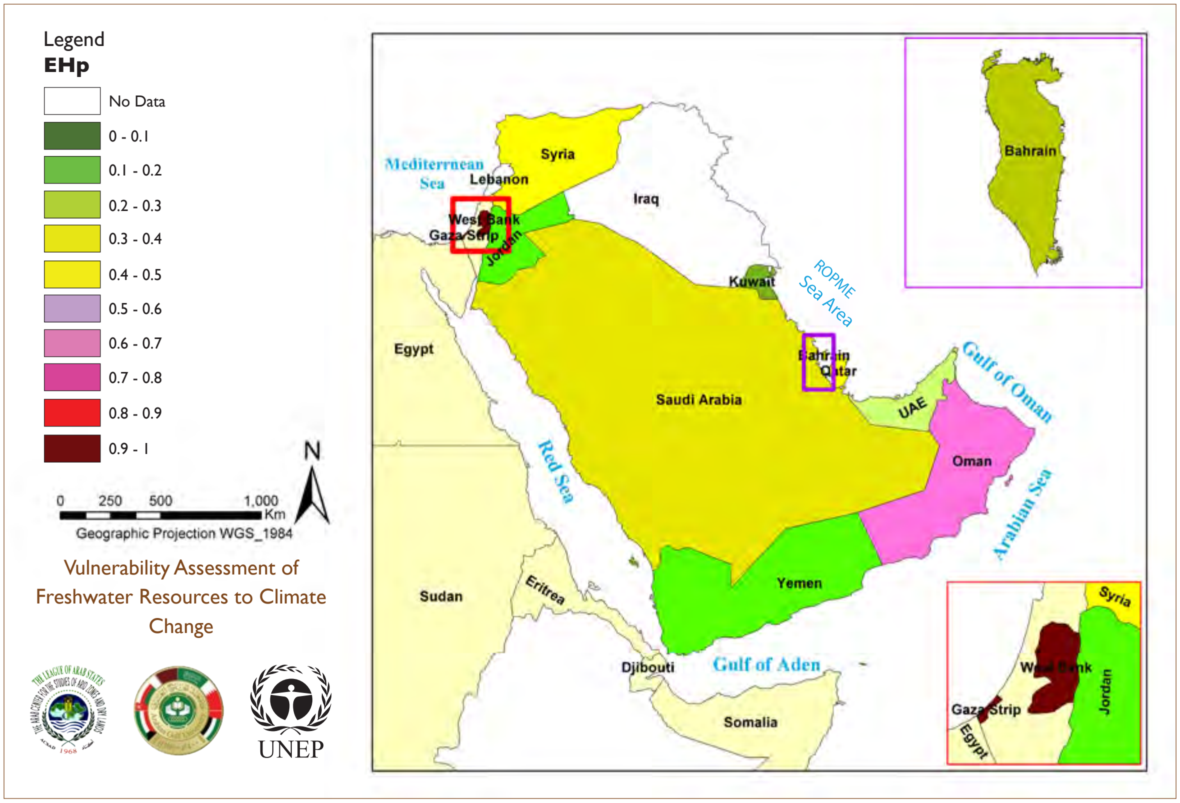


Figure 23: Areal variation of water pollution (EHp) for the year 2005



Oman

Ecosystem deterioration (EHe)

Ecosystem deterioration is defined in this study using the State of Desertification report for the Arab region (ACSAD, CAMRE and UNEP, 2004). In this report, an estimation of the annual degradation rate compared to the total area of each country was calculated to estimate the ecosystem deterioration parameter. A decrease in vegetation coverage due to natural and anthropogenic activities has been observed in most WA countries, particularly after 1995, as shown in Figure 24 and Table 6. With the exception of Saudi Arabia, a high degree of deterioration is due to unsustainable land use practices. Four countries, namely Iraq, Lebanon, the OPT and Yemen are experiencing moderate ecosystem deterioration that may have resulted from a decrease in vegetation cover due to a decrease in rainfall, overgrazing and urban expansion into farm areas. Syria has relatively reasonable vegetation cover that can be attributed to higher rainfall. Severe deterioration is estimated for most countries of the AP GCC sub-region. Ecosystem deterioration values are higher than 0.86 for all countries except for Saudi Arabia which has values ranging between 0.1 and 0.44. The low values are due to the fact that most land in Saudi Arabia is considered rangeland (about 80 per cent of the total area) (ACSAD, CAMRE and UNEP, 2004). The decrease in the value from 0.44 to 0.1 indicates improvement of land management. For Bahrain, Kuwait, Oman, Qatar and UAE, overall conditions improved slightly over time. Areal variation is shown in Figure 25.

Table 6: Trend in ecosystem deterioration (EHe)

Values of 0 indicate least vulnerable and values of 1 indicate most vulnerable

	EHe		
Country	1985	1995	2005
Syria	0.23	0.13	0.22
Jordan	0.07	0.06	0.18
OPT	0.55	0.55	0.44
Lebanon	0.50	0.52	0.54
Iraq	0.60	0.61	0.58
Yemen	0.66	0.65	0.66
Bahrain	0.89	0.87	0.86
Kuwait	0.92	0.92	0.91
Oman	0.97	0.97	0.94
Qatar	0.95	0.94	0.94
Saudi Arabia	0.44	0.10	0.10
UAE	0.94	0.93	0.90

Figure 24: Ecosystem deterioration (EHe) trend

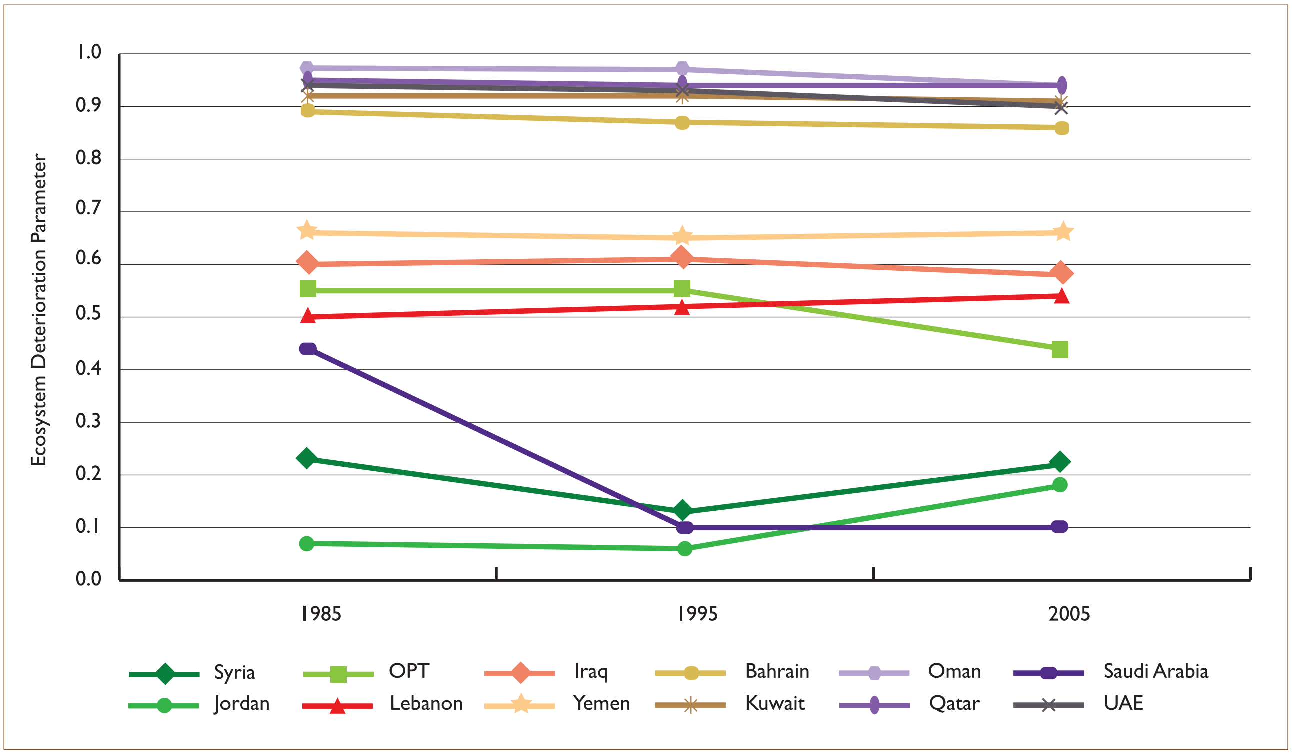
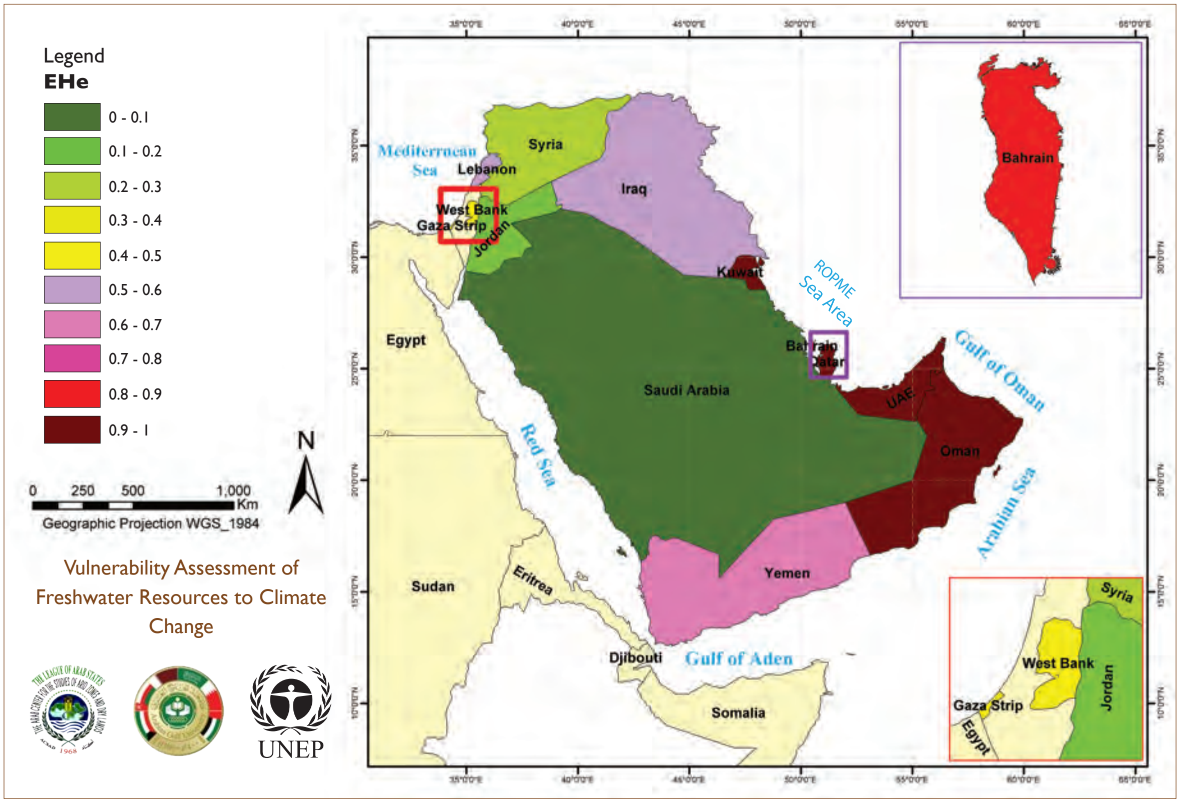


Figure 25: Ecosystem deterioration (EHe) for the year 2005



Jordan

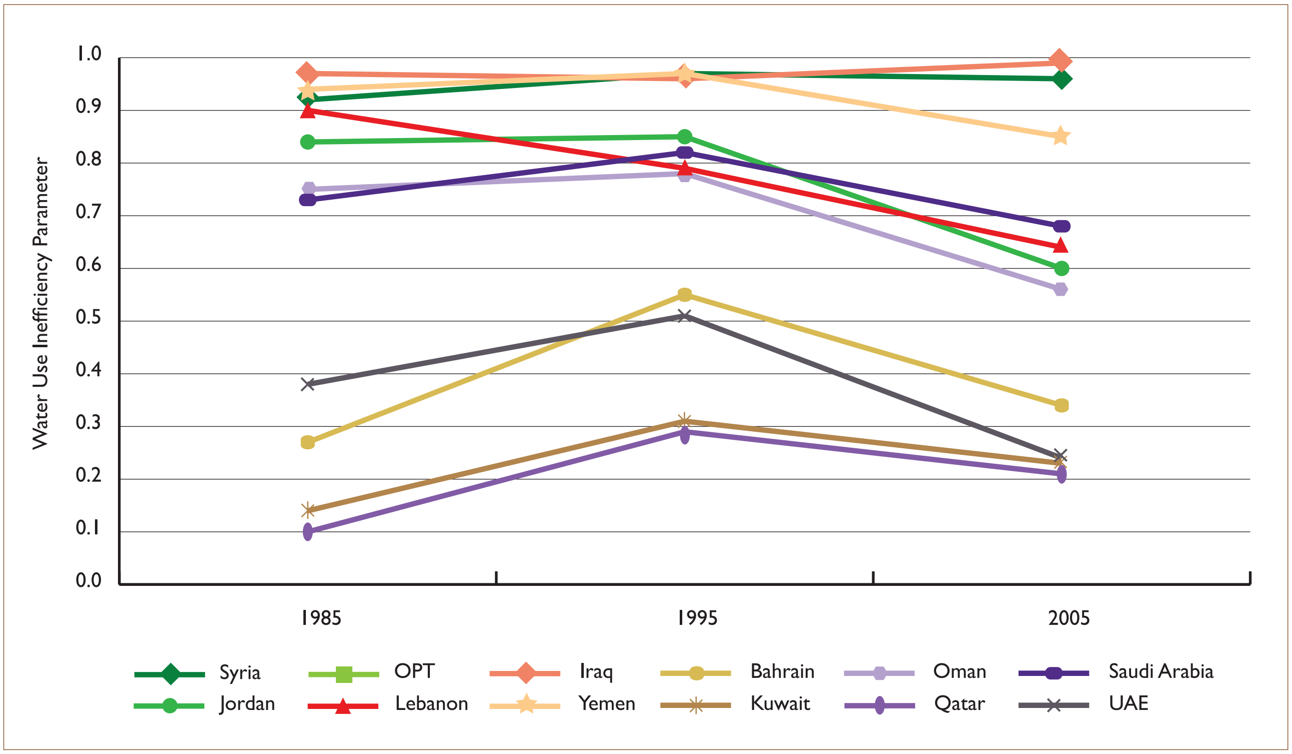
4.2.4. Management Capacity Parameter (MC)

The capacity of the water sector to manage its freshwater resources can be assessed using three variables: efficiency in water utilization, human health in relation to accessibility to adequate and safe sanitation services and conflict due to competition for shared surface and groundwater resources. Water utilization inefficiency results in wastage of freshwater resources, especially in the irrigation sector. The human health variable is estimated by the coverage of sanitation facilities and services. Conflict management of shared water resources is estimated through the evaluation of the institutional arrangements, policy formulation, communication mechanisms and effective implementation of agreements. UNEP assessment guidelines contain a matrix that translates these issues into a weighted value to be used in the calculation (see Annex).

Water use inefficiency parameter (MCe)

The water use efficiency estimation is based on the GDP of the country. Efficiency is estimated

Figure 26: Trend of water use inefficiency (MCe)



in terms of the financial contribution to GDP of one cubic meter of water in any of the water-consuming sectors. It can be estimated by the GDP value of one cubic meter compared to the world average for a selection of countries (UNEP, 2009). Since the agriculture sector is the larger consumer of water (at more than 85 per cent), it was used as a variable to indicate the financial return in the use of freshwater.

The water use inefficiency parameter was calculated using US$40 as the mean GDP value produced from one cubic meter of water for the countries of WA[1] . The full equation is included in the Annex.

1. *Personal communication with Yi Huang, one of the authors of the UNEP guidelines (October 2009).*

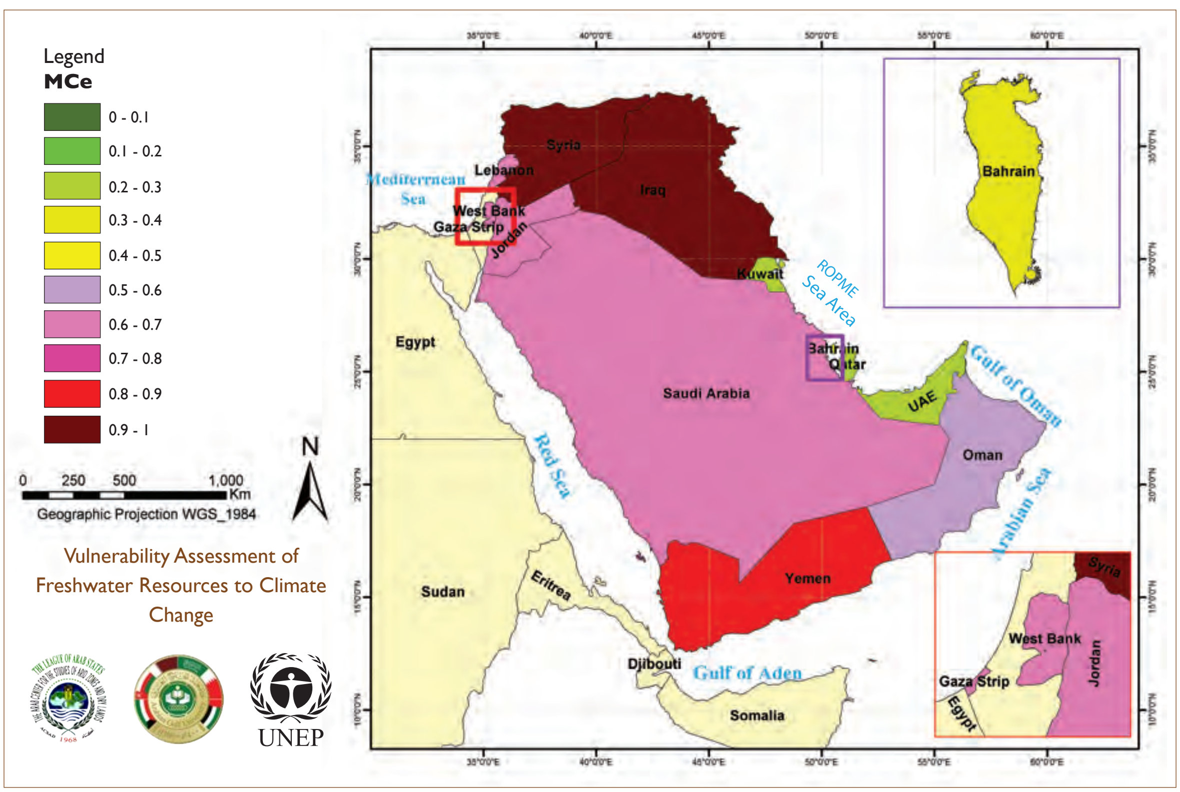
Table 7: Water use inefficiency parameter (MCe) trends

MCe			
Country	1985	1995	2005
Syria	0.92	0.97	0.96
Jordan	0.84	0.85	0.60
OPT			0.61
Lebanon	0.90	0.79	0.64
Iraq	0.97	0.96	0.99
Yemen	0.94	0.97	0.85
Bahrain	0.27	0.55	0.34
Kuwait	0.14	0.31	0.23
Oman	0.75	0.78	0.56
Qatar	0.10	0.29	0.21
Saudi Arabia	0.73	0.82	0.68
UAE	0.38	0.51	0.24

Oman

Most countries of WA showed an improvement (decreasing inefficiency) between 1995 and 2005, despite trends of increasing inefficiency in the previous decade, 1985-1995 (Figure 26 and Table 7). Qatar and Kuwait show the lowest levels of water inefficiency overall and this has been decreasing since 1995; however, Oman and Jordan have shown the greatest efficiency gains since 1985. Iraq and Syria are the countries with the highest levels of water use inefficiency and what is more, are the only two countries not to have shown improvements between 1985 and 2005. Efficiency gains can be attributed to the uptake of more modern and efficient irrigation infrastructure systems, which countries such as Iraq and Syria would be well placed to adopt.

Figure 27: Water use inefficiency coverage for the year 2005



Improved Sanitation inaccessibility (MCs)

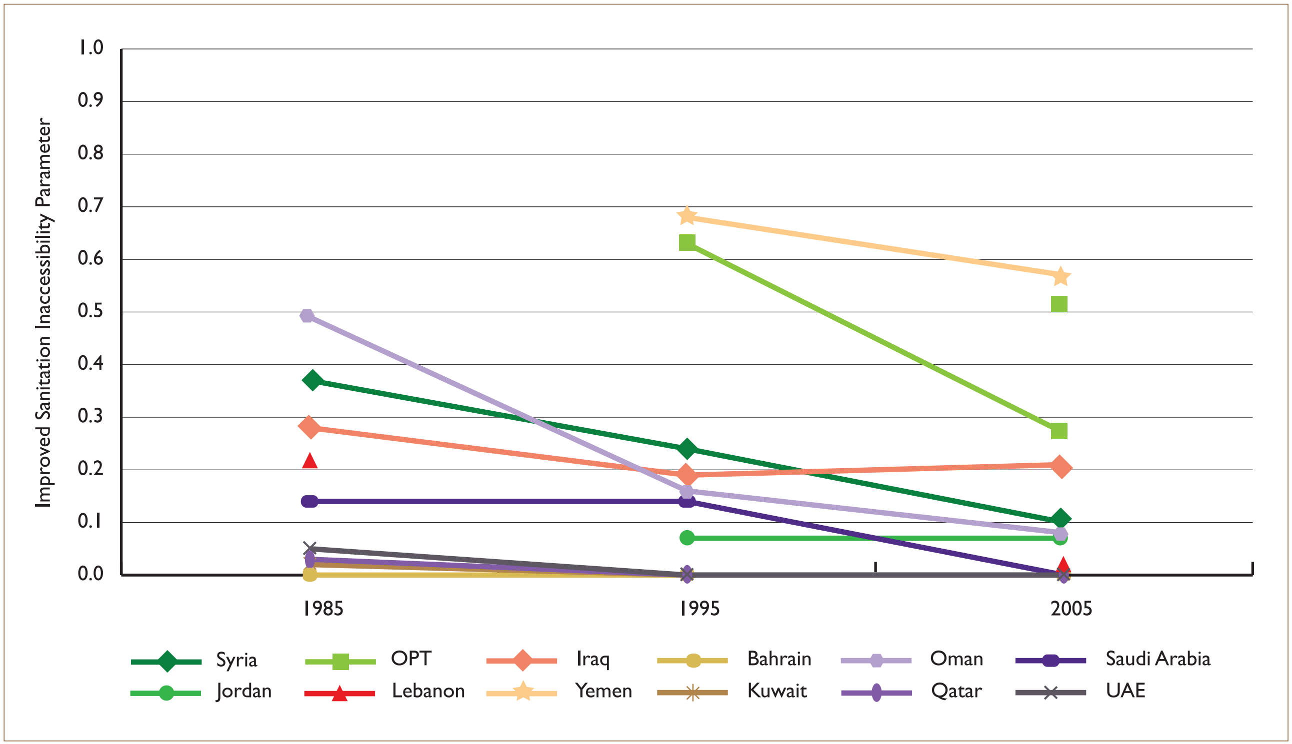
This parameter is calculated as the proportion of the population without access to improved sanitation facilities (Figure 28 and Table 8). The analysis indicates that more than 95 per cent of populations have access to improved sanitation facilities in Bahrain, Kuwait, Qatar and the UAE, while the lowest accessibility percentage is recorded for Yemen and the OPT. Decreasing inaccessibility levels indicate efficient implementation of well-being improvement policies for all countries and may be due to investment in sanitation facilities by the majority of countries, except Yemen and the OPT. In Yemen, most of the population is spread out over in rural areas with no adequate sewage networks. In the OPT, the situation is deteriorating as a result of the embargo on importing equipment due to border closures, coupled with the collapse

Table 8: Trend in improved sanitation inaccessibility, (MCs)

Values of 0 indicate least inaccessible and values of 1 indicate most inaccessible.

	MCs		
Country	1985	1995	2005
Syria	0.37	0.24	0.10
Jordan		0.07	0.07
OPT		0.63	0.27
Lebanon	0.22		0.02
Iraq	0.28	0.19	0.21
Yemen		0.68	0.57
Bahrain	0.00	0.00	0.00
Kuwait	0.02	0.00	0.00
Oman	0.49	0.16	0.08
Qatar	0.03	0.00	0.00
Saudi Arabia	0.14	0.14	0.00
UAE	0.05	0.00	0.00

Figure 28: Trend variation of Improved Sanitation Inaccessibility Parameter (MCs)



of the sewage system in the Gaza strip. Nearly all sewage and water pumps are now out of operation due to lack of electricity and diminished fuel supplies to operate backup power generators (World Bank, 2009). The areal variation of this data is shown in Figure 29.

Conflict Management Capacity Parameter (MCg)

This parameter defines the capacity of the country to manage competition over water utilization among different sectors at the national and regional levels, including neighbouring countries with which they share surface and groundwater resources. This parameter was determined through expert consultations using the conflict management capacity scoring criteria (see Annex). The OPT has the lowest score since the Israeli occupation has overall control on water resources (UNEP, LAS and CEDARE, 2010). Other countries' scores vary according to the criteria mentioned in the Methodology Guidelines (UNEP, 2009). There is the potential for high levels of conflict (> 0.95) between Bahrain, Kuwait and Saudi Arabia, since they are sharing the same groundwater aquifers which constitute the main source, other than desalination, of water supply. To date, there are no coordination or cooperation mechanisms between these countries concerning the sharing of groundwater resources (Figure 30 and Table 9).

4.2.5. Vulnerability index (VI)

Based on the estimations, and following the expert consultation for assigning equal weights among the parameters in the same category and also among different categories, the vulnerability index was calculated as presented in Tables 10 and 11.

Figure 29: Improved sanitation inaccessibility parameter (MCs) for 2005

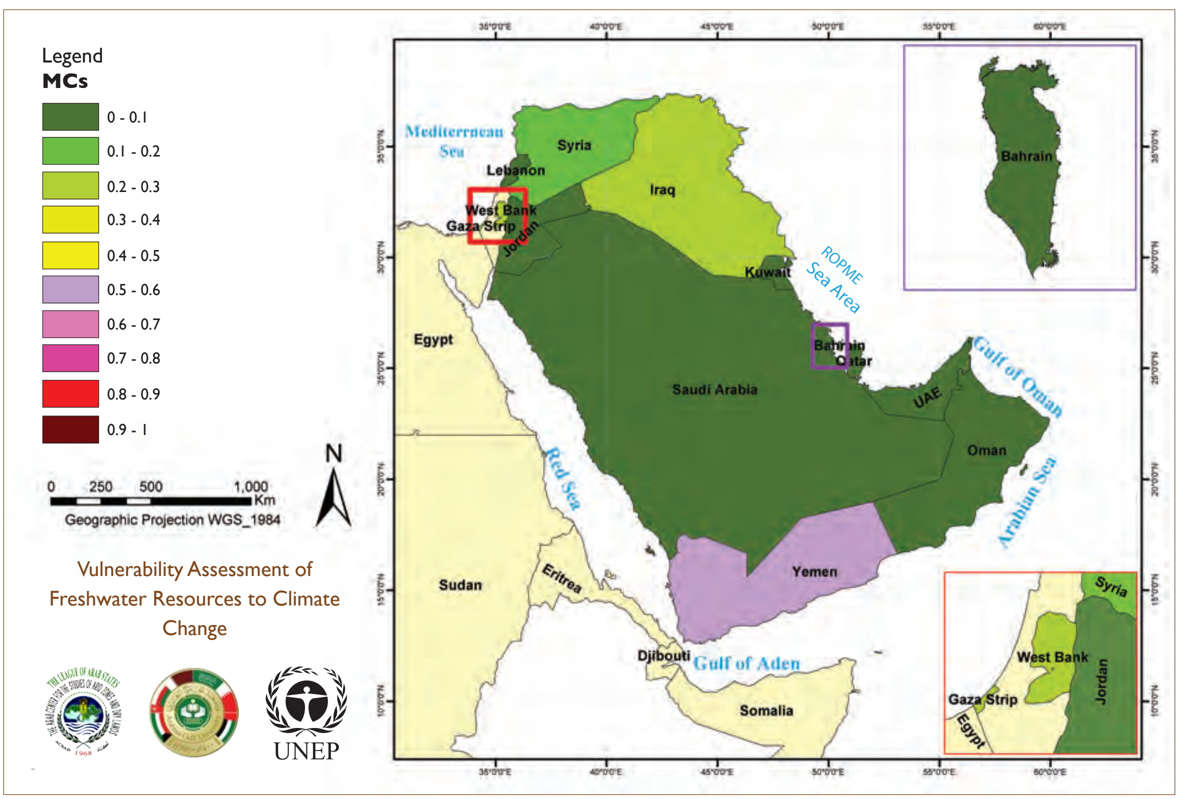


Table 9: Conflict management capacity parameter (MCg)

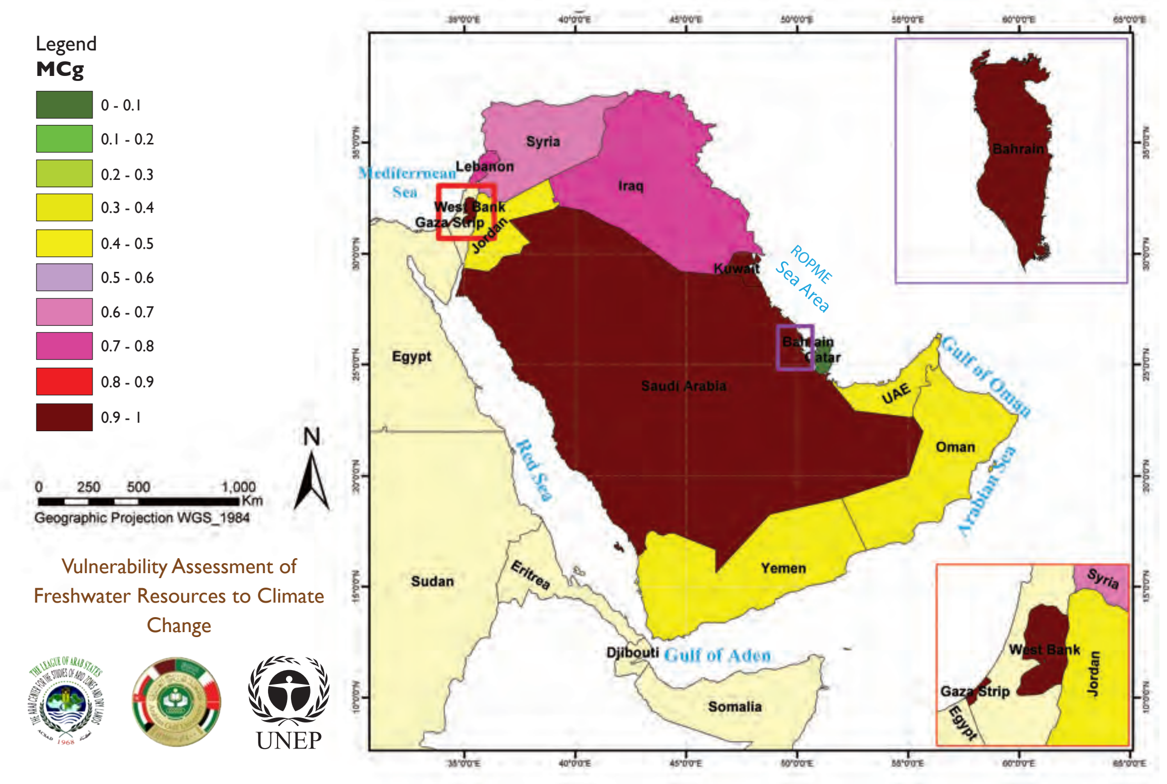
Values of 1 indicate high levels of conflict and values of 0 indicate low levels.

Country	MCg
Syria	0.60
Jordan	0.40
OPT	1.00
Lebanon	0.70
Iraq	0.70
Yemen	0.40
Bahrain	0.95
Kuwait	0.95
Oman	0.48
Qatar	0.00
Saudi Arabia	0.95
UAE	0..48

To analyse which is the most important factor for each country, the previous graph was re-plotted as a stacked bar showing all the component factors. As shown in Figure 31, the most dominant factor is the Water Variation Parameter (RSv), which is a natural factor and could be used as an indicator to highlight how vulnerable the region is to climate change. The second most important factor is the Water Exploitation Pressures (DPs), which reflects the effort of countries to satisfy their water needs from their limited water resources.

The estimations provided in Table 10 show that the VI for all countries for the period 1985-2005 lies within the range of 0.4-0.7. Since values less than 0.4 would indicate moderate to low vulnerability, this means that all WA countries are characterized by high vulnerability. As shown in Table 11, vulnerability is increasing for Bahrain and Oman while for the remaining countries it is either decreasing or

Figure 30: Conflict management capacity parameter (MCg), year 2005



constant (Figure 32). The results indicate that the countries of WA are experiencing high stresses, and greater efforts should be made to design policies to provide technical support and policy backup to mitigate the pressures. A longer term and appropriate strategic development plan should be made, with a focus on enhancing management capacity to deal with the main threatening factors. Areal distribution is shown in Figure 33.

For the Mashriq sub-region, vulnerability is increasing in all countries. The analysis indicates that most countries have been experiencing different degrees of water stress depending on the availability of dependable flows from major rivers, particularly shared ones. Countries such as Jordan and Yemen are under severe stress while the remaining countries have adequate surface water sources. Additional effort is needed to improve water use efficiency in most Mashriq countries, since any variation in precipitation will affect the available water resources. The estimated VI showed that all Mashriq countries are very vulnerable to climate change. This reflects an urgent need for mitigation and adaptation plans to be adopted by all the countries of the region.

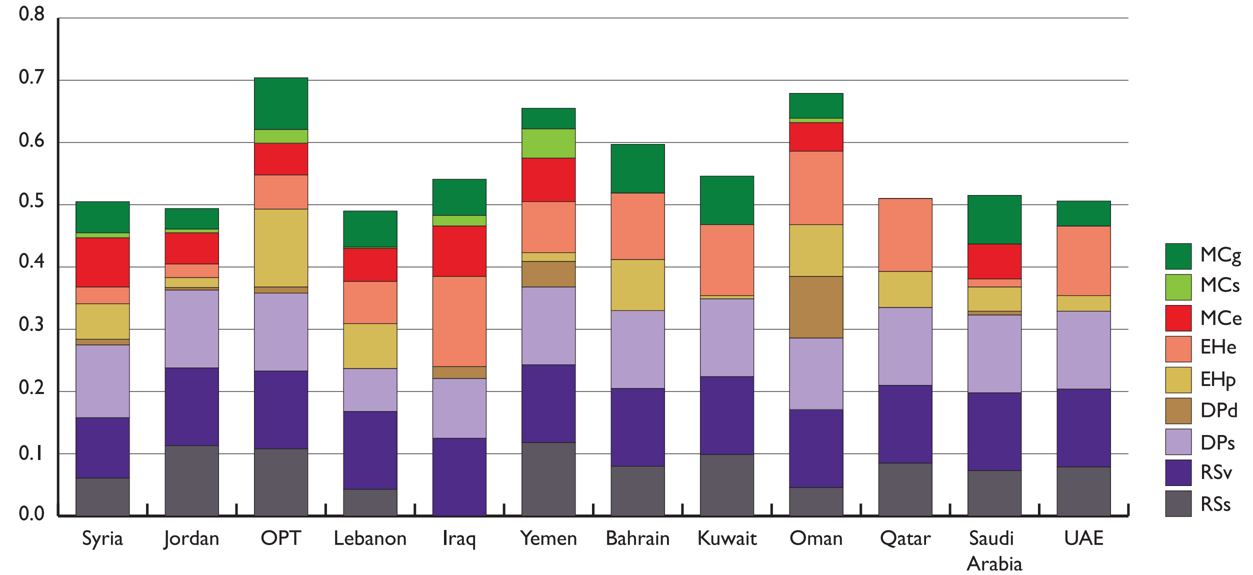
The GCC countries have also been experiencing a high degree of water stress and all of them exhibit a high level of vulnerability, with Oman at the top. Water resources variation due to variation in precipitation is the dominant parameter, with development pressure influencing the vulnerability of the region.

Table 10: Calculated Vulnerability Index with various parameters for 2005

Category	Resource Stress (RS)		Development Pressure (DP)		Ecological Health\ (EH)		Management Capacity (MC)		
Parameter	**RSs**	**RSv**	**DPs**	**DPd**	**EHp**	**EHe**	**MCe**	**MCs**	**MCg**
Syria	0.061	0.097	0.117	0.009	0.057	0.027	0.079	0.008	0.050
Jordan	0.113	0.125	0.125	0.004	0.016	0.022	0.050	0.006	0.033
OPT	0.108	0.125	0.125	0.010	0.125	0.055	0.051	0.022	0.083
Lebanon	0.043	0.125	0.069	0.000	0.072	0.068	0.053	0.002	0.058
Iraq	0.000	0.125	0.096	0.019	No Data	0.145	0.081	0.017	0.058
Yemen	0.118	0.125	0.125	0.041	0.014	0.082	0.070	0.047	0.033
Bahrain	0.080	0.125	0.125	0.000	0.082	0.107	0.000	0.000	0.078
Kuwait	0.099	0.125	0.125	0.000	0.005	0.114	0.000	0.000	0.078
Oman	0.046	0.125	0.115	0.099	0.083	0.118	0.046	0.007	0.040
Qatar	0.085	0.125	0.125	0.000	0.058	0.117	0.000	0.000	0.000
Saudi Arabia	0.073	0.125	0.125	0.006	0.039	0.013	0.056	0.000	0.078
UAE	0.079	0.125	0.125	0.000	0.025	0.112	0.000	0.000	0.040

RSs is Water Resources Stress; RSv is Water Variation; DPs is Water Exploitation; DPd is Safe Drinking Water Inaccessibility; EHp is Water Pollution; EHe is Ecosystem Deterioration; MCe is Water use Inefficiency; MCs is Improved Sanitation Inaccessibility; and MCg is Conflict Management Capacity.

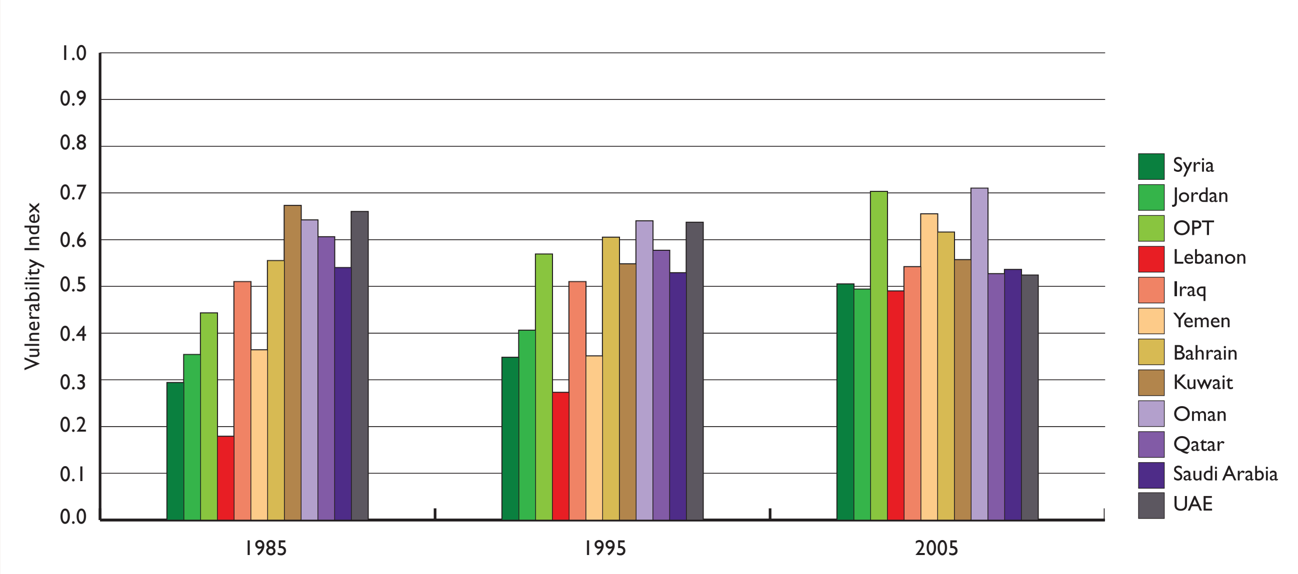
Figure 31: Calculated vulnerability index with different parameters



■ Values of 1 indicate most vulnerable and 0 indicate least vulnerable

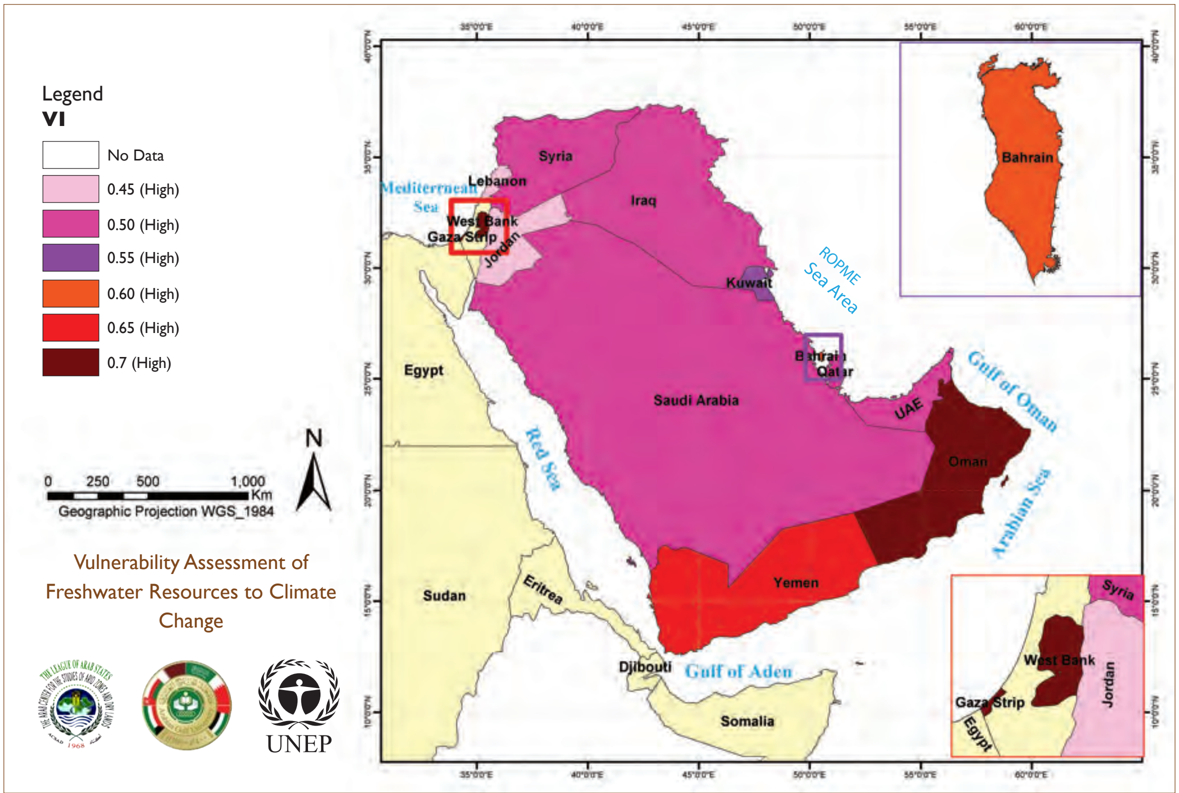
Euphrates river, Syria

Figure 32: Calculated Vulnerability Index for each country according to the parameters (RS, DP, EH and MS)



■ Values of 1 indicate most vulnerable, while values of 0 indicate least vulnerable

Figure 33: Vulnerability Index map, 2005



Euphrates river, Syria

Table 11: Vulnerability Index values for West Asia countries			
VI			
Country	1985	1995	2005
Syria	0.294	0.348	0.505
Jordan	0.354	0.406	0.494
OPT	0.443	0.569	0.703
Lebanon	0.179	0.273	0.490
Iraq	0.510	0.510	0.542
Yemen	0.364	0.351	0.655
Bahrain	0.555	0.605	0.616
Kuwait	0.673	0.548	0.557
Oman	0.642	0.640	0.710
Qatar	0.606	0.577	0.527
Saudi Arabia	0.540	0.529	0.536
UAE	0.660	0.637	0.524

The trends for the four major parameters: resources stress, development pressure, ecological health and management capacity for 1985, 1995 and 2005 for each country are shown in Figures 34 to 45. All countries are experiencing high stress, with Oman, Yemen and the OPT being the worst off.

Figure 34: Share of the parameters group to the final Vulnerability Index for Bahrain

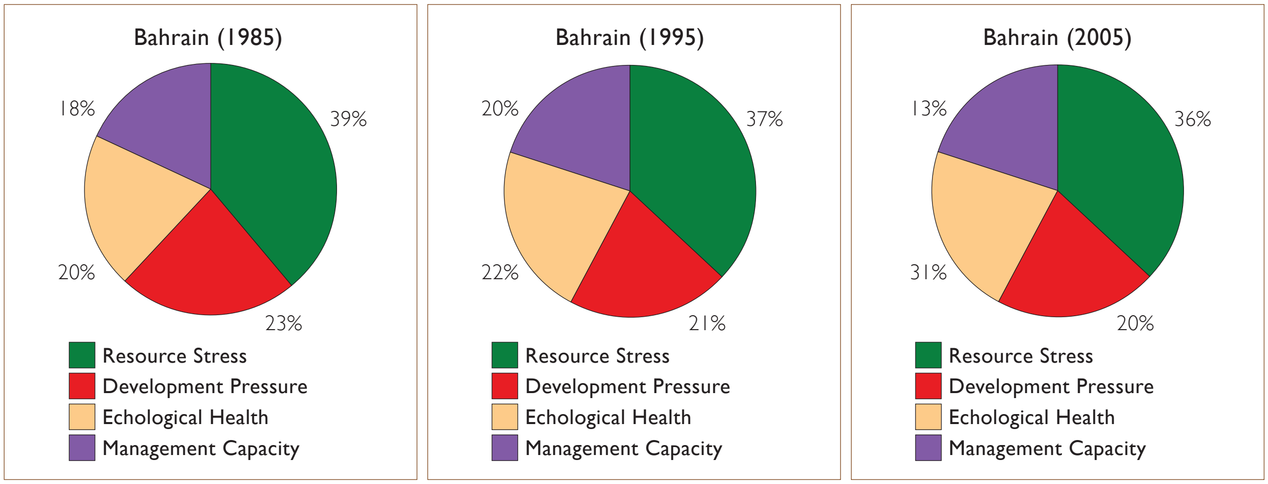


Figure 35: Share of the parameters group to the final Vulnerability Index for Kuwait

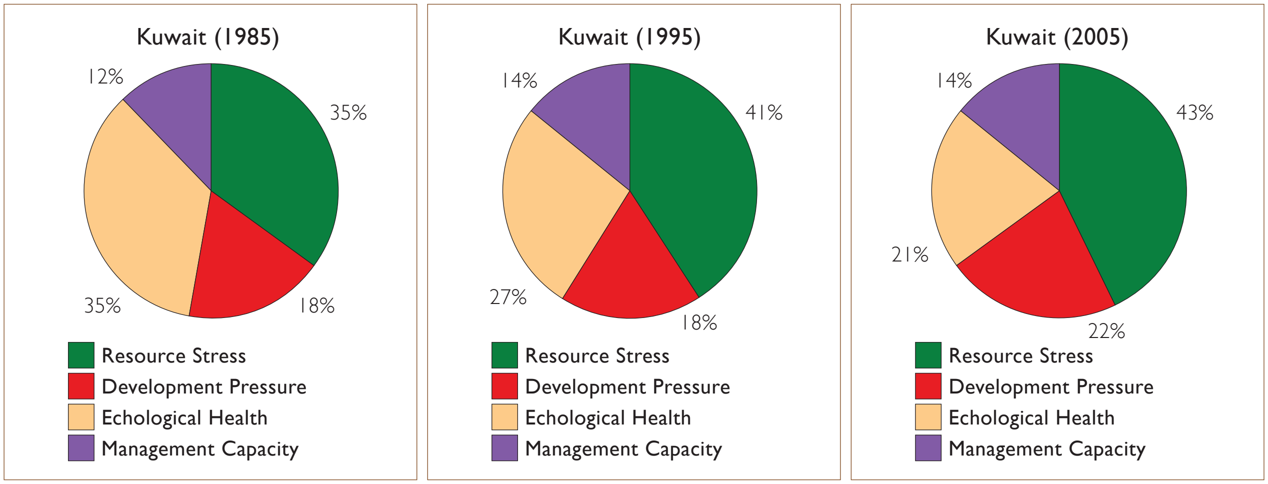


Figure 36: Share of the parameters group to the final Vulnerability Index for Oman

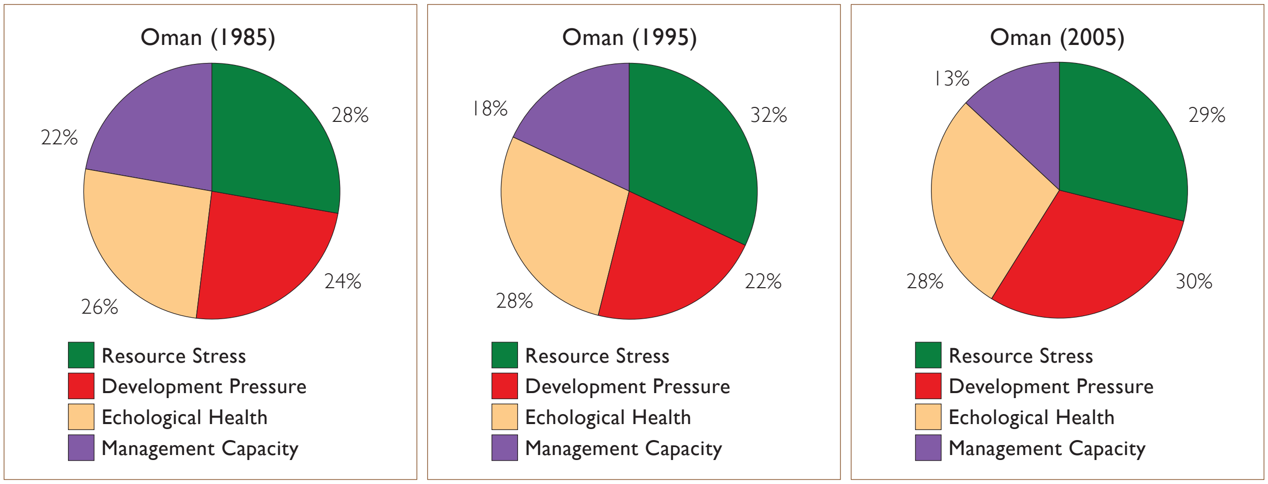


Figure 37: Share of the parameters group to the final Vulnerability Index for Qatar

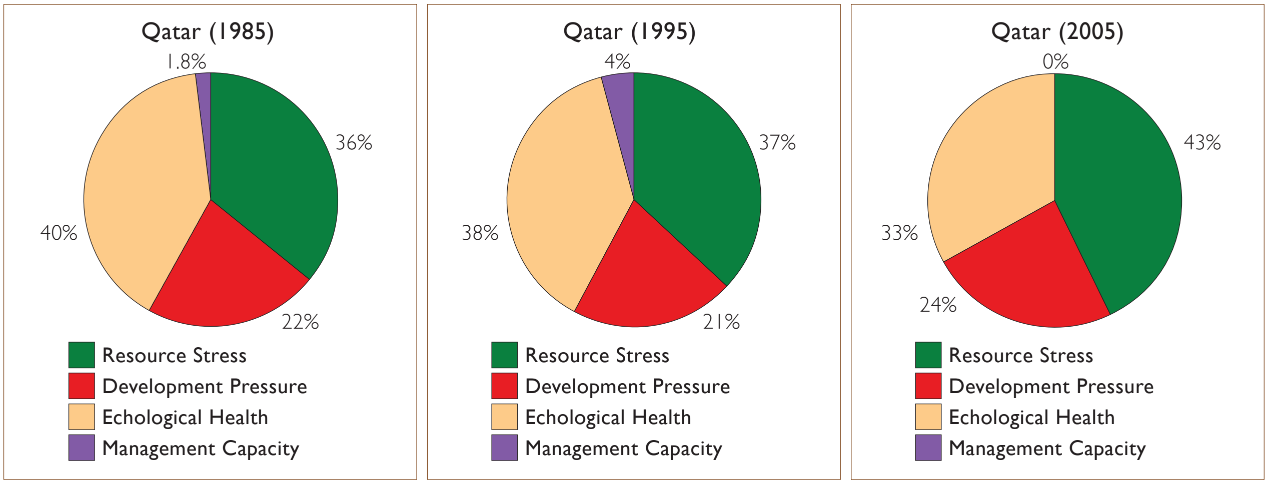


Figure 38: Share of the parameters group to the final Vulnerability Index for Saudi Arabia

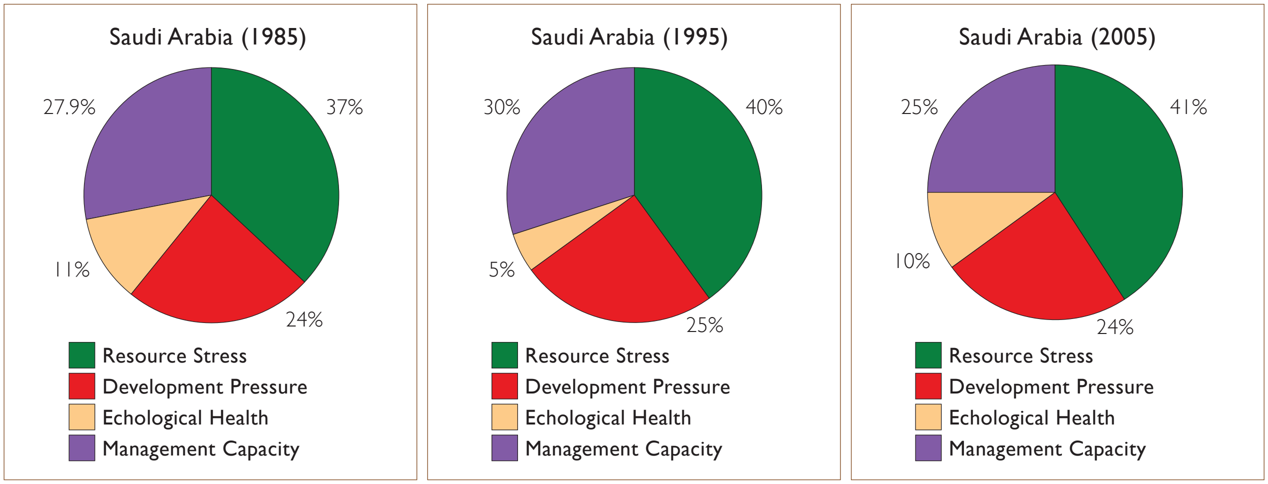


Figure 39: Share of the parameters group to the final Vulnerability Index for UAE

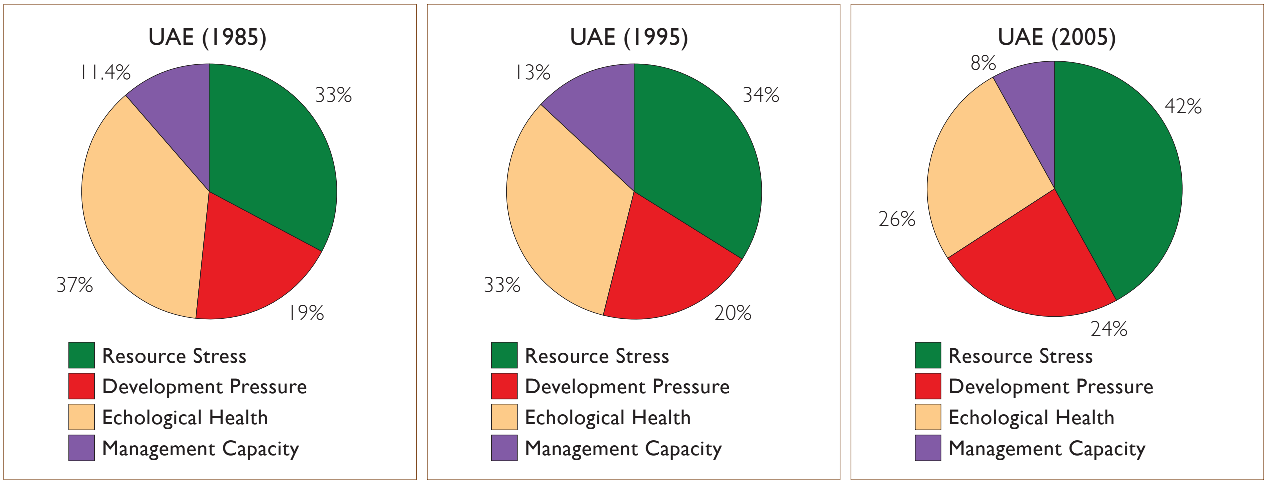


Figure 40: Share of the parameters group to the final Vulnerability Index for Syria

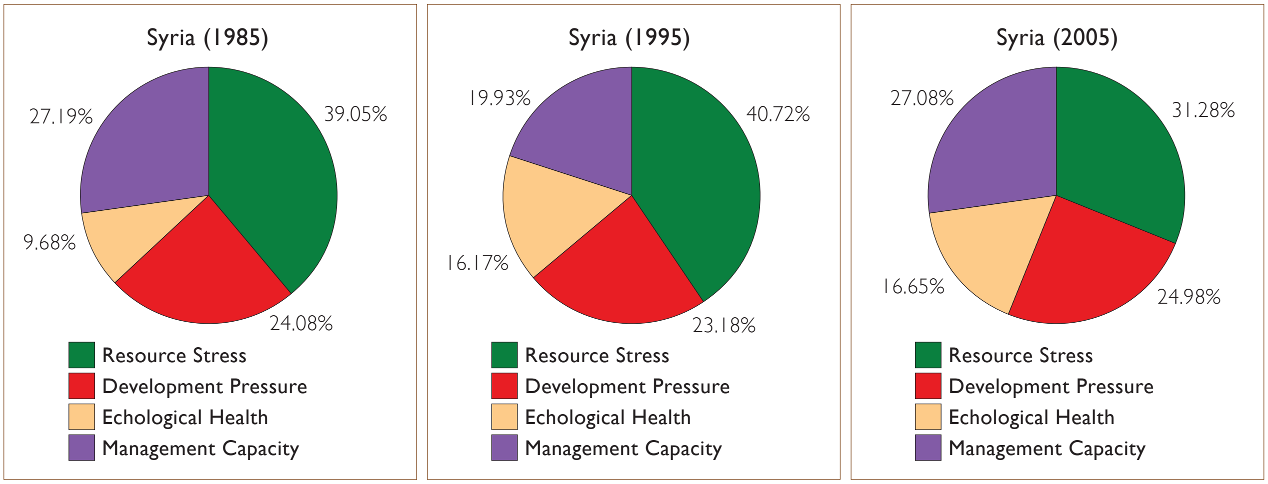


Figure 41: Share of the parameters group to the final Vulnerability Index for Jordan

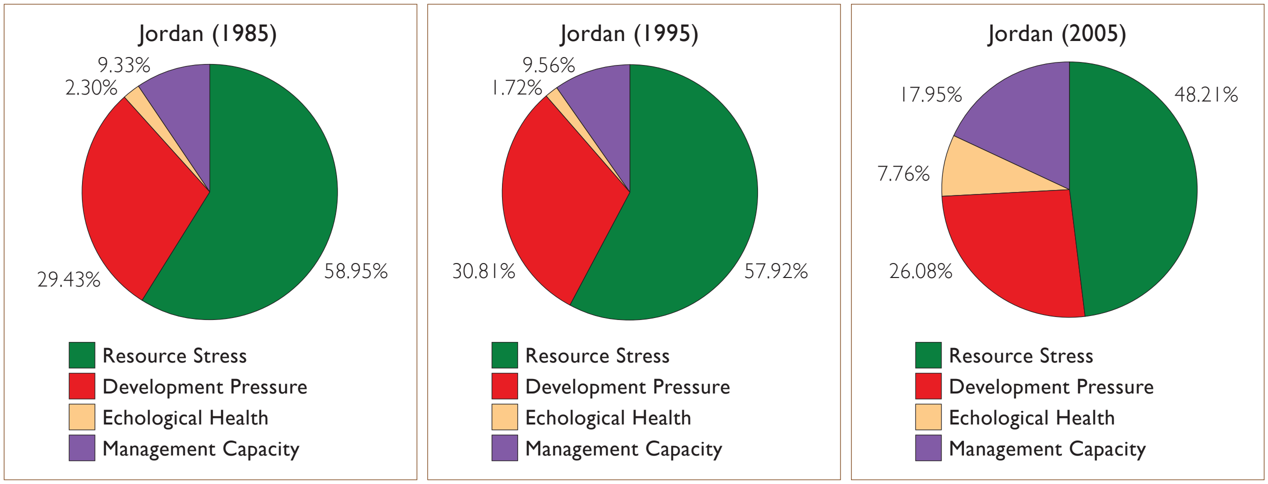


Figure 42: Share of the parameters group to the final Vulnerability Index for the Occupied Palestinian Territories

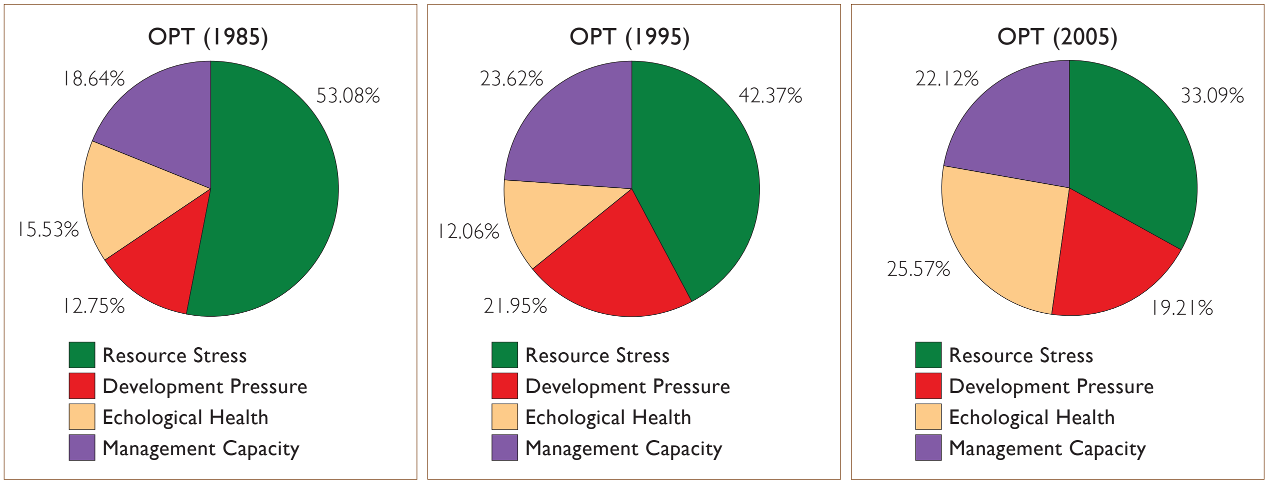


Figure 43: Parameters group to the final Vulnerability Index for Lebanon

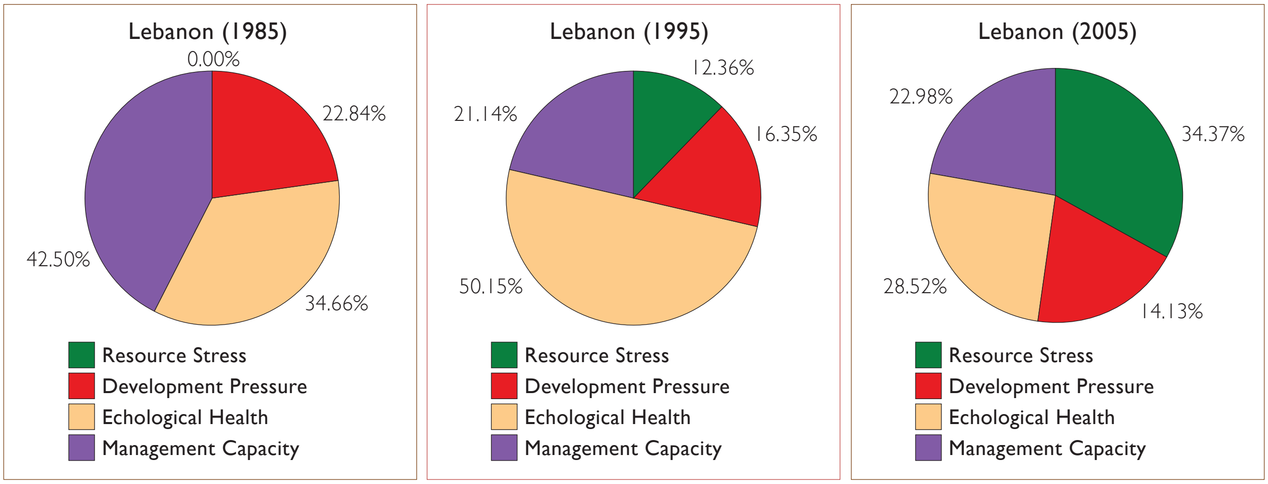


Figure 44: Share of the parameters group to the final Vulnerability Index for Yemen

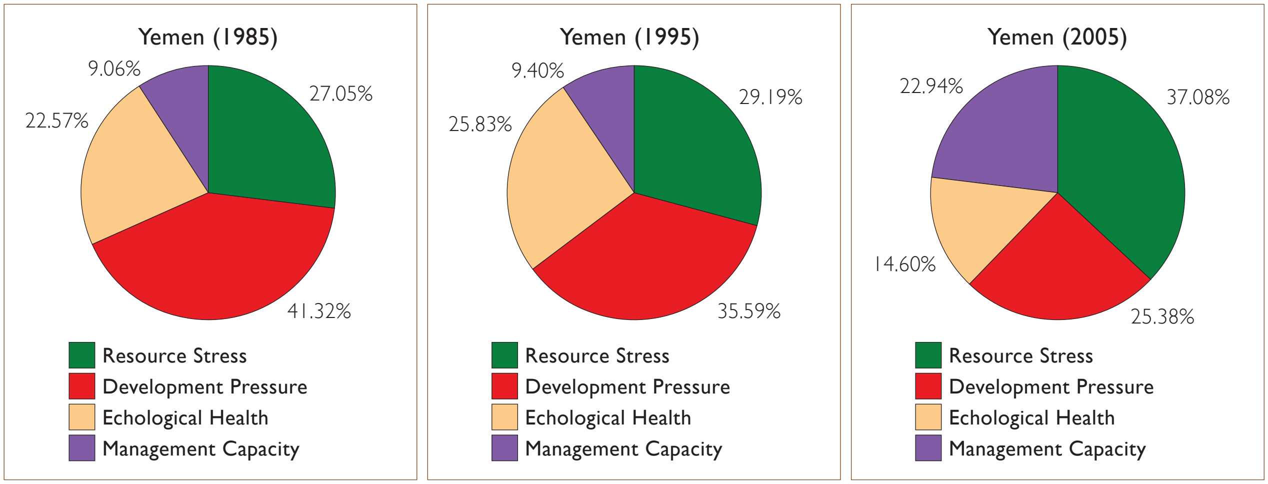
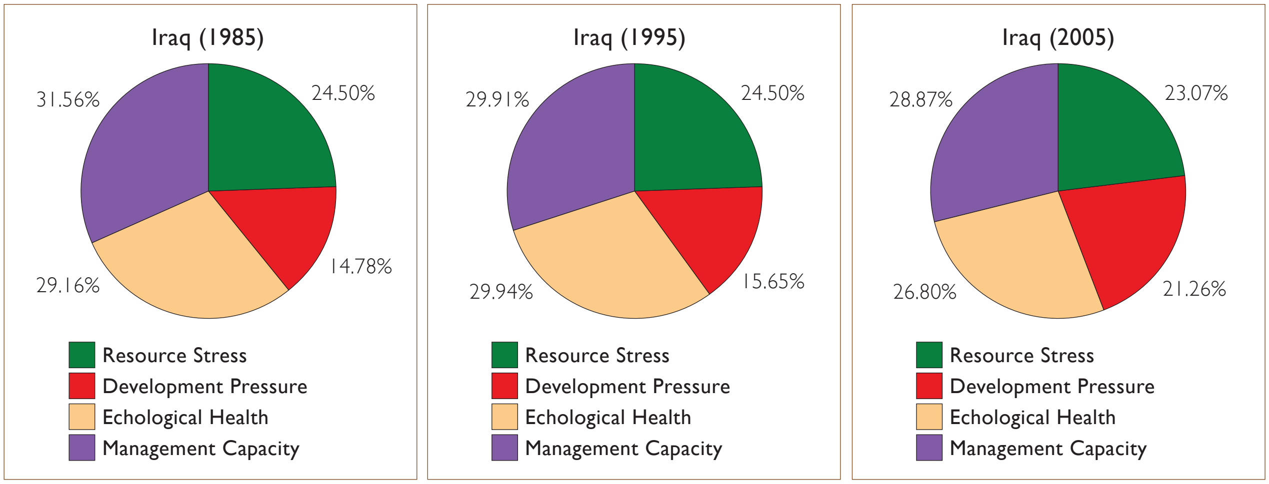


Figure 45: Share of the parameters group to the final Vulnerability Index for Iraq



CHAPTER FIVE

SHARED FRESHWATER VULNERABILITY TO CLIMATE CHANGE

5

Tristan Schmurr, www.flickr.com

Key Messages

Euphrates basin countries will suffer from increasing freshwater vulnerability due to climate change. Climate change scenarios predict a 20 per cent decrease in precipitation and an increase in temperatures in the Eastern Mediterranean region including Euphrates River upstream areas in the coming decades.

Most Dammam aquifer countries have enough financial resources to invest in desalination and wastewater treatment facilities for domestic use. Due to limited surface water availability, the impact of climate change, in terms of affecting rainfall amount, is expected to be low.

The current development practice and lack of coordinated management of the Dammam aquifer is expected to have political, technical, economic and social implications, that can potentially lead to future disputes among countries of the region.

Suspension bridge over Euphrates at Deir El Zore, Syria

Around 25 water basins, surface and groundwater, are shared between at least two riparian countries in WA region, while many basins extend beyond the region. These shared water resources play a significant role in the region, linking populations and cultures and creating hydrological, social and economic relations and interdependencies between riparian countries. Cross-border cooperation and coordination are the cornerstones of sustainable development and management of shared water resources (see Chapter 2 of this report). In Syria, around 75 per cent of water resources are shared with neighbouring countries, and half of the total available water resources come from the Syrian share of the Euphrates. For Iraq, the dependency on outside resources is between 51 and 75 per cent (UN-ESCWA, 2009).

The expected environmental impacts on shared water resources from water depletion, pollution and climate change have been evaluated here for two case studies in WA: the Euphrates River and the non-renewable Dammam aquifer. The Euphrates basin is an important shared basin among Syria, Iraq and Turkey, while the Dammam aquifer is shared among Saudi Arabia, Kuwait, Bahrain, Qatar, UAE and Oman. The VI was estimated for these two shared sources, taking into consideration climate change impacts that may modify rainfall patterns in WA and their impact on water availability stress (RS), development pressure (DP), ecological health (EH) and management capacity (MS).

5.1. CASE STUDY: EUPHRATES BASIN

5.1.1. Introduction

The Euphrates and Tigris rivers have been critical to Mesopotamian civilizations for over six thousand years, providing irrigation and domestic water supplies. The countries sharing the Euphrates River are Syria, Iraq and Turkey. Saudi Arabia could also be considered a riparian state, since many wadis in the Saudi territories drain to the Euphrates (ACSAD and UNEP, 2001). On the other hand, the Tigris basin is shared by Syria, Iraq, Turkey and Iran.

The Euphrates catchment area is estimated at 444 000 km^2, while the Tigris catchment is estimated at 471 000 km^2 with a total area of 915 000 km^2 (ACSAD and UNEP, 2001). Recent socio-economic development combined with population growth have placed increasing pressures on the water resources of the Euphrates River basin, presenting

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Providing freshwater to an increasing population is a major challenge in the region

Figure 46: The Euphrates and Tigris river basins and their drainage networks

■ Source: ACSAD and UNEP, 2001

a major challenge to sustainable development and management of this shared surface water resource. Climate change impacts will also present additional challenges to the conservation and protection of water resources in the region.

5.1.2. Characteristics

Location

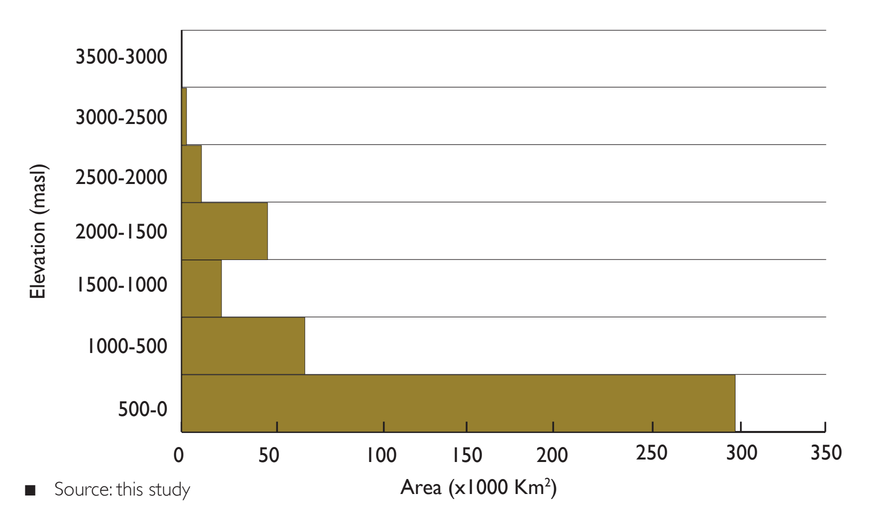
The Euphrates River basin is characterized by a variety of morphological and geological features that were formed through tectonic activities and geological transformations. The wet climate during past geological ages, and later the extreme climatic conditions that prevailed in the basin, have influenced current topographic features of the river basin. The regional topographic features consist of two main units, the hilly areas in the north, northeast and east, and the plains in the rest of the basin with a gradual transition through a semi-hilly plain area between these two units as shown in Figure 46.

Conflicting literature has been published with respect to the length of the shared Euphrates River in each of the three states. The information presented by the Iraqi Ministries of Foreign Affairs and Water Resources provide the most recent official information on this subject, indicating that the length of the river's main channel is estimated at 2 940 km with a 40 per cent share in Turkey, 20.5 per cent in Syria, and 39.5 per cent in Iraq (ACSAD and UNEP, 2001). Estimates of the drainage area of the basin according to most references are around 444 000 km^2 while recent Digital Elevation Model (DEM) data (90x90m) estimated the area at

450 000 km² (this study). In the four riparian countries, the spatial coverage of the basin is as follows: Turkey is covered by an area of 119 042 km² (26.5 per cent), Syria by 93 675 km² (20.8 per cent), Iraq by 195 928 km² (43.5 per cent) and Saudi Arabia by 41 355 km² (9.2 per cent) (this study).

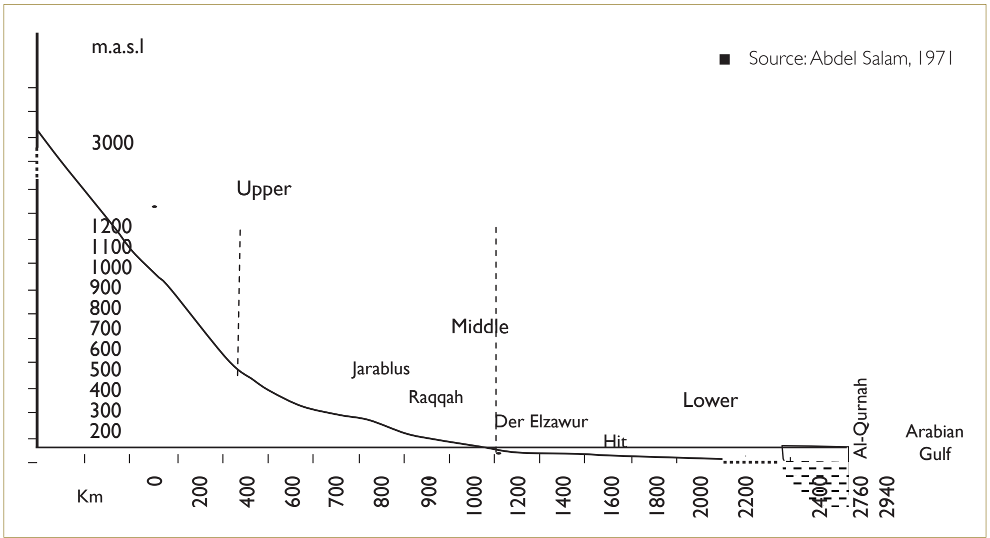
The Euphrates River originates in the Armenian highlands and the high mountains east of the Anatolia plateau in Turkey, extending between the Van Lake, with an elevation of 4 363 m, and the Black Sea at elevations ranging between 3 000 and 4 000 m above sea level. The catchment area in the hills of Keban is about 76 000 km², where the elevation ranges between 1 000 and 3 500 m above sea level (ACSAD and UNEP, 2001). More than two thirds of this area lies at an elevation of more than 1 500 m above sea level, while its eastern sections lying in relatively flat areas. The distribution of the basin area in relation to elevation is shown in Figure 47. The difference in elevations of the river course across the shared countries is shown in the longitudinal profile in Figure 48.

Figure 47: Area distribution according to the elevation of Euphrates basin (Using DEM data of 90x90 m resolution)



■ Source: this study

Figure 48: Longitudinal section along Euphrates River course



■ Source: Abdel Salam, 1971

Properties

Although more than the two thirds of the Euphrates drainage area lies outside of Turkey, 93 per cent of its water supply originates in Turkish territories. Even the two Syrian tributaries, the Khabur and the Balikh, both have their catchments in Turkey. The total water resources of the Euphrates are estimated at about 32 000 mcm/year. A small amount of this water comes from Euphrates tributaries on the Syrian side and none from Iraqi territories, yet their combined river drainage area constitutes about half of the total drainage area of the Euphrates basin. The flow of the river has changed due to the construction of many dams, most notably the Keban Dam in Turkey. The monthly average discharge of the river before the construction of this dam ranged between 309 m^3/s in September and 2 709 m^3/s in April. After construction of the dam, the monthly average discharge reaches 1 024 m^3/s in April. Of the annual average discharge of 32 000 mcm for the Euphrates, Syria and Iraq receive 15 700 mcm (ACSAD and UNEP, 2001).

Climate

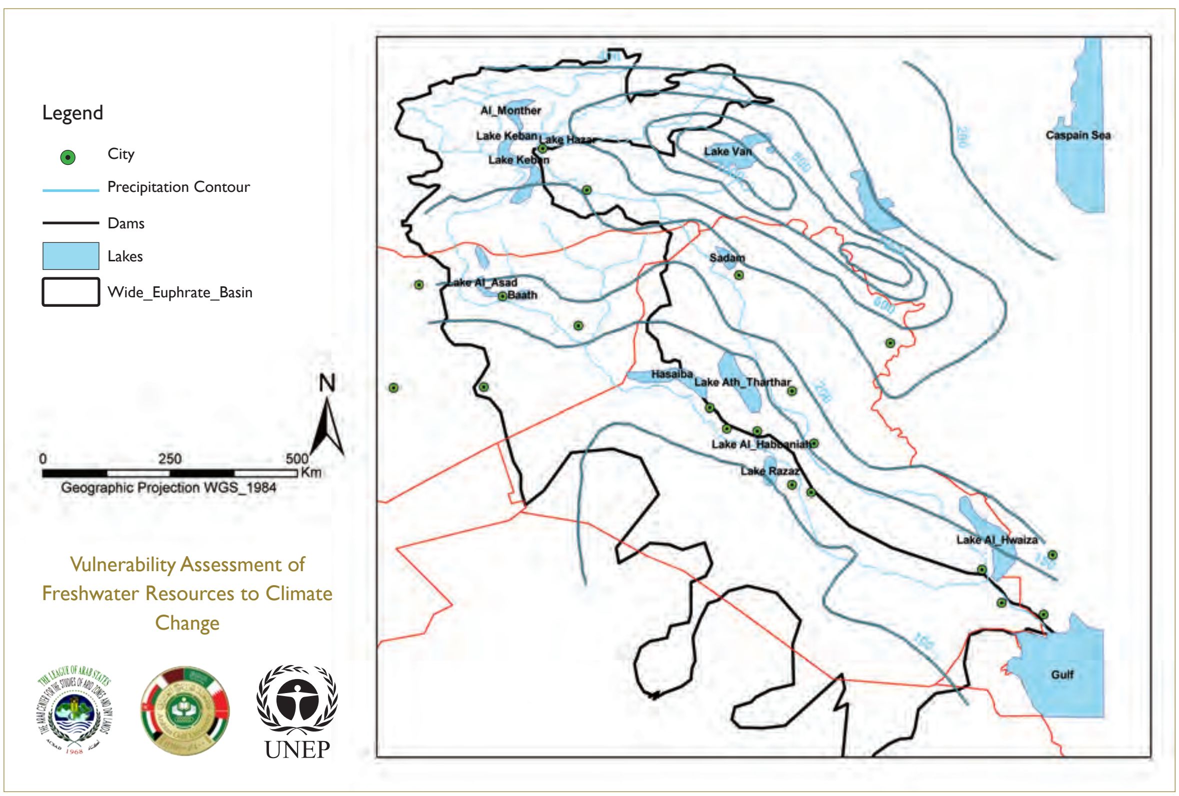
Various climatic systems prevail over different areas of the Euphrates basin, ranging from semi-arid in the northern area, to arid in the southern estuary area of the ROPME Sea Area. The climate is influenced by elevation and the general weather circulation pattern. The high mountainous areas in Turkey, the highland areas of Syria and Iraq and the flat floodplains in Iraq influence the amount and frequency of rainfall and snow events. Moreover, the location of the basin between latitudes 25° and 40°N influences the regional variation of pressure and temperatures during summer and winter seasons, and consequently, the quantities of snow and rainfall (ACSAD and UNEP, 2001).

Euphrates river, Syria

The basin is characterized by four different climate zones: the Mediterranean mountainous, Mediterranean interior, interior lowlands and desert climates. The climate is influenced mainly by the Mediterranean dry, hot summer and cold, rainy winter seasons. The amount of rainfall decreases from north to south and from west to east with much higher amounts over the Zeros Mountains, while temperature and evaporation increase in the same spatial directions (ACSAD and UNEP, 2001). The topographic elevation features, especially at upstream areas of the basin, influence annual rainfall distribution with values ranging between 300 and 1 000 mm, and with a rainy season extending from October to May. In addition, the eastern part of Anatolia and the Armenian Highlands usually receives heavy snow accumulation. High accumulation of snow and rainfall ranging between 400 and 1 000 mm per year falls on the upstream portion of the basin, while snow covers the mountain peaks all around the year but starts to melt in mid-April (ACSAD and UNEP, 2001).

Average annual rainfall in the three countries sharing the Euphrates River varies between 700-1 000 mm in Turkey, 150 mm in Syria and 75 mm in Iraq (ACSAD and UNEP, 2001). Rainfall rates decrease south of Turkey and north of Syria (Al-Kabul River sub-catchments) to about 300-450 mm. The average annual precipitation over the three major reaches of the river decreases from about 1 000 mm at the upper course at Anatolia, to 200-400 mm in the Syrian upper island (upper part of the middle course) and reaches 100-200 mm in most of the middle course and the lower course. The rainfall variation is shown by the Isohyetal map for Euphrates basins (Figure 49).

Figure 49: Isohyetal map for the Euphrates River basin



Since there is no rainfall during summer and autumn in Syria and Iraq, the source of water supply for all purposes in the basin is provided from the River.

Water quality

The quality of the water of the river and its tributaries is an important issue. The Euphrates River enters Syrian territories with an average salinity of about 0.6 g/l, rising to more than 1 g/l at the Iraqi-Syrian borders. The increasing water salinity and pollution is a result of Syrian agricultural drainage and sewage systems which flow into the River. In general, water quality is not well-monitored. The ramifications of Turkey's South Eastern Anatolia Development Project, known as GAP, will include both a reduction in water quality and a reduction of Syria's water supply from 500 m^3/s to less than 300 m^3/s by 2030 (Guner, 1997). In addition, the quality of water will further diminish, due to increased salinization and the use of pesticides and fertilizers upstream (Guner, 1997). This will also affect Iraq as it is downstream from both Syria and Turkey (Gruen, 2000).

5.1.3. Water management

The Euphrates provides approximately 19 per cent of Turkey's total water resources, or 180 000 mcm/year (UNEP, 2009). The Syrian share of the Euphrates water resources (approximately 6 600 mcm/year) constitutes two thirds of total surface water resources in Syria and is used for domestic water supply for the major cities, Aleppo and Raqqa, and for irrigation purposes (ACSAD and UNEP, 2001). With population and economic pressures resulting in unilateral development projects, the situation remains tenuous. The total storage of the dams on the Euphrates is 148 800 mcm, which amount to five times its average annual flow. It is estimated that a deficit of 2 000 to 12 000 mcm is expected if all development plans are realized by the three countries (ACSAD and UNEP, 2001). Water originating in the hills of Kebanre present 72 per cent of the total resources of the Euphrates. The amount of water received from the drainage area in Syria is limited to the flow from three tributaries: Al-Sajur, Al-Balikh, and Al-Khabur rivers, and some seasonal flow tributaries depending on the intensity and amounts of rainfall. Recently, Turkey has detained most of the flow of these seasonal tributaries. The contribution of wadis to the Euphrates flow reflects the wide range of rainfall variability in the different reaches of the basin (ACSAD and UNEP, 2001).

According to the provisional agreement between Turkey, Iraq and Syria (protocol signed with Turkey in 1987), Turkey releases a minimum discharge of 500 m^3/second to the river (15 700 mcm/year) at the Turkish-Syrian border. Of this amount, about 42 per cent, equivalent to an average annual discharge of about 6 600 mcm/year, is considered for use within Syria (after the agreement signed between Syria and Iraq in 1989). However, up to time of writing, there has been no final official agreement between the three countries for sharing the river resources. At the basin level, there is no regular cooperation between the three riparian countries sharing the basin. The first tripartite meeting was held in Baghdad in 1965 though no formal agreement was reached. The technical committee held about 16 meetings over a decade but did not fulfil any of its objectives (ACSAD and UNEP, 2001).

5.1.4. Freshwater vulnerability assessment of the shared Euphrates River

The analysis of both the state and trends regarding the vulnerability of this shared surface water was performed through the application of the same methodology applied at the national level for countries of WA (UNEP, 2009) as presented in Chapter 3. The availability of data on the basin scale in the three countries limited the analysis. If no data was available, the figures available at the level of each country were used in place of basin values. Thus, the present analysis provides a general trend rather than an accurate estimation of the different parameters of the vulnerability index for the Euphrates basin. The four main parameters of water resources stress (RS), development pressure (DP), ecological health (EH) and management capacity (MS) are estimated using the available information to provide an estimation of the VI. Due to lack of information and data, we are limiting the estimation of VI to the year 2000. Based on the data available for this year, the VI for the year 2040 was estimated considering that agriculture demand will remain as it is for the year 2000, while domestic water demand will increase from year 2000 levels in accordance with population growth rates.

The resources stress (RS) Parameter

The water stress indicator is influenced by the renewable water resources availability and consumption pattern of the growing population (RSs) and water variation parameter resulting from long term rainfall variability (RSv).

Water resources stress (RSs)

The water resources stress parameter is the per capita renewable national or regional water resources compared to the internationally agreed water poverty index of 1 700 per capita share of water resources.

Renewable water stress for each country was estimated based on per capita water resources. The analysis indicates that the parts of the basin within Syria and Iraq have comparable stress values ranging from 0.27 to 0.20 in Syria and Iraq respectively. The low values indicate more than adequate water resources availability; however, the upstream controls of the flow can contribute to a large degree of vulnerability. The basin area located in Turkey has an abundance of water and explains the very low water stress value shown in Figure 50.

Water variation (RSv)

Water variation stress can be estimated by the CV of the long-term average precipitation over a long period of observation, preferably 50 years. All countries seem to suffer from different degrees of precipitation variation. The indices range from 0.9 to 1 as shown in Figure 51. Results show that Iraq experiences large variation as most of the basin is located in areas characterized by arid or extreme arid climate. Syria and Turkey suffer from high precipitation variation due to the prevailing semi-arid climate in the region as shown in Figure 51. Since high variation in precipitation is a major characteristic of arid and semi-arid zones, moving from humid and semi humid zones to more arid zones increases the variation and adds more pressure on the available resources in these areas.

Figure 50: Water stress for the year 2000

Water Stress Parameter for year 2000, RSs			
Country	R (m^3/person)	RSs	Equation
Turkey	2180.22	0.00	RSs = (1700-R)/1700
Syria	1245.39	0.27	RSs = (1700-R)/1700
Iraq	1356.13	0.20	RSs = (1700-R)/1700

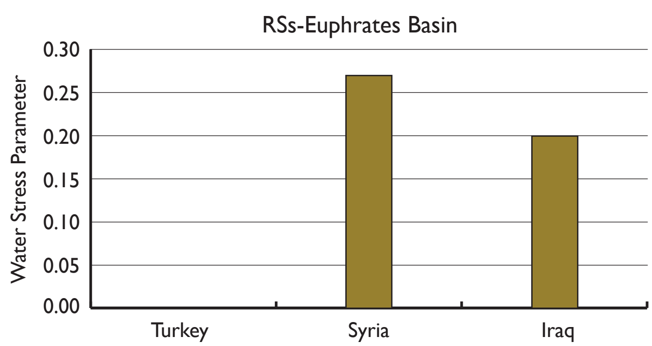
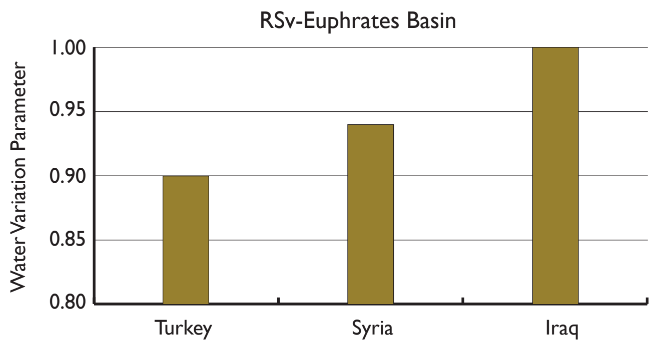


Figure 51: Water variation for the year 2000

Water Variation Parameter RSv					
Country	CV	S	ρ	**RSv**	Equation
Turkey	0.27			0.90	RSv=CV/0.3
Syria	0.28	249.47	70.14	0.94	RSv=CV/0.3
Iraq	0.40	127.05	50.74	1.00	RSv=CV/0.3



Water development pressure (DP) parameter

This parameter is defined by overexploitation of water resources and the provision and accessibility of safe drinking water supply.

Water exploitation (DPs)

The water exploitation variable is the ratio of the total water demand (domestic, industrial and irrigation) for a given year to the available amount of renewable water sources. The basin is under heavy agricultural and other socio-economic activities and the available data shows high water demand and limited water supply. The exploitation values are high, indicating high development rates as shown in Figure 52.

Safe drinking water inaccessibility (DPd)

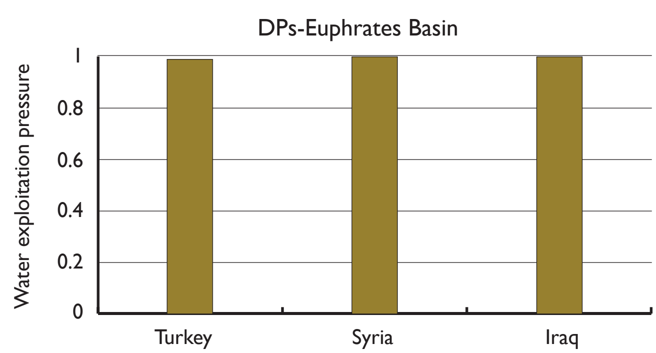
This parameter represents the percentage of the population without access to improved drinking water resources. Based on country values, Turkey performs strongest in improving drinking water supply, as shown in Figure 53, while Syria and Iraq are largely behind. The key factors making the latter two countries highly vulnerable is the high population growth rate, limited financial resources and finally, limited availability of water resources.

Ecological health (EH) parameter

This parameter is calculated by evaluating the level of pollution and deterioration that may be experienced by the ecosystem.

Figure 52: Water exploitation pressure for the year 2000

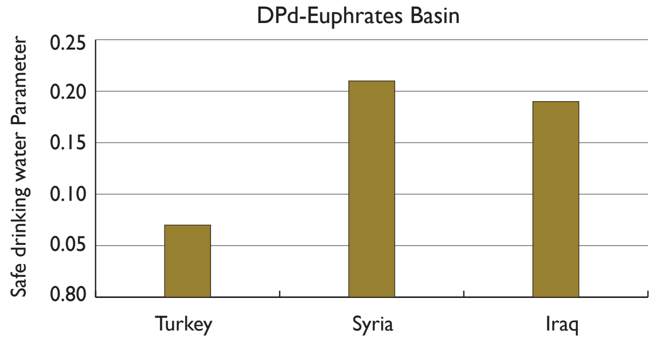
Water Exploitation Pressure - DPs 2000				
Country	WRs	Date	WR	**DPs**
	Water Supply		Total water resources	
Turkey	15700000	2000	15,848,000	0.99
Syria	7740000	2000	6,531,840	1.00
Iraq	20000000	2000	9,020,160	1.00



■ Source: data compiled from ACSAD and UNEP, 2001

Figure 53: Safe drinking water inaccessibility for the year 2000

Safe Drinking Water Parameter (2000)	
Country	DPd
Turkey	0.07
Syria	0.21
Iraq	0.19



Water Pollution Parameter (EHp)

The vulnerability of water resources to pollution is estimated by the ratio of the total untreated wastewater discharge in water-receiving systems to the total available renewable water resources. No data was found for Iraq, therefore this parameter was not calculated.

Ecosystem Deterioration Parameter (EHe)

Population growth and the associated urbanization and other socio-economic development activities are impacting surface and groundwater systems by increasing depletion and pollution rates. Due to the lack of data regarding land degradation at the basin level for the three countries, and since the available country level data cannot be used as a substitute at the basin level, another alternative was used. Ecosystem deterioration is defined in this case study as the decrease in vegetation coverage due to natural and human activities, and the EHe parameter was estimated using the Normalized Difference Vegetation Index (NDVI). This index is usually used to estimate vegetation cover (negative index values indicate no vegetation cover and positive values indicate vegetation cover). Based on this principal, we can monitor the variation in vegetation cover seasonally or annually, so that this index can be used as an indicator for ecosystem deterioration. The value of NDVI was estimated using satellite images (SPOT, 1 km) for the period 1999-2007 as shown in Figure 54. The area with medium to high land degradation (more than 50 per cent) was used to calculate this parameter. The analysis indicated a high degree of deterioration in Iraq, followed by Turkey and then Syria (Figure 55).

Water Wheel, Hama, Syria

Figure 54: Normalized Difference Vegetation Index values for the Euphrates River (1999-2007)

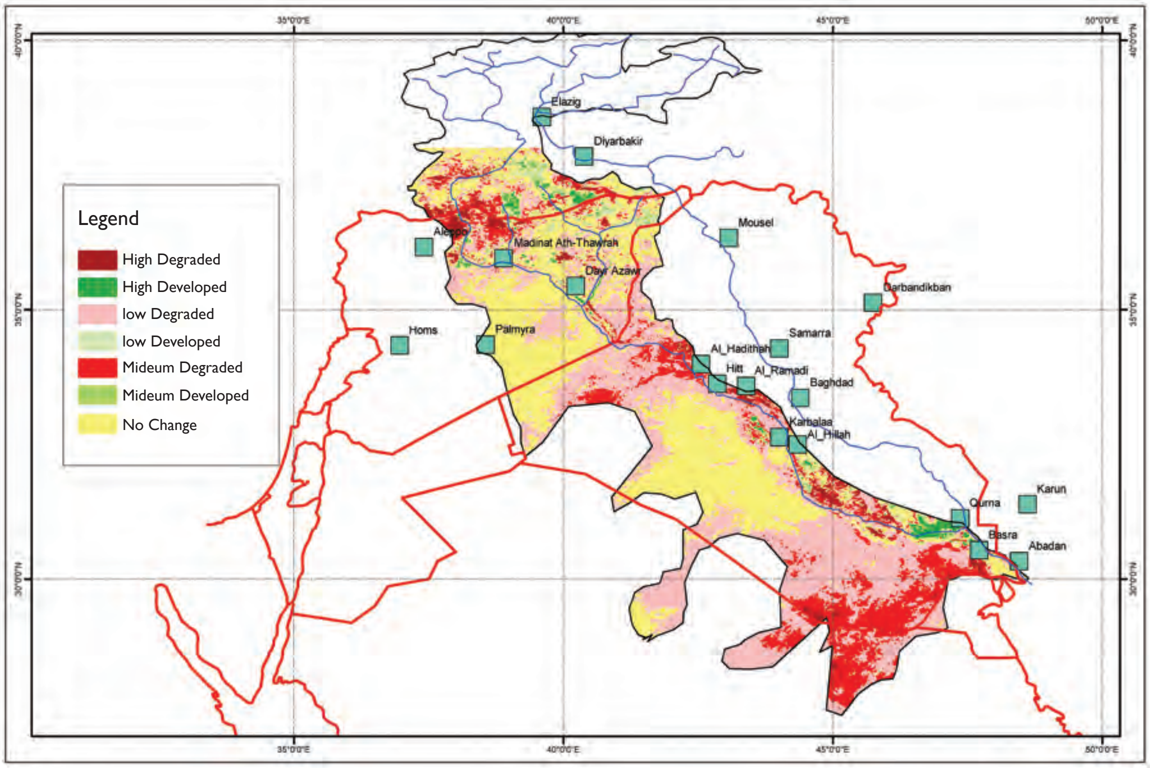
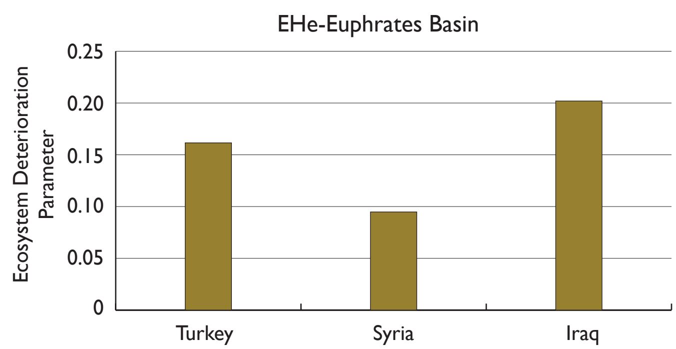


Figure 55: Ecosystem deterioration, 1999-2007

Ecosystem Deterioration Parameter EHe			
Country	Ad (km^2) (1) Area without vegetation	A (km^2) Total Area	EHe
Turkey	19227	119042	0.161514423
Syria	8879	93675	0.094785161
Iraq	39566	195928	0.20194153

(1) From Change of NDVI between 1999-2007, using Satellite image (spot 1Km), Land degradation more than 18 per cent



Management capacity (MC) parameter

Evaluation of the management capacity is used to evaluate how effective the water sector is being managed. The lack of effective management practices can be assessed by the vulnerability of the management capacity (MC) of freshwater according to three variables, namely, water use inefficiency (MCe), improved sanitation inaccessibility (MCs) and conflict management of the shared water resources (transboundary).

Water Use Inefficiency Parameter (MCe)

Efficiency in water use enhances water availability for food production and enhances the standard of living. Assessment of the management of available water can be examined in terms of water use efficiency and the financial return generated from the use of a unit of water in any sector. It can be estimated by the GDP value of one cubic meter compared to the world average for a selection of countries. Data at the basin level was not available, which made it necessary to use national information for the three countries. The analysis indicates high values for all countries indicating high water use inefficiencies (Figure 56).

Improved Sanitation inaccessibility (MCs)

Availability of sanitation infrastructures reduces pollution levels and preserves water resources. Accessibility to improved sanitation is used as a typical value to measure the capacity of a management system to deal with likelihood improvement in reducing pollution levels. This parameter is calculated as the proportion of population without access to improved sanitation facilities. The country value was used since no data was available at the basin scale. Turkey has better sanitation accessibility than Syria and Iraq, as shown in Figure 57.

Figure 56: Water use inefficiency for the year 2000

Water Use Inefficiency Parameter Mce

Country	WEwm	WE	MCe
Turkey	40	4.00	0.90
Syria	40	1.29	0.97
Iraq	40	1.32	0.97

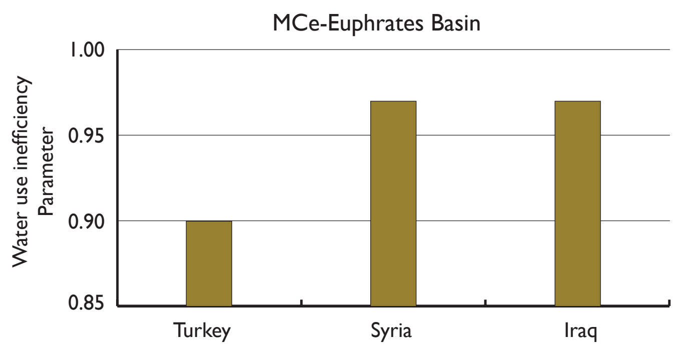
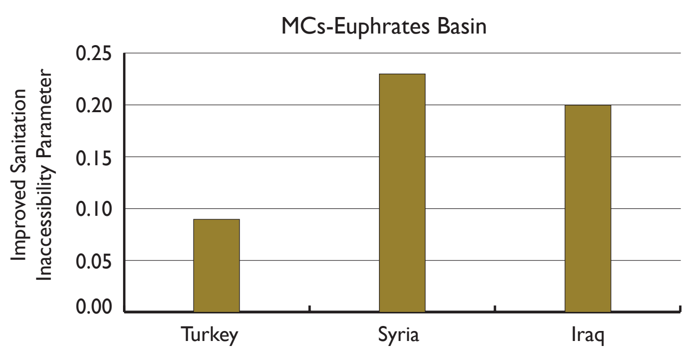


Figure 57: Inaccessibility to improved sanitation for the year 2000

Improved Sanitation Inaccessibility Parameter Mcs

Country	MCs
Turkey	0.09
Syria	0.23
Iraq	0.20



Jebel Bishri, Syria

Conflict Management Capacity (MCg)

This parameter was determined by expert consultation using the scoring criteria about conflict management capacity (MCg) (see Annex). The three countries have similar values for MCg as shown in Figure 58. This means that the three countries sharing the resource are able to manage any conflict regarding the use of shared water resources.

Freshwater vulnerability index estimation (VI)

The VI was calculated for each country sharing the surface water of the Euphrates River. No information was available to calculate the EHp parameter, therefore EHe is the sole constituent for EH in this case.

Figure 58: Conflict management capacity for the year 2000

Conflict management capacity Parameter MCg

Country	MCg
Turkey	0.65
Syria	0.65
Iraq	0.65

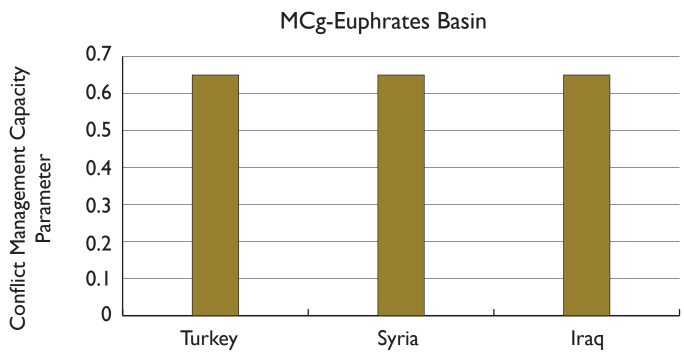
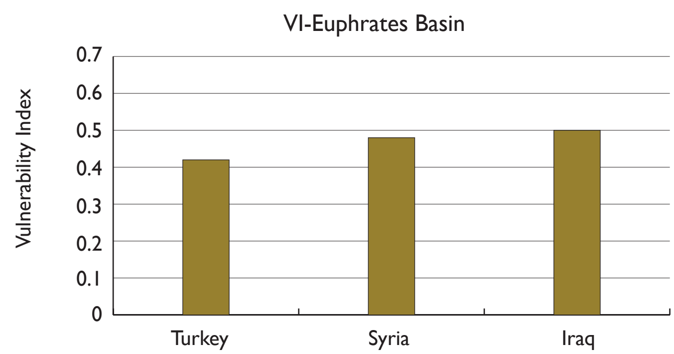


Figure 59: Vulnerability Index for Euphrates basin

Vulnerability Index

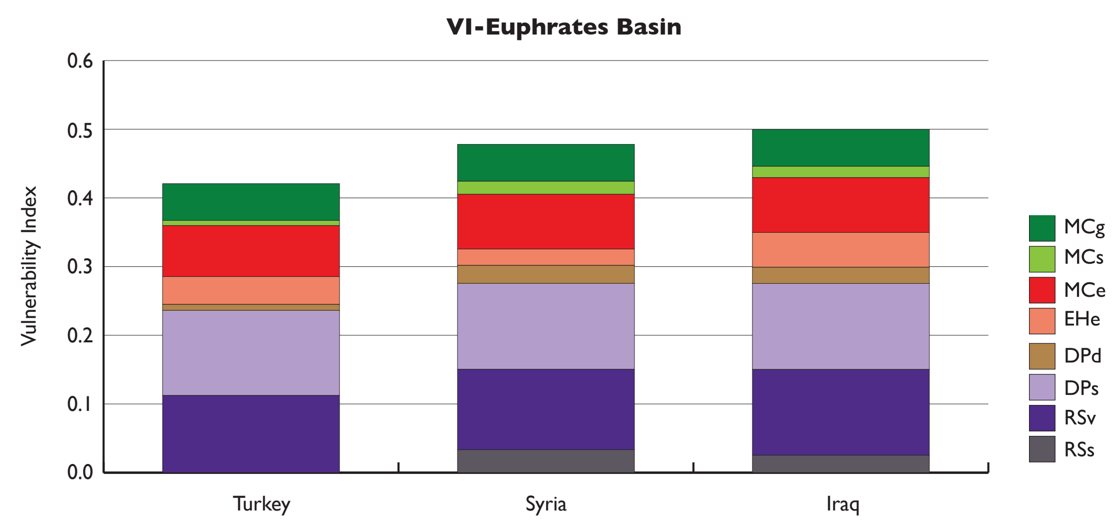
Country	VI
Turkey	0.42
Syria	0.48
Iraq	0.5



The analysis indicates that all the countries are experiencing high stress (values in excess of 0.4), with Syria and Iraq experiencing the highest stress as shown in Figure 59 below. The abundance of water in Turkey is reflected by a low water stress as the stress value was estimated at Rs=0, thus contributing to an improved overall freshwater vulnerability value (VI) of 0.42.

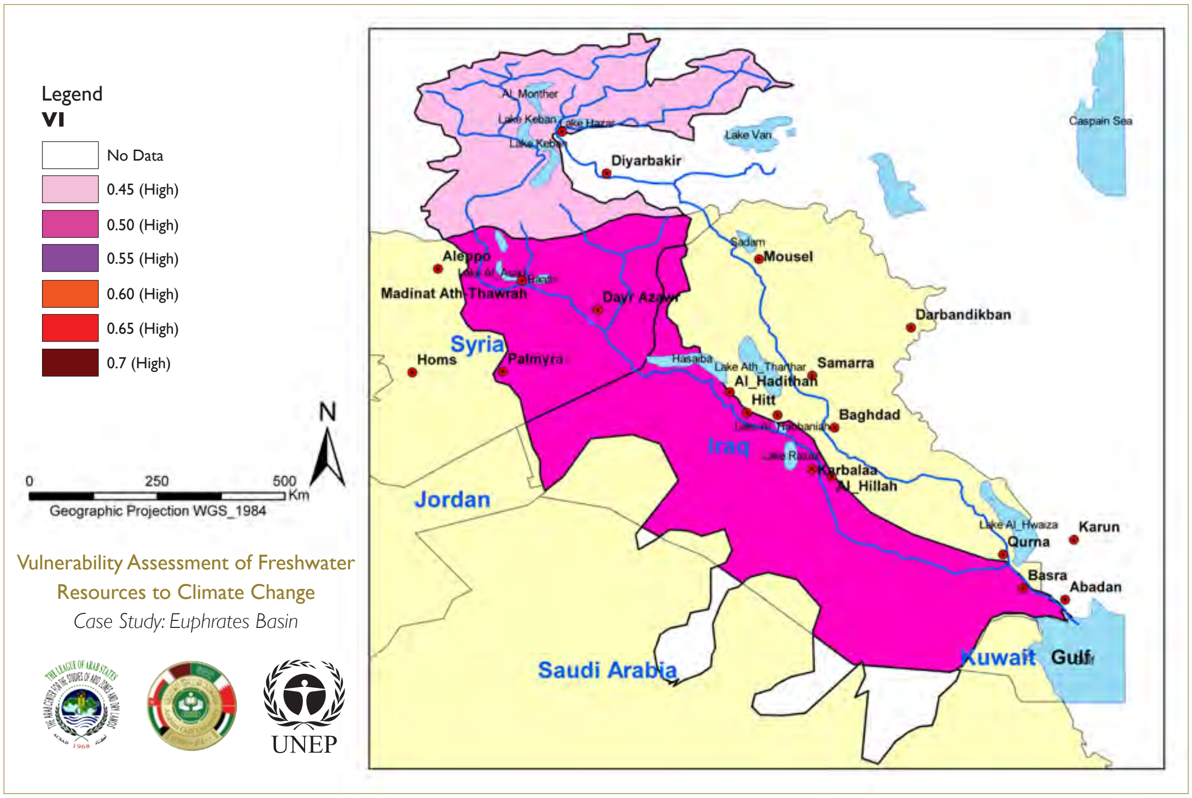
Further analysis of the data was undertaken and the values replotted as stacked bars illustrating the influence of resource stress, development pressure, ecological health and management capacity parameters. Figure 60 indicates that the most dominant factor contributing to vulnerability is the water variation parameter (RSv) since rainfall and snow amount and frequency control freshwater availability. Furthermore, climate change is expected to have a major impact on rainfall and snow variations. The second most influential factor is the water exploitation pressure (DPs) which indicates that most countries are developing their water resources to satisfy their water needs from the shared river flow. The variation of each parameter for each country is shown in Figures 60 and 61.

Figure 60: Vulnerability of Euphrates basin



Category	Resource Stress		Development Pressure		Echological Health	Management Capacity		
Parameter	RSs	RSv	DPs	DPd	EHe	MCe	MCs	MCg
Turkey	0.0000	0.1125	0.1238	0.0088	0.0404	0.0743	0.0074	0.0536
Syria	0.0334	0.1172	0.1250	0.0263	0.0237	0.0798	0.0190	0.0536
Iraq	0.0254	0.1250	0.1250	0.0238	0.0505	0.0800	0.0165	0.0536

Figure 61: Euphrates basin Vulnerability Index map, 2000



5.1.5. Conclusion

The three countries sharing the Euphrates River basin are vulnerable in various degrees to environmental change (high VI). Even if the VI is less for Turkey because of its upstream location and additional water resources, the situation could deteriorate in the future as a result of climate change. To decrease the vulnerability of the countries of the basin, it is necessary to have an integrated vision for the management of the basin that would ensure optimum allocation of available water. This requires close cooperation with regards to the sharing and management of the water resource for all countries involved. It would be even more beneficial for the riparian countries to finalize an official agreement to avert any future conflict. As a first step towards full future cooperation, and to overcome the problem of incompatible data, it would be useful to agree on the principals, norms and standards of monitoring measures. This will benefit future cooperation and protect the interests of future generations and the environment of the region. Once this harmonization has been established, it will be easier to determine practical measures for basin-level cooperation.

5.1.6. Future Scenarios of Freshwater Vulnerability

The analysis focused on two scenarios for the years 2000 to 2040: the impact of population growth on freshwater availability, and an assumed decrease in water availability by 7 per cent due to climate change. As discussed below, the VI was estimated for both scenarios in line with the methodology presented in Chapter 3.

Scenario 1: *Increased population growth*

The population growth scenario suggests an increase of 2.5 per cent for Syria based on present current population growth trends, 1 per cent for Turkey (UNICEF and WHO, 2008) and 3 per cent for Iraq (ACSAD-UNEP, 2001). To calculate the different parameters, it was assumed that the water requirement per person for the agriculture and domestic sectors would remain unchanged at year 2000 levels. The water requirements for the domestic sector were increased by the same rate as population growth.

The water resource stress (RS) was estimated at 0.27 for Syria, 0.20 for Iraq and 0 for Turkey in the year 2000, implying adequate water resources for all countries sharing the basin. The 2040 projection indicates much higher water stress for both Syria (Rs 0.8) and Iraq (Rs 0.82) and adequate water availability for Turkey (Figure 62). This implies that competition for shared water resources, driven by increased water consumption resulting from higher population growth, could lead to future water disputes in the absence of any permanent agreement concerning the apportionment of water in existing Euphrates River agreements. The estimated VI for the years 2000 and 2040 is shown in Figure 63. For the year 2000, the VI ranged from 0.42 for Turkey to 0.48-0.5 for Syria and Iraq, respectively. Higher values are predicted for the year 2040 for Syria and Iraq, estimated at 0.54 and 0.58, respectively. Higher population

Figure 62: Water stress (RSs) estimates for scenario 1

Country	RSs 2000	RSs 2020	RSs 2040
Turkey	0.00	0.00	0.10
Syria	0.27	0.67	0.80
Iraq	0.20	0.67	0.82

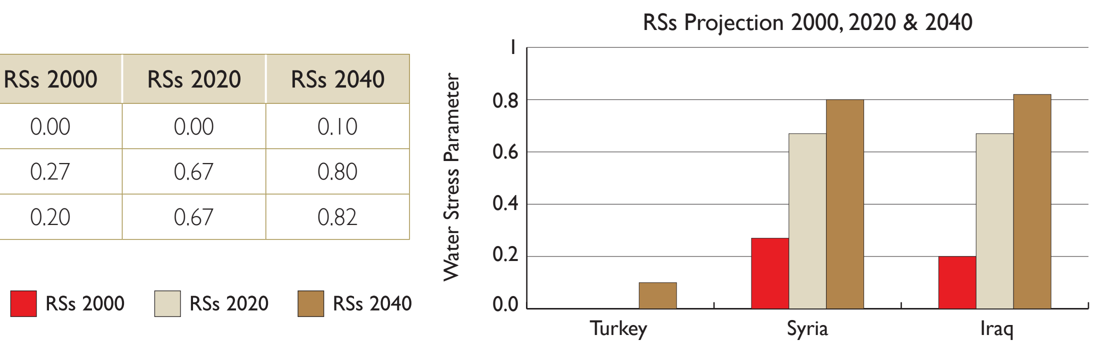
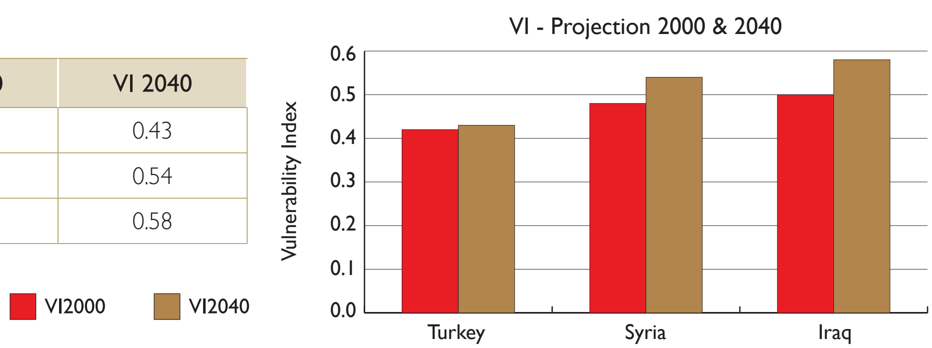


Figure 63: Vulnerability Index for scenario 1, projection 2000 and 2040

Country	VI 2000	VI 2040
Turkey	0.42	0.43
Syria	0.48	0.54
Iraq	0.5	0.58



growth combined with reduced precipitation due to climate change is expected to lead to further increases in freshwater vulnerability. It is imperative that the countries concerned focus on areas of potential conflict, and find areas of mutual agreement and build on them. This will encourage dialogue and reduce potential future tensions among them.

Scenario 2: *Decrease of 7 per cent in freshwater availability due to climate change*

To calculate these VI values, the data concerning population growth in Scenario 1 (2.5 per cent for Syria, 1 per cent for Turkey and 3 per cent for Iraq) were used and a decrease in available water resources by 7 per cent due to climate change for all the countries was assumed and applied. The water stress (RS) estimation indicates an increase from 0.27 in 2000 to 0.81 in the year 2040 for the basin area located in Syria, and an increase from 0.20 to 0.83 for the basin area in Iraq for the same period. Even the basin area located in Turkey will experience an increase in water stress estimated at 17 per cent, as shown in Figure 64. The estimated VI illustrated in Figure 65 indicates that Turkey will have a small increase in vulnerability, estimated at 2 per cent, while Syria and Iraq will witness a higher increase because of higher population growth rates and lower water availability rates (expressed as per capita water resources). Water availability is expected to decrease in the future due to population growth and the impacts of climate change.

Figure 64: Water stress (RSs) estimates for scenario 2

Country	RSs 2000	RSs 2020	RSs 2040
Turkey	0.00	0.00	0.17
Syria	0.27	0.68	0.81
Iraq	0.20	0.68	0.83

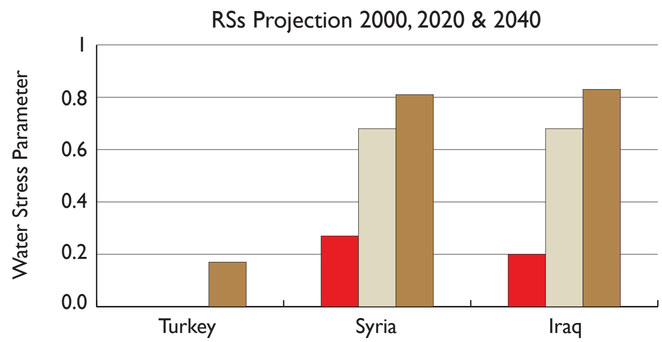
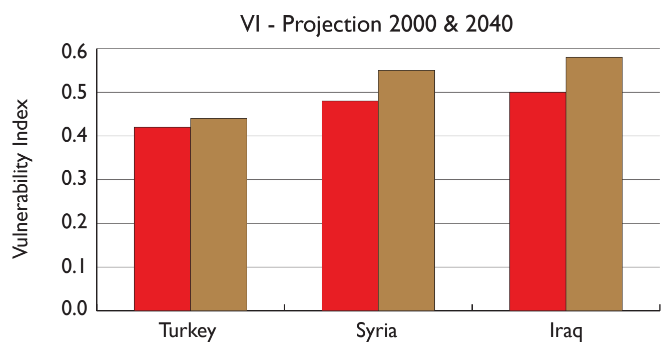


Figure 65: Vulnerability Index estimates for scenario 2

Country	VI - 2000	VI - 2040
Turkey	0.42	0.44
Syria	0.48	0.55
Iraq	0.50	0.58



Iraq

The application of the vulnerability assessment indicates that all the countries within the Euphrates basin, even Turkey, will have heightened freshwater vulnerability due to climate change. Climate change scenarios predict a 20 per cent decrease in precipitation and an increase in temperatures in the Eastern Mediterranean area, including upstream parts of the Euphrates River. It is also expected that snowfall over the mountainous area in the Euphrates basin where the river originates will decline, resulting in a decrease in river discharge. The expected increase in population in the future requires more water to be provided to meet the needs of the agriculture and domestic sectors. Under climate change predictions, this will contribute to severe water shortage in the river basin. Agricultural activity is the main source of income for the population living in the basin area and is the main food producer for the three countries, which leaves the population and the basin highly vulnerable to climate change. Adaptation to climate change is therefore an economic and social imperative for the countries sharing the basin. Action is needed to develop a plan for adaptation and risk management. As the countries and populations living in the Euphrates basin heavily rely on agriculture, the focus of much of the adaptation strategy should be on the agriculture sector and on water resources management, for example:

- Improving water use efficiency, mainly in irrigation.
- Development of new varieties of crops that can cope with drought and salinity.
- Developing mechanisms for coordinating conservation actions between the riparian countries to support cooperation and exchange of expertise and data.
- Raising awareness and capacity building will help countries adapt to climate change and reduce vulnerability.

5.2. CASE STUDY: DAMMAM SHARED GROUNDWATER AQUIFER

5.2.1. Introduction

In all WA countries, water scarcity in conjunction with rising water demand in all sectors is leading to the full utilization of available renewable water resources and the depletion of non-renewable water resources, particularly groundwater. With few exceptions, non-renewable groundwater is being exploited in an unplanned and unsustainable manner, causing rapid depletion with an uncertain trajectory (Al-Zubari, 2008). The water available in non-renewable shared aquifers is being mined at different rates in GCC countries, mainly for irrigation. The significant spatial and temporal variation in rainfall patterns has a major impact on aquifer replenishment. Present groundwater recharge rates are very limited, compared to the volume of groundwater stored in the aquifer during previous pluvial periods when most recharge occurred (Burdon, 1973; Edgell, 1987; GDC, 1980).

The aquifer structure is characterized by a sequence of layered formations separated by confining layers with interflows across international boundaries. Leakage across layers is controlled by the prevailing hydrodynamic equilibrium flow regime. The most important shared aquifers in WA, in terms of potential development and utilization, are shown in Table 12. Their water resources are being utilized in the countries of the GCC, Syria, Jordan and the OPT (West Bank) for the agriculture sector and, to a certain extent, for the domestic sector.

Current uncontrolled groundwater development practices, in the absence of joint agreements to manage the shared aquifers in a somewhat sustainable manner, has resulted in detrimental effects including high depletion rates, rising pumping costs and deterioration of water quality. These negative impacts combined with the increasing demand for water which is expected to lead to further development, creates potential dispute among WA countries. Moreover, climate change impacts such as changing rainfall regimes and sea level rise are expected to place additional pressure on these aquifers.

The shared Dammam aquifer system of the complex Paleogene formation has been selected as a case study because it highlights the vulnerability of shared groundwater resources to the impacts of uncoordinated development and climate change. The aerial coverage of the Paleogene formations, which contain the Dammam aquifer (including the outcrop and discharge areas) is shown in Figure 66 (UN-ESCWA, 1999).

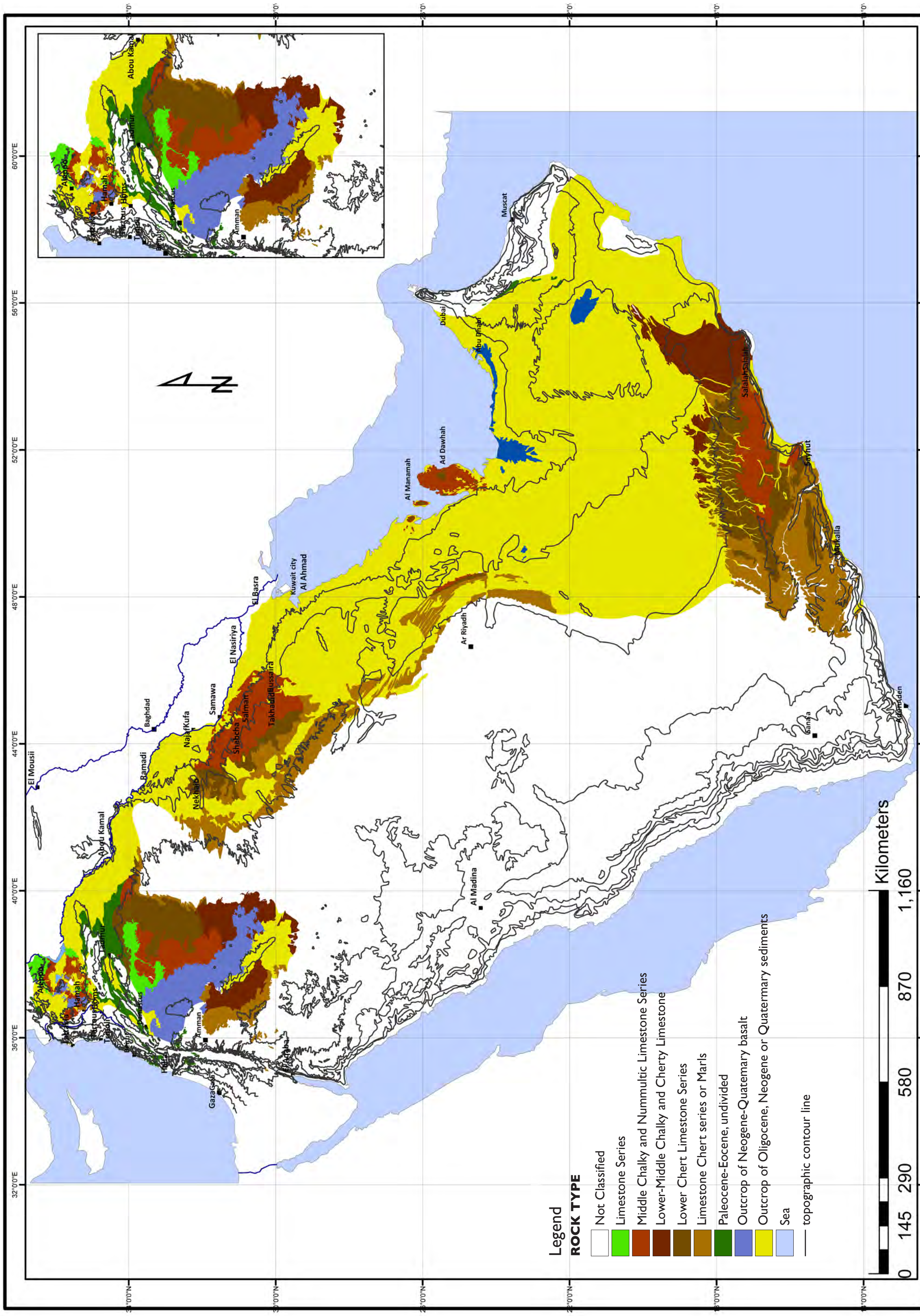
Table 12: Characteristics of non-renewable shared aquifers in West Asia

mcm= million cubic meters; ppm = parts per million

Aquifer	Reserve (mcm)	Recharge (mcm)	Thickness (m)	Depth from surface (m)	Quality (ppm)
Shaq	280 000	310	500-600	100-1500	300-1500
Taboo	205 000	450	1000-1200	10-1400	400-3500
Wahid	225 000	104	300-400	15-1100	500-1000
Wasia/Biyadh	590 000	480	200-230	230-1200	900-3000
Um ErRaduma	190 000	410	500-700	250-600	2000-20000
Dammam	45 000	200	50-250	100-500	1000-6000
Khuf	30 000	132			3800-6000
Aruma	85 000	80			1600-2000
Neogene4	130 000	290	30-100	10-150	3500-4500

Sources: MAW, 1984; World Bank, 2005

Figure 66: Aerial coverage of Palaeogene formations in West Asia including the Dammam Aquifer



■ Source: UN-ESCWA/BGR, 2001

Agricultural production is the largest water resources user
Source: UNEP,

5.2.2. Characteristics of the shared Dammam groundwater aquifer

The Dammam formation is part of a complex Palaeogene carbonate aquifer of the Eocene geological era. The shared Dammam aquifer covers a large area of WA including parts of Syria, Jordan, Iraq, Saudi Arabia, Bahrain, Kuwait, Qatar, UAE and parts of Oman and Yemen.

Main regional hydrogeological features

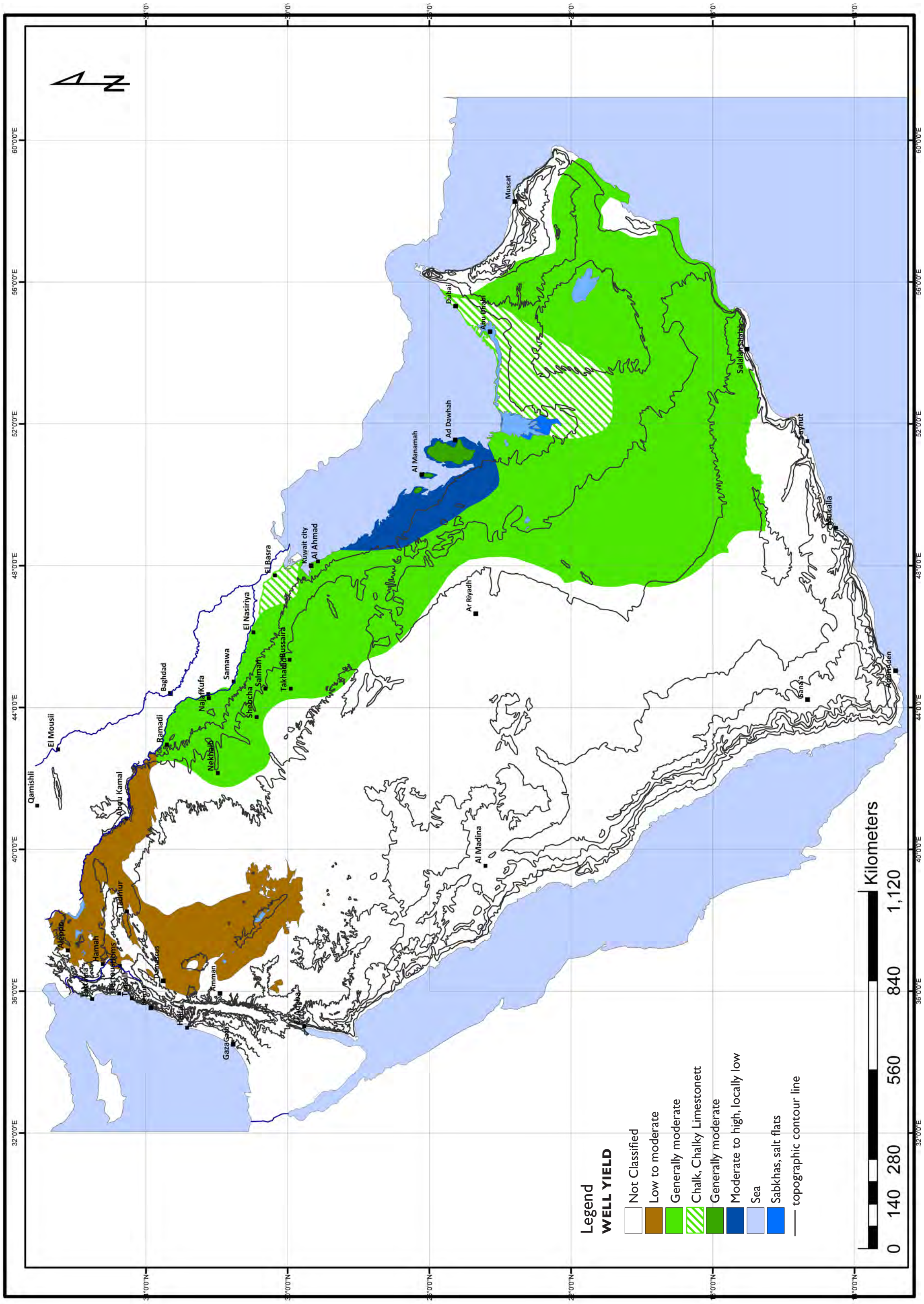
The Dammam aquifer is composed mainly of limestone, dolomite, chalk and marl limestone belonging to the lower and middle Eocene geological Era (UN-ESCWA, 1999). The aquifer is bounded at the bottom by the Rus formation, which overlays the Umm Er-Radhoma formation, and is bounded at the top by the Neogene formation. The main groundwater production units are the Khobar and Alat members. The Dammam aquifer is being tapped by a large number of wells mainly in Saudi Arabia, Bahrain, Kuwait and Qatar for irrigation purposes and, to a limited extent, for domestic supply in Jordan, Syria, southern Iraq and Bahrain, whenever the water quality permits utilization. The Alat and Khobar aquifers have relatively high productivities in GCC countries (UN-ESCWA, 1999). The aquifer is being mined at abstraction rates far exceeding the recharge rates. Figure 67 illustrates the aquifer's range of productivity in each country, while Table 13 shows the countries sharing the Dammam aquifer and local names.

Table 13: Dammam aquifer characteristic in countries of the Mashriq sub-region
mcm= million cubic metres

Country	Thickness (m)	Member name	Member name
Syria	40-100		35
Jordan	50-100	Shallala-Umm Rijan	12
Iraq	30-80	Ratga-Jaddala	50
Saudi Arabia	50-260	Alat - Khobar	450
Kuwait	120-350	Alat-Khobar	120
Bahrain	15-45	Alat(B)-Khobar(A)	220
Qatar	10-50	Abarauq-Simsima	400
UAE	60-500	Hafit-Saraya	
Oman	150	Andur-Qara	
Yemen	50-200	Hbshiya	

Source: UN-ESCWA, 1999

Figure 67: Aquifer productivity classified as low, moderate and high in each country (GCC)



■ Source: UN-ESCWA/BGR, 2001

Wadi Hanifah pools, Riyadh, Saudi Arabia

The aquifers are mostly under confined conditions due to their depth below the surface and the presence of confining shale layers. They become phreatic near discharge areas in the southern part of Shat Al Arab, coastal zones of Kuwait, Bahrain, Saudi Arabia and Qatar and at the Liwa area of Abu Dhabi. The main hydrologic parameters of the aquifer exhibit large variation in depth and area which can be attributed to past tectonic structural activities and deposition environments. The magnitude of transmissivity (T), or how much water can be transmitted horizontally through the full section of the aquifer, are classified as moderate for aquifers in Syria and Jordan (with a limited thickness) due to the nature of fracturing and karstification (0.03-450 m^2/d), while in southern Iraq and GCC countries, the transmissivity ranges from 2 to 200 m^2/d. Storativity, or the storage capacity of the aquifer and the volume of water that can be released from the aquifer storage per unit decline in hydraulic head, is in the range of 0.1x10-2-2x10-9, reflecting the confined nature of the aquifer.

Recharge to the aquifer is very limited and is mainly from rainfall infiltration at the outcrop areas, which is limited compared to the size of the aquifer. The average thickness of the aquifer ranges from 50 to 250 m. Generally, the depth increases in a southerly direction towards the coastal zone of the ROPME Sea Area. The volume of groundwater reserve in the Dammam aquifer is estimated at 4 500 mcm.

Climate

The prevailing climatic conditions range from sub humid in the northwest to arid in the AP. Average annual rainfall varies between 50 and 110 mm. Random and localized storms are a common feature throughout the region. In the central areas, summer temperatures can reach up to 50ºC. The predominant characteristic of rainfall patterns in AP is the temporal and spatial variability. The mean annual precipitation is about 110 mm in Kuwait, 74 mm in Bahrain and 75 mm in Qatar.

Exploitation

Prior to the advent of well abstraction, the aquifer's main discharge was in the form of natural land and offshore springs and inland and coastal sabkhas located mainly in Eastern Saudi Arabia and Bahrain. The total discharge rate of these was estimated at approximately 855 mm^3/y for sabkhas (Bakiewicz and others, 1982) and about 300 mm^3/y for springs (GDC, 1980; Bakiewicz and others, 1982). These figures do not distinguish between the Umm Er Radhuma and the Dammam aquifer discharges, and represent the pre-development conditions of the Palaeogene aquifer system as a whole.

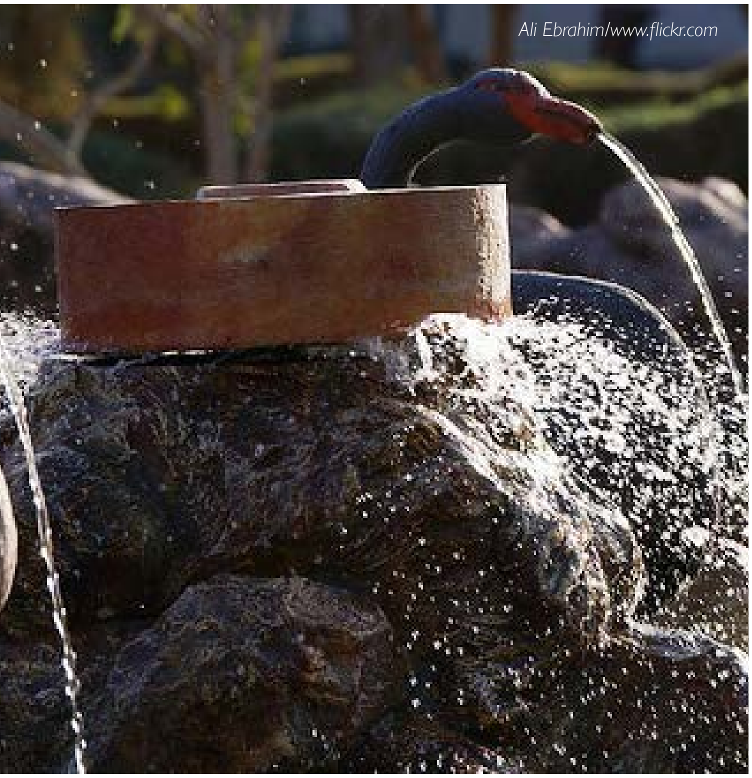
Mechanized well drilling and abstraction was introduced to the region in the late 1920s along with oil exploration activities. Oil discovery in the1930s and particularly the sudden increase in riparian countries' oil revenues in the early 1970s, has resulted in rapid population growth, urban development and industrial and agricultural expansion, and was accompanied by a dramatic increase in water demand and consumption rates. These demands have been met mainly by groundwater abstraction in place of natural springs, which, as a result, have experienced a significant reduction in their discharge.

While the Dammam aquifer exists under confined conditions for most of the area, hydraulic connections exist between the lower Rus-Umm Er Radhumma aquifer and the overlying Neogene aquifer, which makes it difficult to accurately estimate Dammam aquifer abstraction, in addition to the practice in many countries of dual and multiple completions of wells. Nevertheless, pumping records indicate a continuous increase in extraction rates since 1940 and a marked upward trend after 1965. The Dammam aquifer is used extensively in coastal cities of the Eastern Province of Saudi Arabia for domestic, irrigation and industrial purposes. Available records indicate that the abstraction rate from the aquifer was about 171 mm^3/y in 1967, and increased to about 430 mm3/y in 1990 (Abderrahman and others, 1995). In the north-eastern region of the Eastern Province, which is characterised by significant agricultural activities, total Dammam aquifer abstraction was reported at about 540 mm^3/y in the early 1990s (Hasan, 1995). A large proportion (80 per cent) of the water abstracted is used for agricultural purposes, while the rest is used for domestic, livestock and industrial purposes. Currently, groundwater abstraction from the Dammam aquifer in the coastal zone exceeds 450 mm^3/y.

In Bahrain, groundwater abstraction has been gradually increasing since the early 1930s, peaking at 250 mm^3 in 1998 (Al-Zubari and Lori, 2006). Since then, abstraction has dropped, reaching about 130 mm^3/y in 2009, as a result of water

Water fountain, Bahrain

quality deterioration and government intervention measures (introduction of Treated Sewage Effluent (TSE) use in agriculture, well metering, improvement of irrigation methods). Extracted water is used mainly for agricultural purposes, with small amounts used for blending with desalinated water for domestic supply, and industrial purposes.



Ali Ebrahim/www.flickr.com

Water use Al-Areen Zoo, Bahrain

In Kuwait, groundwater abstraction, for public and private sector, is mainly from the Dammam aquifer. However, many government well fields are developed as dual completion in the Dammam and the upper Kuwait group aquifer. Total groundwater abstraction in Kuwait was about 35 mm^3 in the early 1970s, rising to 71 mm^3 in the early 1990s (Al-Murad, 1994), reaching 460 mm^3 in 2005 (El-Awar, 2005). Groundwater extraction is used for both domestic non-drinking purposes and agricultural purposes.

Water quality

Water salinity, or Total Dissolved Salts (TDS), in the aquifer ranges between 2 000 and 6 000 ppm, due to mixing with groundwater from other aquifer systems with much higher salinity in some locations or due to seawater intrusion along the coastal zones of the ROPME Sea Area. Average salinity (in terms of TDS) for both Alat and Khobar aquifers ranges between 1 000 ppm (west of the outcrop areas of the eastern part of Saudi Arabia) to more than 100 000 ppm (at the Gulf). Both the Alat and Khobar aquifers show similar water quality characteristics with hydrochemical facies dominated by sodium and chloride ions, while Alat is dominated by calcium ions (UN-ESCWA, 1999).

Intensive exploitation of the Dammam aquifer mainly for irrigation has caused significant declines of its potentiometric levels and, subsequently, considerable increases in the salinity of extracted groundwater in all the countries tapping the Dammam aquifer (Al-Zubari, 2001; Sayid and Al-Ruwaih, 1995; Al-Mahmoud, 1987).

Management of the resource (Legislation, water sharing plans, institutions)

Development of the Dammam aquifer units (Alat and Khober zones) varies among countries of the region due to many factors. These include aquifer productivity in term of quantity, quality, and depth from the surface as well as areal extent. However, these developments are being made in uncoordinated manner among the sharing countries. Conventions and agreements on sharing and management of the Dammam aquifer do not exist yet. The current uncoordinated development is in fact contributing to the decline in the piezometric head, increased level of salinity, mixing of water among aquifers and depletion of aquifer reserves. These negative impacts are likely to be exacerbated by the impacts of climate change due to the

Irrigation fields, Kuwait, July 2002

expected changes in rainfall intensity and frequency, increased sectoral demands leading to more groundwater abstraction and sea level rise leading to more saline water intrusion, thus increasing the vulnerability of this shared aquifer, and complicating national water resources management and planning in the countries.

5.2.3. Vulnerability assessment

The vulnerability of the shared Dammam aquifer was evaluated using the same data used in the analysis of AP countries since it is not available at the aquifer level for all countries. Data was available from Kuwait, Bahrain, Qatar and UAE. Since the Dammam aquifer is not considered a productive aquifer in Syria and Jordan, compared to its status in AP, these countries were not included in the case study. The availability of detailed data on recharge rates in each country and the rates of water being extracted from the Dammam aquifer to satisfy water demands would have been useful for this research. Information was available for the area covered by the Dammam aquifer in eastern Saudi Arabia regarding pumping volume, recharge rates, desalinated water, wastewater, population and water demand. The 1985-2005 trends for the variation of the main parameters; renewable water stress, water development pressure, ecological health and management capacity, were estimated using the governing equations discussed in chapter 3 to provide an approximate VI.

Hot Spring Water Rustaq, Oman

Resources stress (RS)

The water stress indicator is influenced by renewable water resources availability, including the consumption pattern of the growing population (RSs), and the water variation parameter resulting from long term rainfall variability (RSv).

Water resources stress (RSs)

The availability of renewable water resources (surface and groundwater), supplemented by desalination, available over time in the past and the future will decide to what extent it can meet past and future water demands of the contemporary population.

Water stress (RSs) values for the year 1985 range from 0.57 in Oman to 0.89 in Kuwait. A small increase in water stress was observed in 1995. The values for 2005 range from 0.73 in Oman to 0.87 in Kuwait (Table 14). Water stress is still high; however, the increase in desalinated water production which represents a significant amount of available freshwater in most countries (with the exception of Saudi Arabia and Qatar), reduced water deficits (Table 14 and Figure 68).

Water stress is influenced by the amount of desalinated water, as the other sources from run-off during flooding events and recharge are very small by comparison.

Table 14: Water stress variation, 1985-2005

RSs			
Country	1985	1995	2005
Bahrain	0.83	0.86	0.82
Kuwait	0.89	0.81	0.87
Oman	0.57	0.71	0.73
Qatar	0.79	0.74	0.75
Saudi Arabia	0.87	0.86	0.85
UAE	0.81	0.80	0.84

Figure 68: Degree of water stress for the Arabian Peninsula sub-region

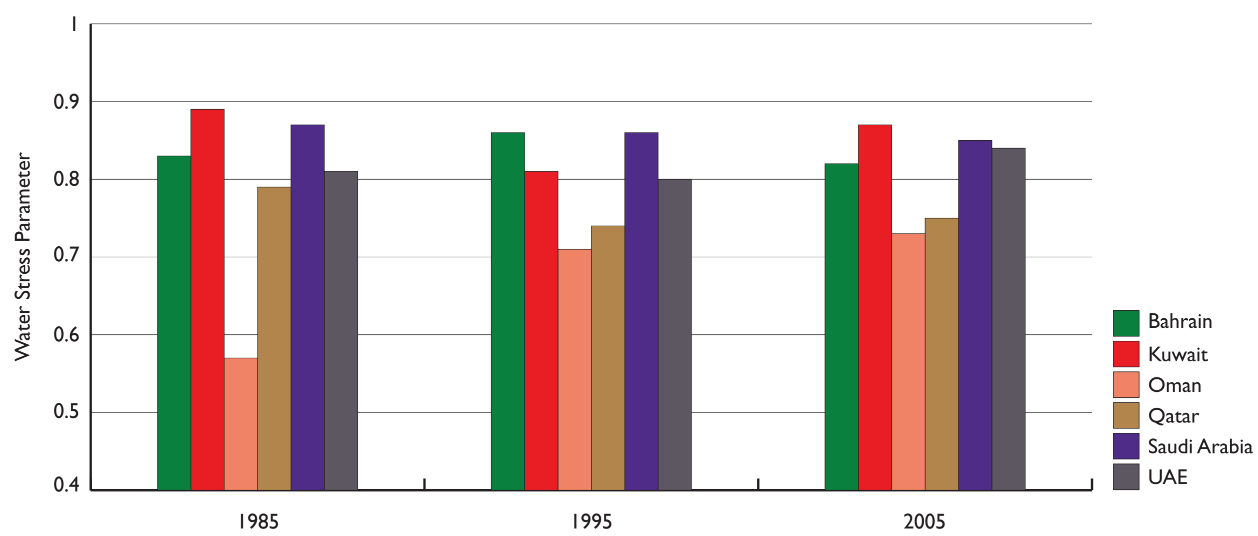


Table 15: Water availability variation (RSv) due to rainfall variability

Water Variation Parameter RSv					
Country	CV	Mean	Sandard deviation	**RSv**	equation
Bahrain	0.69	79.3	54.5	1.00	RSv=CV/0.3
Kuwait	0.49	112.7	55.13	1.00	RSv=CV/0.3
Oman	0.74	105.7	78.5	1.00	RSv=CV/0.3
Qatar	0.85	79.8	67.9	1.00	RSv=CV/0.3
Saudi Arabia	0.75	75.5	56.75	1.00	RSv=CV/0.3
UAE	0.91	92.05	83.44	1.00	RSv=CV/0.3

Water Variation (RSv)

Water resource variability is estimated by the CV of a long rainfall record for a period (20-50 years). Estimated water variation is very extreme in the region as a result of the random nature of rainfall (Table 15).

Water development pressures (DP)

The water development parameter can be estimated using two variables: water exploitation (DPs) and safe drinking water accessibility (DPd).

Water exploitation (DPs)

The water exploitation variable is the ratio of total water demand (domestic, industrial and irrigation) (WRs) for a given year, to the available amount of renewable water sources (WR). Water exploitation (DPs) analysis indicates high values for the period 1985-2005 as water demand far exceeds the available water. All countries seem to face water shortages in the irrigation sector. Domestic water demand is being met from desalinated sources and also through groundwater. Water shortage is being met through the mining of non-renewable groundwater resources from many aquifers, including the Dammam. The values reported in Table 16 and Figure 69 reflect the high degree of water exploitation for all countries of the GCC sub-region.

Safe drinking water inaccessibility (DPd)

Supply services coverage depends on water resources development activities to provide the basic water needs of the different segments of society. Drinking water supply inaccessibility varies among the countries, ranging from 0.00 to 0.43 for the year 1985, as shown in Table 17 and Figure 70. The analysis indicates that water supply services coverage is very high for all countries with the exception of Saudi Arabia and Oman. These two countries, because of the size of their area and population, need additional financial resources to improve coverage especially in rural areas. The 1995 and 2005 figures indicate less coverage in Oman for the year 2005, while the situation in Saudi Arabia indicates improved coverage for the period 1995-2005.

Table 16: Water exploitation variation (DPs)

DPs			
Country	1985	1995	2005
Bahrain	1.00	1.00	1.00
Kuwait	1.00	0.92	1.00
Oman	1.00	1.00	1.00
Qatar	1.00	1.00	1.00
Saudi Arabia	1.00	1.00	0.98
UAE	1.00	1.00	1.00

Figure 69: Water exploitation variation

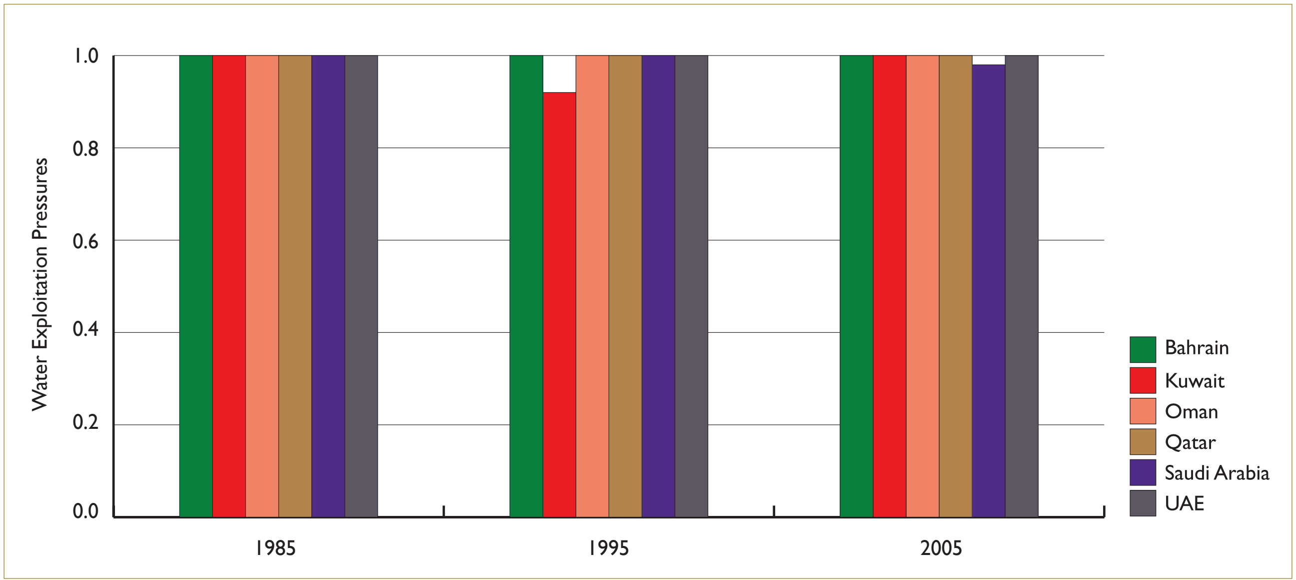


Figure 70: Drinking water supply inaccessibility

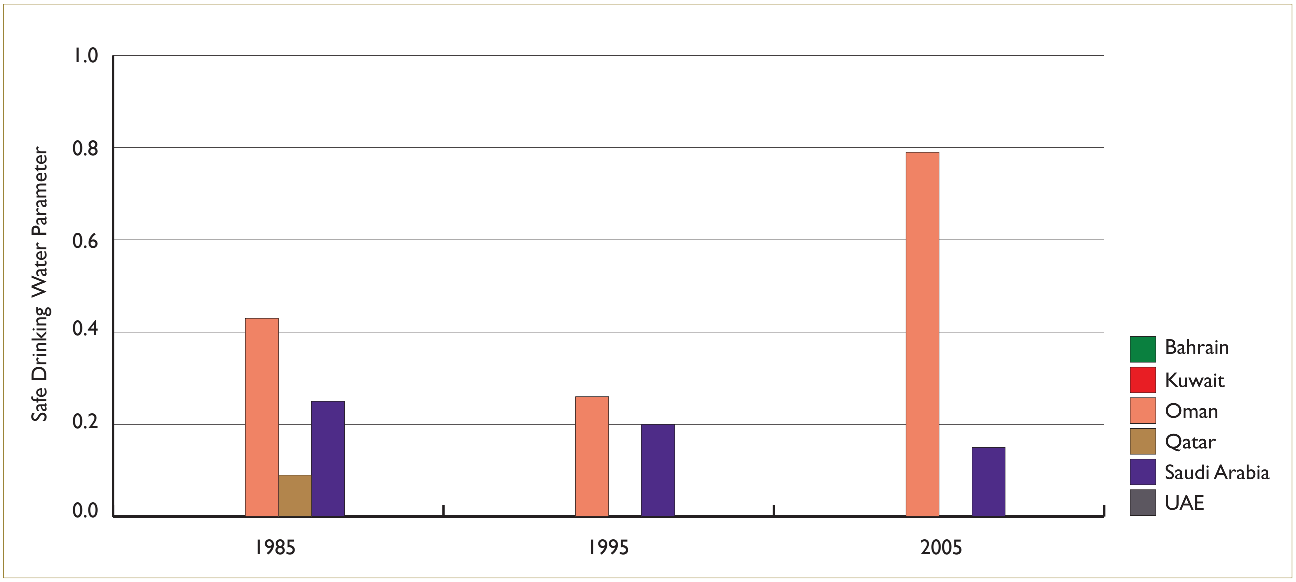


Table 17: Drinking water supply inaccessibility

DPd			
Country	1985	1995	2005
Bahrain	0.00	0.00	0.00
Kuwait	0.00	0.00	0.00
Oman	0.43	0.26	0.79
Qatar	0.09	0.00	0.00
Saudi Arabia	0.25	0.20	0.15
UAE	0.00	0.00	0.00

Shaumari Nature Reserve, Jordan

Ecological Health (EH) Parameter:

This parameter evaluates the degree of water pollution (Ehp) and the deterioration (EHe) that may be experienced by the ecosystem.

Water pollution (EHp):

Water resources pollution is estimated by the ratio of total untreated wastewater (WW) discharge in water receiving systems to the total available renewable water resources (WR). Water pollution analysis indicates high pollution in 1985, as the estimated values ranged from 1 to 0.55, with very high pollution levels in Kuwait, Qatar and UAE, and relatively less pollution in Saudi Arabia and Oman. The pollution level has decreased in Saudi Arabia, Qatar, Kuwait and UAE for the period 1985-2005, but increased in Bahrain and Oman. In the year 2005, pollution from wastewater in all countries decreased with the exception of Oman and Bahrain, as shown in Table 18 and Figure 71. Values in 2005 ranged between 0.05 in Kuwait, 0.29 in UAE and 0.54 in Saudi Arabia. Most countries, because of the availability of adequate financial resources, were able to invest in waste treatment facilities by treating their wastes to tertiary or advanced treatment levels.

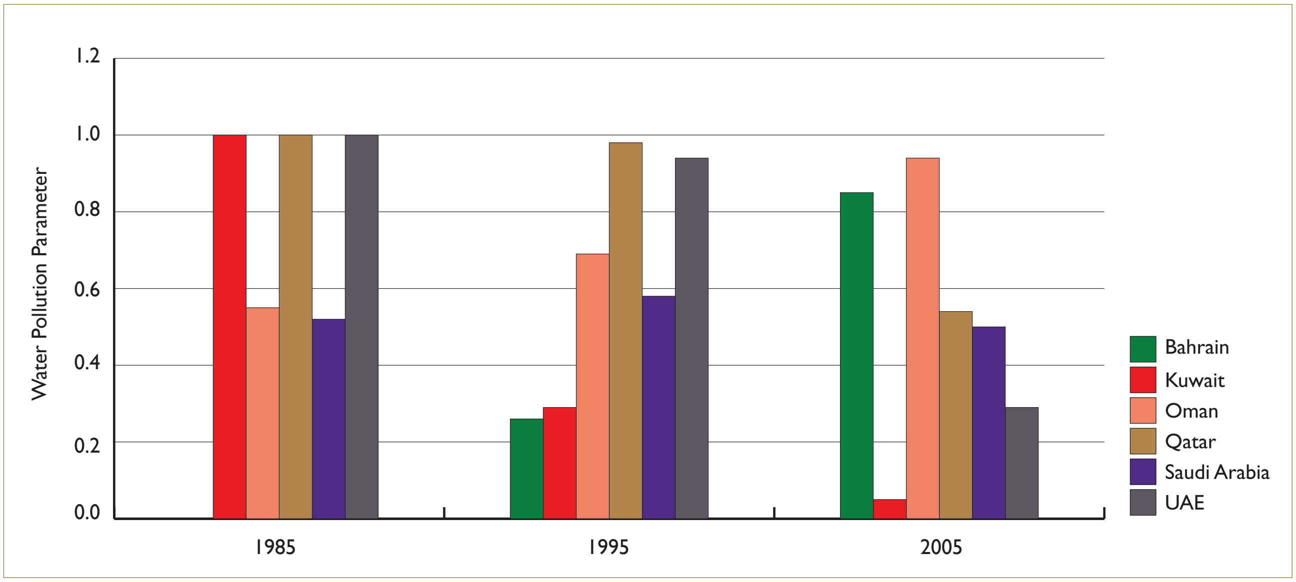
Ecosystem deterioration (EHe)

The ecosystem deterioration parameter is estimated as the ratio of land size without vegetation cover (Ad) to the total size of the country (A) assessed.

Table 18: Water pollution parameter

Ehp			
Country	1985	1995	2005
Bahrain	0.00	0.26	0.85
Kuwait	1.00	0.29	0.05
Oman	0.55	0.69	0.94
Qatar	1.00	0.98	0.54
Saudi Arabia	0.52	0.58	0.50
UAE	1.00	0.94	0.29

Figure 71: Water pollution variation



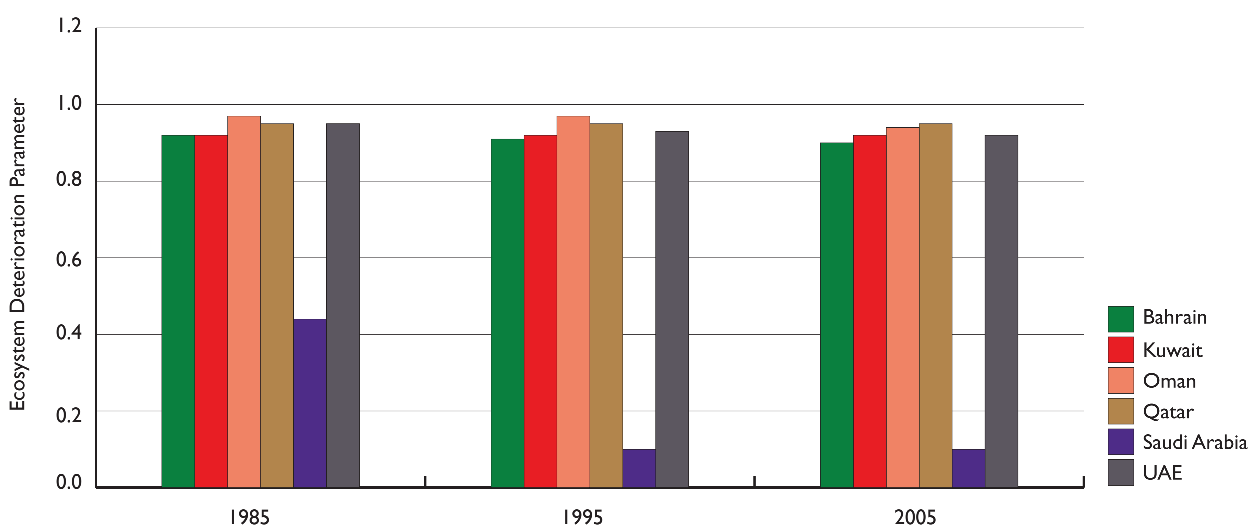
Ecological deterioration values were high for all countries, being in the range of 0.92-0.97, with the exception of Saudi Arabia (a range of 0.44 in 1985 to 0.10 in 2005) as shown in Table 19 and Figure 72. All countries sharing the Dammam aquifer suffer from extreme desertification and the absence of adequate vegetation cover. The low values in Saudi Arabia could be misleading as only the eastern part of Saudi Arabia is covered by the Dammam aquifer, compared to other countries sharing the aquifer and in which the aquifer covers almost all the surface area. Values for Oman for the period

Cisterns of Tawila, Yemen

Table 19: Ecological parameter

Ehe			
Country	1985	1995	2005
Bahrain	0.92	0.91	0.90
Kuwait	0.92	0.92	0.92
Oman	0.97	0.97	0.94
Qatar	0.95	0.95	0.95
Saudi Arabia	0.44	0.10	0.10
UAE	0.95	0.93	0.92

Figure 72: Ecosystem deterioration variation



1985-2005 may also be misleading as most of its southern areas have adequate vegetation cover, due to agricultural activities and rainfall.

Management capacity (MC)

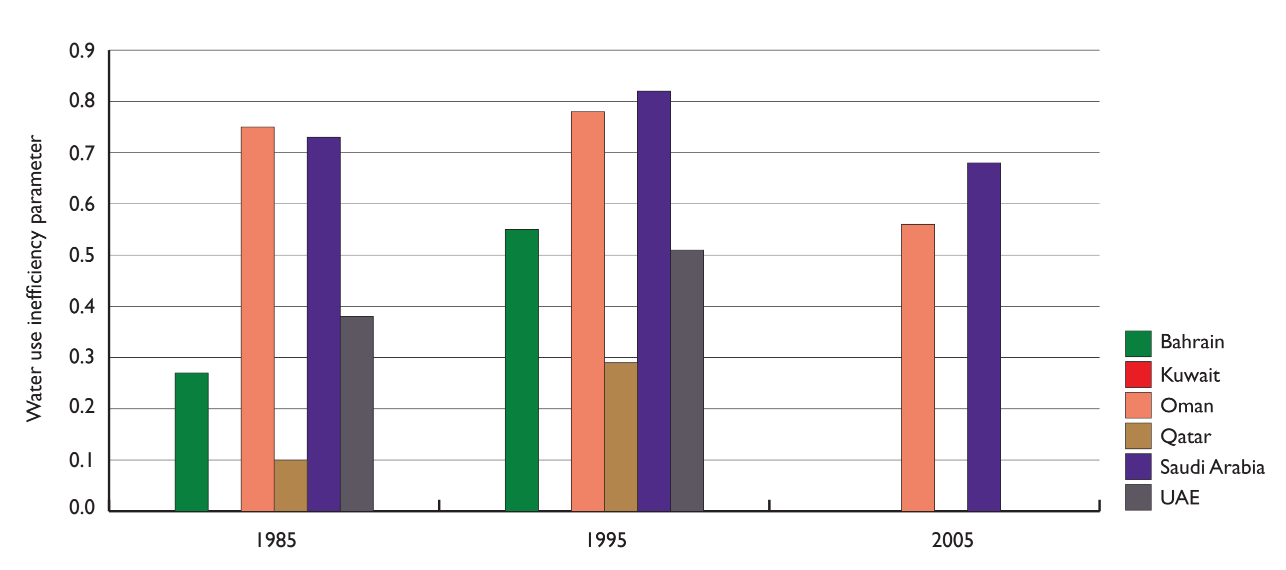
This parameter is represented by three variables: water use inefficiency (MCe), improved sanitation inaccessibility (MCs) and conflict management capacity (MCg). Water use inefficiency is very high in Oman and Saudi Arabia, in the range of 0.73-0.75 in 1985. Low values in remaining countries, ranging between 0.10 and 0.38, in 1985 indicate higher water use efficiency. Efficiency improved over the period 1995-2005 for all countries as shown in Table 20 and Figure 73.

The sanitation inaccessibility values reported in Table 21 and Figure 74 are very low (close to zero for most countries). Relatively high values were calculated for Oman and Saudi Arabia in 1985

Table 20: Water use inefficiency parameter

Mce			
Country	1985	1995	2005
Bahrain	0.27	0.55	0.00
Kuwait	0.00	0.00	0.00
Oman	0.75	0.78	0.56
Qatar	0.10	0.29	0.00
Saudi Arabia	0.73	0.82	0.68
UAE	0.38	0.51	0.00

Figure 73: Water use inefficiency parameter

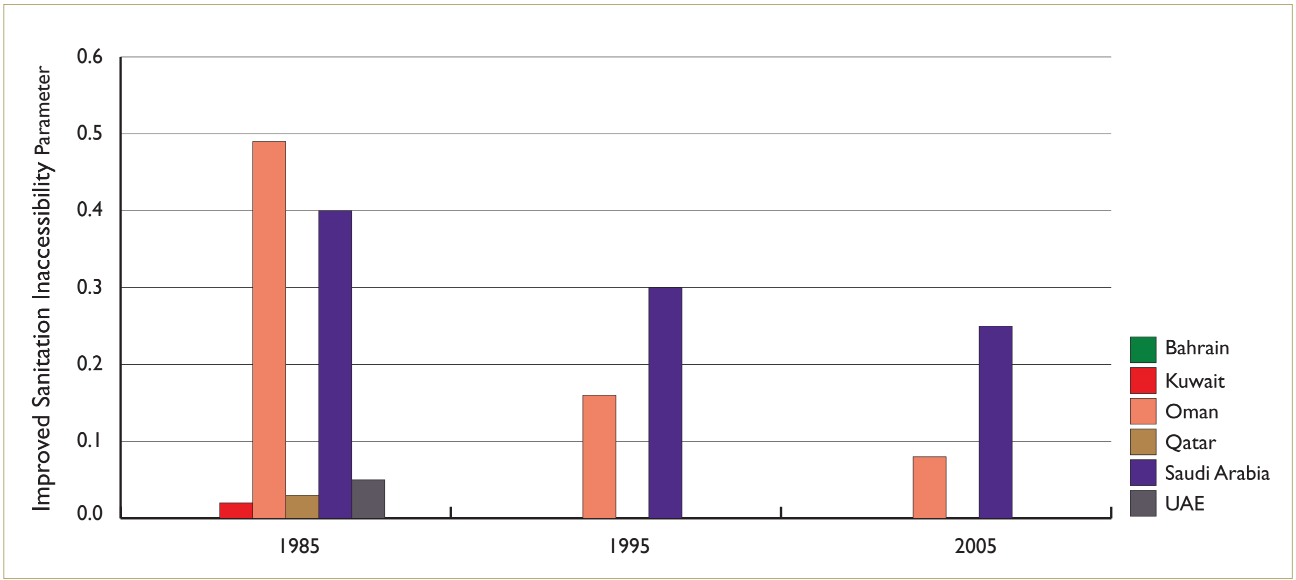


(in the range of 0.4-0.49); however, the values decreased during the period 1995-2005. Countries of the AP sub-region, because of their oil income, have adequate financial resources to invest in waste treatment facilities and the associated collection network systems. The analysis indicated very low values for most countries, such as Bahrain, Kuwait and Qatar, as most of their areas are considered urban, where coverage is usually more efficient. Sanitation services coverage is adequate in most countries, with the exception of Saudi Arabia and Oman, which have lower coverage in rural areas. Even though high sanitation coverage exists, pollution by wastewater occurs since some wastewater treatment plants are operating in excess of their capacities. Large volumes are being disposed of into the sea and wadi channels. The amount of treated wastewater reuse is very small compared to available volumes.

Table 21: Sanitation inaccessibility parameter

MCs			
Country	1985	1995	2005
Bahrain	0.00	0.00	0.00
Kuwait	0.02	0.00	0.00
Oman	0.49	0.16	0.08
Qatar	0.03	0.00	0.00
Saudi Arabia	0.40	0.30	0.25
UAE	0.05	0.00	0.00

Figure 74: Sanitation Inaccessibility variation



Euphrates river, Deir ez-Zor, Syria

Conflict management capacity values are very high for Bahrain, Kuwait, and Saudi Arabia estimated at 0.95; while lower values are estimated for Qatar and Oman, ranging from 0.00 to 0.48 for the period 1985-2005 as shown in Table 22. These lower values stem from the lack of coordination among different Ministries and departments within the same Ministry in these countries.

Table 22: Management conflict parameter

Country	MCg
Bahrain	0.95
Kuwait	0.95
Oman	0.48
Qatar	0.00
Saudi Arabia	0.95
UAE	0.48

Results

The calculation of the four main parameters for each country of the AP sub-region for the periods 1985-2005 is shown in Table 23. The parameter values were used to estimate the VI for each country.

Table 23: Calculation of the four main parameters used for estimating the Vulnerability Index for each country (a. Bahrain)

Bahrain 1985									
Category	Resource Stress		Development Pressure		Echological Health		Management Capacity		
Parameter	RSs	RSv	DPs	DPd	Ehp	EHe	Mce	MCs	MCg
Calculated	0.8299	1.0000	1.0000	0.0000	0.0000	0.9155	0.2735	0.0000	0.9500
Weight in Category	0.50	0.50	0.50	0.50	0.50	0.50	0.33	0.33	0.33
Weighted	0.4150	0.5000	0.5000	0.0000	0.0000	0.4577	0.0903	0.0000	0.3135
Component Total	0.9150		0.5000		0.4577		0.4038		
Weight for Category	0.25		0.25		0.25		0.25		
Weighted	0.2287		0.1250		0.1144		0.1009		
Overall Score	0.5691								
Bahrain 1995									
Category	Resource Stress		Development Pressure		Echological Health		Management Capacity		
Parameter	RSs	RSv	DPs	DPd	Ehp	EHe	Mce	MCs	MCg
Calculated	0.8578	1.0000	1.0000	0.0000	0.2571	0.9085	0.5508	0.0000	0.9500
Weight in Category	0.50	0.50	0.50	0.50	0.50	0.50	0.33	0.33	0.33
Weighted	0.4289	0.5000	0.5000	0.0000	0.1286	0.4542	0.1818	0.0000	0.3135
Component Total	0.9289		0.5000		0.5828		0.4953		
Weight for Category	0.25		0.25		0.25		0.25		
Weighted	0.2322		0.1250		0.1457		0.1238		
Overall Score	0.6267								
Bahrain 2005									
Category	Resource Stress		Development Pressure		Echological Health		Management Capacity		
Parameter	RSs	RSv	DPs	DPd	Ehp	EHe	Mce	MCs	MCg
Calculated	0.8150	1.0000	1.0000	0.0000	0.8537	0.9014	0.0000	0.0000	0.8500
Weight in Category	0.50	0.50	0.50	0.50	0.50	0.50	0.33	0.33	0.33
Weighted	0.4075	0.5000	0.5000	0.0000	0.4268	0.4507	0.0000	0.0000	0.2805
Component Total	0.9075		0.5000		0.8775		0.2805		
Weight for Category	0.25		0.25		0.25		0.25		
Weighted	0.2269		0.1250		0.2194		0.0701		
Overall Score	0.6414								

Kuwait 1985									
Category	Resource Stress		Development Pressure		Echological Health		Management Capacity		
Parameter	RSs	RSv	DPs	DPd	Ehp	EHe	Mce	MCs	MCg
Calculated	0.8929	1.0000	1.0000	0.0000	1.0000	0.9220	0.0000	0.0200	0.9500
Weight in Category	0.50	0.50	0.50	0.50	0.50	0.50	0.33	0.33	0.33
Weighted	0.4465	0.5000	0.5000	0.0000	0.5000	0.4610	0.0000	0.0066	0.3135
Component Total	0.9465		0.5000		0.9610		0.3201		
Weight for Category	0.25		0.25		0.25		0.25		
Weighted	0.2366		0.1250		0.2402		0.0800		
Overall Score	0.6819								

Kuwait 1995									
Category	Resource Stress		Development Pressure		Echological Health		Management Capacity		
Parameter	RSs	RSv	DPs	DPd	Ehp	EHe	Mce	MCs	MCg
Calculated	0.8110	1.0000	0.9215	0.0000	0.2882	0.9203	0.0000	0.0000	0.9500
Weight in Category	0.50	0.50	0.50	0.50	0.50	0.50	0.33	0.33	0.33
Weighted	0.4055	0.5000	0.4607	0.0000	0.1441	0.4602	0.0000	0.0000	0.3135
Component Total	0.9055		0.4607		0.6043		0.3135		
Weight for Category	0.2500		0.2500		0.2500		0.2500		
Weighted	0.2264		0.1152		0.1511		0.0784		
Overall Score	0.5710								

Kuwait 2005									
Category	Resource Stress		Development Pressure		Echological Health		Management Capacity		
Parameter	RSs	RSv	DPs	DPd	Ehp	EHe	Mce	MCs	MCg
Calculated	0.8661	1.0000	1.0000	0.0000	0.0472	0.9158	0.0000	0.0000	0.8500
Weight in Category	0.50	0.50	0.50	0.50	0.50	0.50	0.33	0.33	0.33
Weighted	0.4330	0.5000	0.5000	0.0000	0.0236	0.4579	0.0000	0.0000	0.2805
Component Total	0.9330		0.5000		0.4815		0.2805		
Weight for Category	0.25		0.25		0.25		0.25		
Weighted	0.2333		0.1250		0.1204		0.0701		
Overall Score	0.5488								

Oman 1985									
Category	Resource Stress		Development Pressure		Echological Health		Management Capacity		
Parameter	RSs	RSv	DPs	DPd	Ehp	EHe	Mce	MCs	MCg
Calculated	0.5721	1.0000	1.0000	0.4300	0.5472	0.9671	0.7454	0.4900	0.4800
Weight in Category	0.50	0.50	0.50	0.50	0.50	0.50	0.33	0.33	0.33
Weighted	0.2861	0.5000	0.5000	0.2150	0.2736	0.4835	0.2460	0.1617	0.1584
Component Total	0.7861		0.7150		0.7571		0.5661		
Weight for Category	0.25		0.25		0.25		0.25		
Weighted	0.1965		0.1788		0.1893		0.1415		
Overall Score	0.7061								

Oman 1995									
Category	Resource Stress		Development Pressure		Echological Health		Management Capacity		
Parameter	RSs	RSv	DPs	DPd	Ehp	EHe	Mce	MCs	MCg
Calculated	0.7084	1.0000	1.0000	0.2600	0.6932	0.9670	0.7823	0.1600	0.4800
Weight in Category	0.50	0.50	0.50	0.50	0.50	0.50	0.33	0.33	0.33
Weighted	0.3542	0.5000	0.5000	0.1300	0.3466	0.4835	0.2581	0.0528	0.1584
Component Total	0.8542		0.6300		0.8301		0.4693		
Weight for Category	0.25		0.25		0.25		0.25		
Weighted	0.2136		0.1575		0.2075		0.1173		
Overall Score	0.6959								

Oman 2005									
Category	Resource Stress		Development Pressure		Echological Health		Management Capacity		
Parameter	RSs	RSv	DPs	DPd	Ehp	EHe	Mce	MCs	MCg
Calculated	0.7324	1.0000	1.0000	0.7900	0.9398	0.9444	0.5558	0.0800	0.4000
Weight in Category	0.50	0.50	0.50	0.50	0.50	0.50	0.33	0.33	0.33
Weighted	0.3662	0.5000	0.5000	0.3950	0.4699	0.4722	0.1834	0.0264	0.1320
Component Total	0.8662		0.8950		0.9421		0.3418		
Weight for Category	0.25		0.25		0.25		0.25		
Weighted	0.2165		0.2238		0.2355		0.0855		
Overall Score	0.7613								

Qatar 1985									
Category	Resource Stress		Development Pressure		Echological Health		Management Capacity		
Parameter	RSs	RSv	DPs	DPd	Ehp	EHe	Mce	MCs	MCg
Calculated	0.7919	1.0000	1.0000	0.0900	1.0000	0.9534	0.1047	0.0300	0.0000
Weight in Category	0.50	0.50	0.50	0.50	0.50	0.50	0.33	0.33	0.33
Weighted	0.3960	0.5000	0.5000	0.0450	0.5000	0.4767	0.0345	0.0099	0.0000
Component Total	0.8960		0.5450		0.9767		0.0444		
Weight for Category	0.25		0.25		0.25		0.25		
Weighted	0.2240		0.1363		0.2442		0.0111		
Overall Score	0.6155								

Qatar 1995									
Category	Resource Stress		Development Pressure		Echological Health		Management Capacity		
Parameter	RSs	RSv	DPs	DPd	Ehp	EHe	Mce	MCs	MCg
Calculated	0.7446	1.0000	1.0000	0.0000	0.9807	0.9518	0.2918	0.0000	0.0000
Weight in Category	0.50	0.50	0.50	0.50	0.50	0.50	0.33	0.33	0.33
Weighted	0.3723	0.5000	0.5000	0.0000	0.4904	0.4759	0.0963	0.0000	0.0000
Component Total	0.8723		0.5000		0.9663		0.0963		
Weight for Category	0.25		0.25		0.25		0.25		
Weighted	0.2181		0.1250		0.2416		0.0241		
Overall Score	0.6087								

Qatar 2005									
Category	Resource Stress		Development Pressure		Echological Health		Management Capacity		
Parameter	RSs	RSv	DPs	DPd	Ehp	EHe	Mce	MCs	MCg
Calculated	0.7531	1.0000	1.0000	0.0000	0.5436	0.9505	0.0000	0.0000	0.8500
Weight in Category	0.50	0.50	0.50	0.50	0.50	0.50	0.33	0.33	0.33
Weighted	0.3765	0.5000	0.5000	0.0000	0.2718	0.4753	0.0000	0.0000	0.2805
Component Total	0.8765		0.5000		0.7470		0.2805		
Weight for Category	0.25		0.25		0.25		0.25		
Weighted	0.2191		0.1250		0.1868		0.0701		
Overall Score	0.6010								

Saudi Arabia 1985									
Category	Resource Stress		Development Pressure		Echological Health		Management Capacity		
Parameter	RSs	RSv	DPs	DPd	Ehp	EHe	Mce	MCs	MCg
Calculated	0.8681	1.0000	1.0000	0.2500	0.5161	0.4355	0.7331	0.4000	0.9500
Weight in Category	0.50	0.50	0.50	0.50	0.50	0.50	0.33	0.33	0.33
Weighted	0.4340	0.5000	0.5000	0.1250	0.2581	0.2177	0.2419	0.1320	0.3135
Component Total	0.9340		0.6250		0.4758		0.6874		
Weight for Category	0.25		0.25		0.25		0.25		
Weighted	0.2335		0.1563		0.1189		0.1719		
Overall Score	0.6806								
Saudi Arabia 1995									
Category	Resource Stress		Development Pressure		Echological Health		Management Capacity		
Parameter	RSs	RSv	DPs	DPd	Ehp	EHe	Mce	MCs	MCg
Calculated	0.8635	1.0000	1.0000	0.2000	0.5781	0.0997	0.8198	0.3000	0.9500
Weight in Category	0.50	0.50	0.50	0.50	0.50	0.50	0.33	0.33	0.33
Weighted	0.4318	0.5000	0.5000	0.1000	0.2891	0.0499	0.2705	0.0990	0.3135
Component Total	0.9318		0.6000		0.3389		0.6830		
Weight for Category	0.25		0.25		0.25		0.25		
Weighted	0.2329		0.1500		0.0847		0.1708		
Overall Score	0.6384								
Saudi Arabia 2005									
Category	Resource Stress		Development Pressure		Echological Health		Management Capacity		
Parameter	RSs	RSv	DPs	DPd	Ehp	EHe	Mce	MCs	MCg
Calculated	0.8472	1.0000	0.9777	0.1500	0.5028	0.1001	0.6757	0.2500	0.6500
Weight in Category	0.50	0.50	0.50	0.50	0.50	0.50	0.33	0.33	0.33
Weighted	0.4236	0.5000	0.4888	0.0750	0.2514	0.0501	0.2230	0.0825	0.2145
Component Total	0.9236		0.5638		0.3014		0.5200		
Weight for Category	0.25		0.25		0.25		0.25		
Weighted	0.2309		0.1410		0.0754		0.1300		
Overall Score	0.5772								

UAE 1985									
Category	Resource Stress		Development Pressure		Echological Health		Management Capacity		
Parameter	RSs	RSv	DPs	DPd	Ehp	EHe	Mce	MCs	MCg
Calculated	0.8108	1.0000	1.0000	0.0000	1.0000	0.9456	0.3802	0.0500	0.4800
Weight in Category	0.50	0.50	0.50	0.50	0.50	0.50	0.33	0.33	0.33
Weighted	0.4054	0.5000	0.5000	0.0000	0.5000	0.4728	0.1255	0.0165	0.1584
Component Total	0.9054		0.5000		0.9728		0.3004		
Weight for Category	0.25		0.25		0.25		0.25		
Weighted	0.2264		0.1250		0.2432		0.0751		
Overall Score	0.6697								

UAE 1995									
Category	Resource Stress		Development Pressure		Echological Health		Management Capacity		
Parameter	RSs	RSv	DPs	DPd	Ehp	EHe	Mce	MCs	MCg
Calculated	0.7985	1.0000	1.0000	0.0000	0.9424	0.9336	0.5067	0.0000	0.4800
Weight in Category	0.50	0.50	0.50	0.50	0.50	0.50	0.33	0.33	0.33
Weighted	0.3993	0.5000	0.5000	0.0000	0.4712	0.4668	0.1672	0.0000	0.1584
Component Total	0.8993		0.5000		0.9380		0.3256		
Weight for Category	0.25		0.25		0.25		0.25		
Weighted	0.2248		0.1250		0.2345		0.0814		
Overall Score	0.6657								

UAE 2005									
Category	Resource Stress		Development Pressure		Echological Health		Management Capacity		
Parameter	RSs	RSv	DPs	DPd	Ehp	EHe	Mce	MCs	MCg
Calculated	0.8368	1.0000	1.0000	0.0000	0.2905	0.9232	0.0000	0.0000	0.4800
Weight in Category	0.50	0.50	0.50	0.50	0.50	0.50	0.33	0.33	0.33
Weighted	0.4184	0.5000	0.5000	0.0000	0.1452	0.4616	0.0000	0.0000	0.1584
Component Total	0.9184		0.5000		0.6068		0.1584		
Weight for Category	0.25		0.25		0.25		0.25		
Weighted	0.2296		0.1250		0.1517		0.0396		
Overall Score	0.5459								

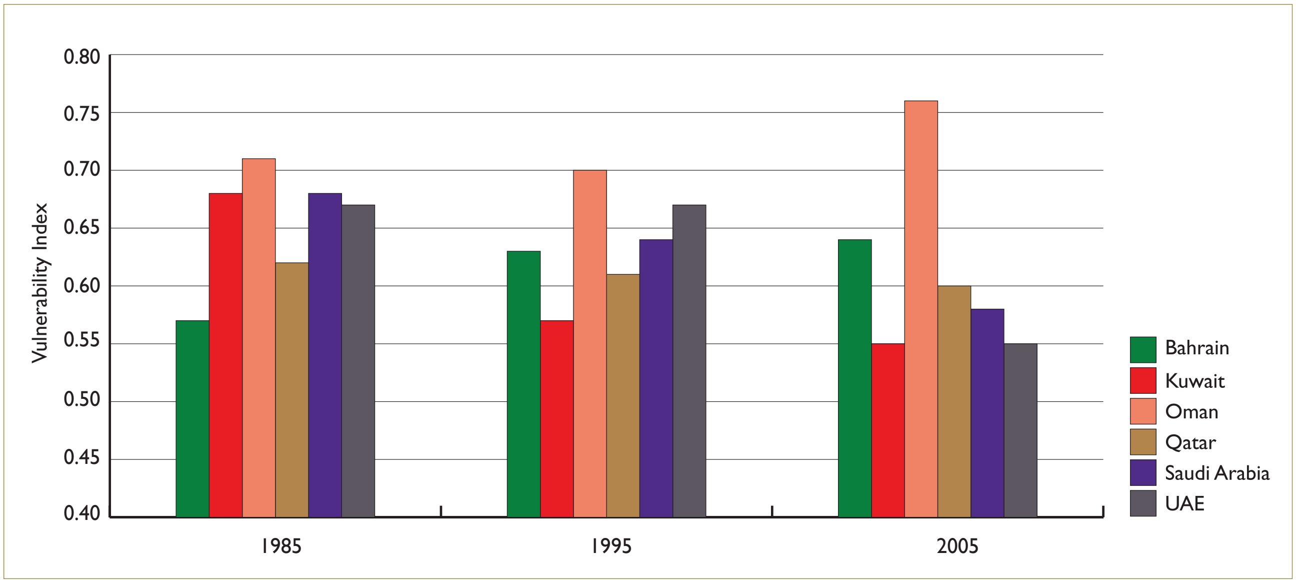
Overall, VI values for the period of the analysis proved relatively high (in the range of 0.53 to 0.77). Bahrain values increased from 0.57 to 0.65, while Kuwait and Qatar showed a decrease from 0.68 and 0.62 to 0.56 and 0.53, respectively, as shown in Table 24 and Figure 75. The same downward trend was observed for Saudi Arabia and UAE. The case of Oman indicates rising vulnerability over time. All countries are not expected to face severe freshwater vulnerability due to the role of

Oman

Table 24: Vulnerability Index variation

VI			
Country	1985	1995	2005
Bahrain	0.57	0.63	0.65
Kuwait	0.68	0.57	0.56
Oman	0.71	0.70	0.77
Qatar	0.62	0.61	0.53
Saudi Arabia	0.68	0.64	0.60
UAE	0.67	0.67	0.55

Figure 75: Variation of Vulnerability Index of Dammam aquifer for all countries



desalination in providing drinking water unaffected by natural supply patterns, with the availability of financial resources. The high water supply and sanitation coverage provided are dominant factors in the VI. Most countries have the needed financial resources to invest in desalination and wastewater treatment facilities for the domestic sector.

Analysis

Current development practices and the absence of coordinated management for the Dammam aquifer are expected to have political, technical, economic and social implications potentially leading to future disputes among countries of the region.

Political aspects

The current unplanned development of the shared Dammam aquifer, where abstraction is taking place in excess of natural recharge rates and without any coordination between the countries concerned, is leading to declining water levels, rising in salinity levels and reduced interflow from Saudi Arabia to Bahrain, Kuwait, UAE and Qatar. This may lead to the migration of saline lenses, mixing of water among layers, reduction of spring discharges in lowland areas and coastal zones and increasing water deficit since the available groundwater will become too saline for drinking water supply.

Decision-makers need to be aware that current practices may result in potential sources of dispute in the near future. At the same time, there has not been much evidence of political will to coordinate groundwater exploitation and establish a coordination management mechanism. Although water professionals in the countries are well aware that mining of the aquifer will result in adverse impacts on water resources sustainability, they have not expressed concerns about future development plans. The issue of shared groundwater resources has been looked at from a national sovereignty point of view and represents a sensitive national issue. Shared water resources have not received adequate public debate, which has contributed to widening the communication and coordination gaps among countries of the region. Adding to these complications is a prevailing view by the public that shared aquifers have extensive reserves and that current development has minimum impact on water resources availability for the sharing countries. The combination of these factors and current development practices are expected to lead to disputes among countries of the region.

Legally binding and implemented agreements can ensure the equitable allocation of water resources and aquifer management based on a limited mining condition. Existing legal frameworks on shared groundwater resources should form the basis for dialogue, debate, cooperation, coordination and development and management of water projects for shared resources, within the framework of the GCC secretariat. The issue of the shared Dammam groundwater resources needs immediate attention in order to avoid potential disputes among countries given the impact of current development on the aquifer in all its countries.

Technical aspects

Current development practices are contributing to the deterioration of water quantity and quality in the Dammam aquifer. In addition, climate change, in terms of reduced recharge and salt water intrusion, will further exacerbate the problems related to the water balance of the aquifer especially for downstream areas of eastern Saudi Arabia, Kuwait, Bahrain and Qatar. Current and future abstraction rates in Saudi Arabia and Kuwait will decrease the piezometric heads, resulting in higher salinity, and mixing of water with water of low quality. The many springs along the coast of Bahrain and Qatar will disappear with the sea wedge advancing inland. Recharge rate, though very limited in quantity, is expected to decrease as a result of large variations of rainfall patterns over the outcropping areas due to climate change. The lack of monitoring and enforcement of drilling licensing procedures has contributed to practices that do not meet the minimum sound technical drilling requirement. The lack of effective monitoring has resulted in the contamination of groundwater due to leakage of water or mixing with water of lower quality. Such practices are diminishing resource availability and disturbing the dynamic balance with a reversal of flow. The lack of information dissemination and exchange among countries has further hindered joint development and management of the aquifer as assessments were made and scenarios were developed at the national level of each sharing countries without taking into consideration their impact on the situation in other riparian countries. Decision-makers in each country must become aware that any mismanagement of aquifer resources will have a negative impact on the aquifer in neighbouring riparian countries. A coordination mechanism should be agreed upon among riparian countries to avoid this impact and to develop a sustainable exploitation policy for the resources of the aquifer.

Social aspects

Every human being has the right to adequate supplies of water for survival including from shared water resources. Depletion of groundwater due to high mining rates has social Implications on future generations who need adequate and safe water supplies for their survival. Societies will flourish in light of equitable and fair allocation of water taking into consideration water quality, while depletion and deterioration of groundwater quality will deprive the population of their human rights. Moreover, governments may not have the adequate financial resources to provide the necessary water supply. Water shortages may therefore lead to urban migration and loss of agriculture. Declining water levels may force low-income farmers to abandon their farms or incur higher costs to deepen their wells.

Economic aspects

Deterioration of shared groundwater in terms of quantity and quality has contributed to increases in water deficits in eastern Saudi Arabia, Bahrain and Kuwait. Lowering of the water table as a result of high abstraction rates has resulted in the abandonment of some wells or deepening of others, requiring higher investments. Deterioration of aquifer water quality has also increased dependency on costly desalinated water. Saudi Arabia, Bahrain, Kuwait and Qatar are increasingly relying on desalinated water from the brackish groundwater of Dammam for domestic purposes, mostly blended with higher salinity water of other overlying saline aquifers. Deterioration of water quality will influence the mixing ratio between desalinated water and pumped saline groundwater, causing a higher cost of water treatment since more desalinated water will be required to compensate for the change in the mixing ratio. Evidence in the region indicates that international lending institutions have been reluctant to provide needed funds for water supply development that depends on shared resources due to the absence of shared agreements.

CHAPTER SIX

FUTURE OF FRESHWATER VULNERABILITY IN WEST ASIA

Tristan Schmurr/www.flickr.com

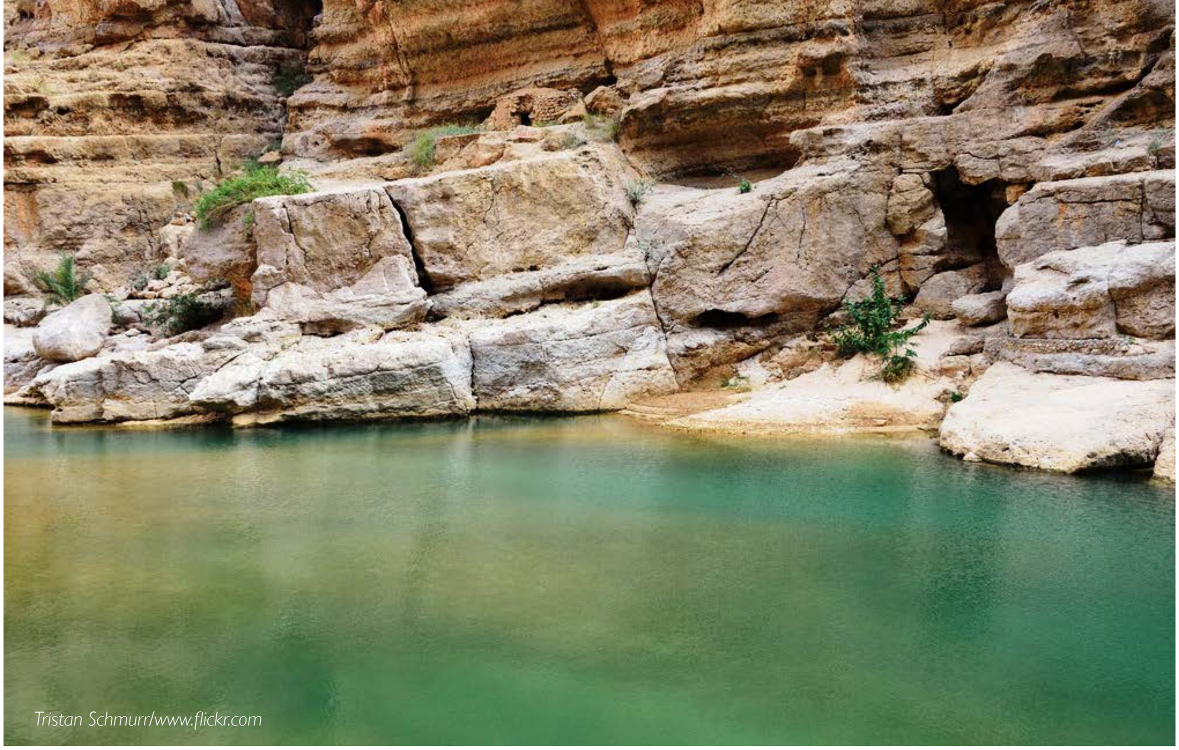
Key Messages

Freshwater vulnerability in West Asia is expected to continue to rise in the future if current trends of population growth and agricultural policies continue, and the issue of shared water resources management is not resolved.

Vulnerability of freshwater resources in the region is expected to become exacerbated by the impacts of climate change, manifested by increasing water scarcity and variability, and increasing water deficits because of the widening gap between availability and demand, and might lead to disputes between riparian countries.

It is imperative that the countries of the region consider the potential impacts of climate change in their water resources planning and management by integrating appropriate adaptation measures into development plans.

The issue of shared water resources among countries outside the region, as well as among countries within the region, is a major driver for the vulnerability of freshwater resources in the region, and the development of a framework for cooperation in the management of shared water resources should be given the highest priority.



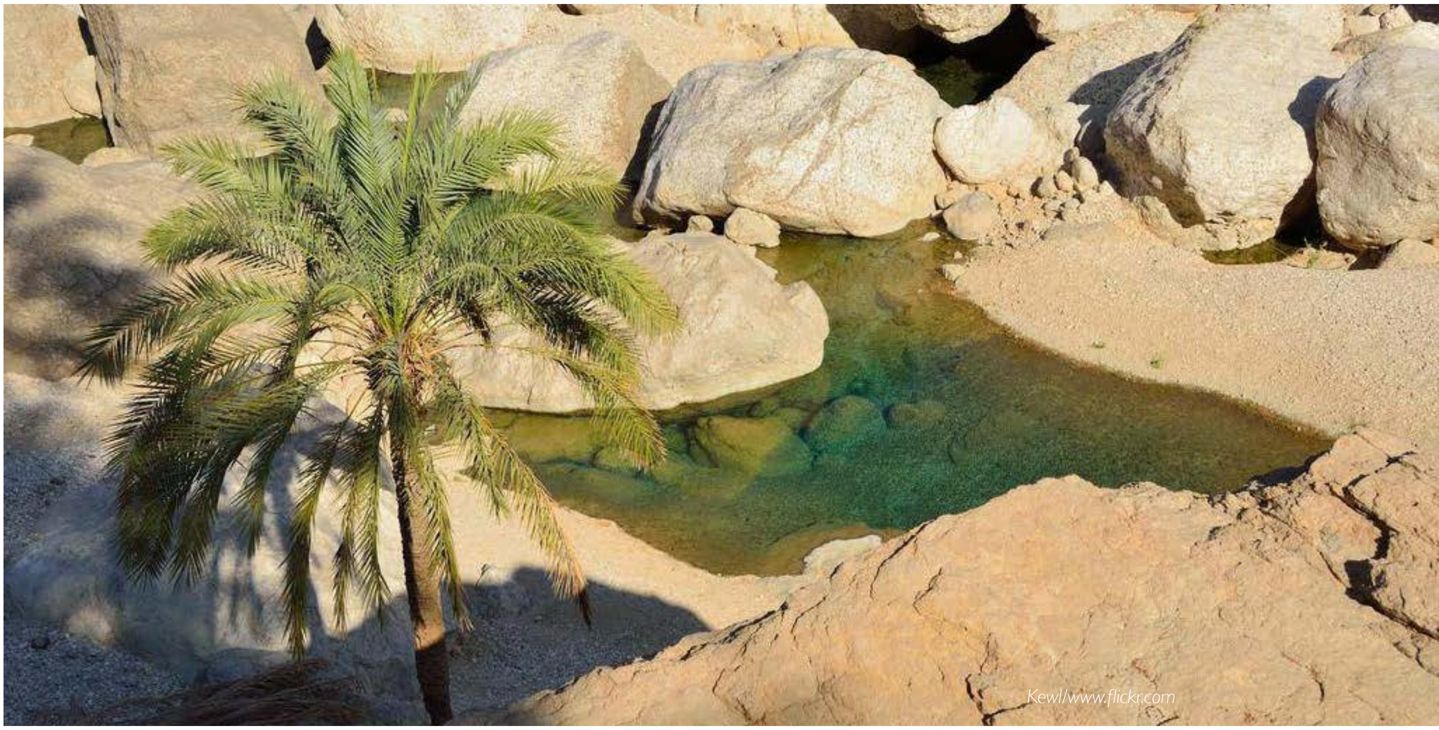
Wadi Shab, Oman

6.1. INTRODUCTION

Inadequate levels of water management, population pressure, unsustainable agricultural policies, and the expected negative impacts of climate change are major challenges to the management of the water sector in WA. Currently, large water deficits in the region's countries are compensated by mining groundwater resources, expansion of desalination capacity and reuse of treated wastewater. Due to the availability of financial and energy resources, the GCC countries are relying largely on the extensive construction of desalination facilities in addition to the exploitation of non-renewable groundwater resources to meet escalating water requirements. In the Mashriq countries and Yemen, groundwater over-exploitation has been the main option to meet increasing water requirements. The continuation of current trends will have significant implications on water availability in the near future and for future generations, in addition to possible deterioration of the fragile desert ecosystem.

Biqawiyya, Jordan

In addition to the many stresses being placed on the available water resources at the national level, the issue of shared surface water and groundwater resources is expected to further complicate water resources management measures. In the Mashriq, shared surface water resources, which contribute more than half the national water balance for some countries, may experience high degrees of uncertainty due to either the lack of effective implementation of some of the existing agreements (between some countries), and/or the complete absence of such agreements. The anticipated impacts of climate change are expected to further complicate the situation in countries sharing surface water with riparian countries outside the region,



Wadi Tiwi, Oman

since 60 per cent of surface water flow originates from outside the region. It is also expected that climate change might cause variations in recharge at the outcrops of shared groundwater sources. Climate change may also affect water resource quality (e.g., from seawater intrusion due to sea level rise), thus increasing water scarcity and decreasing food production. These impacts need to be addressed properly in water resources planning processes at the national and regional levels to ensure the integration of mitigation and adaptation measures in water resources management strategies and programmes.

To explore the possible impacts of these challenges, future vulnerability of freshwater is assessed for the years 2020 and 2040, using the VI methodology previously employed. The future vulnerability indices for each country of the region are estimated for two scenarios. The assumptions and the outcomes of these two scenarios are presented below.

6.2. KEY DRIVERS AND UNCERTAINTIES

The main key drivers that are impacting the water sector and its vulnerability in WA are: population growth, financial capacity, agricultural policies and the issue of shared water resources. On top of these drivers, the incremental impacts of climate change can be imposed.

Quantitative studies on most of these drivers for the countries of WA, or for the WA region[1] as a whole, are rare, which makes it impossible to estimate the VI in the future. Furthermore, many drivers have high degrees of uncertainty that would make the estimation of their impact non-scientific and could be misleading. For example, while there is a considerable degree of certainty in the anticipated population growth rate of the countries of the region, estimates of water availability from major

1. According to the UN's World Population Prospects: The 2008 Revision (2009).

rivers originating outside the region is subject to a number of uncertainties and estimating its impact on future availability of freshwater resources and thus the VI would not be possible; these uncertainties include population growth and socio-economic activities of upstream riparian countries, the volatile hydro-politics of the region, as well as the expected impacts of climate change. However, while it may be difficult to fully quantify the component parameters of freshwater vulnerability as an index, the trend and impact of many of the drivers can be qualitatively predicted, and, supported by some VI parameters that can be calculated with a degree of certainty, a narrative storyline on future vulnerability in the region can be developed.

In this section, future freshwater vulnerability in WA in relation to its associated four main parameters was assessed using two scenarios. The first scenario is the 'Business as Usual' scenario, where the trends of the current drivers and management interventions remain the same and their impact on vulnerability parameters is assessed. In the second scenario, the impact of climate change on the trends and vulnerability of the first scenario is analysed. Despite the uncertainties and assumptions, the scenarios presented here provide valuable insight for decision making today.

6.2.1. Scenario I: 'Business as Usual'

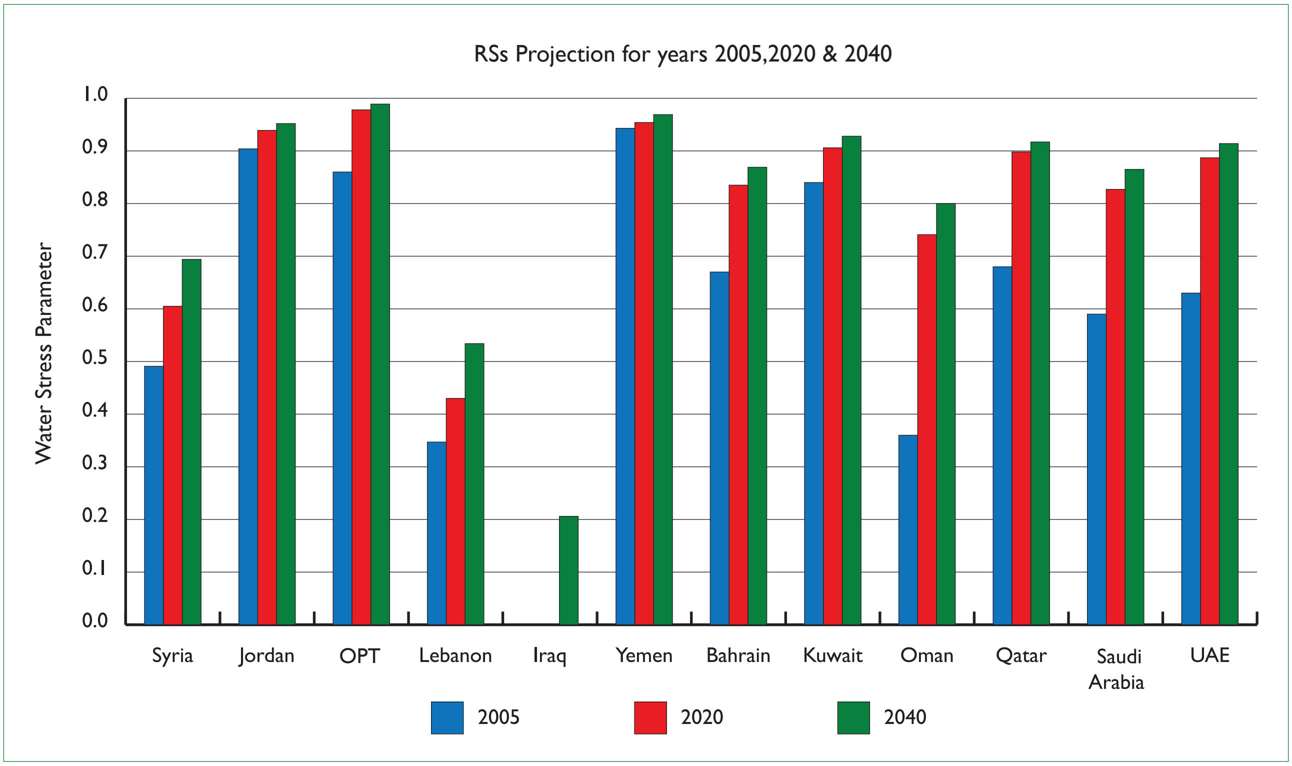
In this scenario, population size and growth rate is based on UN population projection trends (2009). Per capita domestic water consumption in the region is thus assumed to reach 150 l/day by the year 2020 and should remain the same by the year 2040[2] based on demand management and conservation efforts made by the countries of the region in the domestic sector. In addition, it is assumed that water demands in 2005 in the agricultural sector, the main water consumer with the highest potential for savings, remain the same, assuming that countries' on-going efforts in increasing water use efficiency in this sector are successful in achieving an increase in production without an increase in water consumption.

The impact of the future size of the population in WA countries would have direct and indirect impacts on the components of freshwater vulnerability in these countries. The direct impacts would be the general lowering of per capita available water resources (Water Scarcity Parameter (RSs)), while the indirect impacts would be increasing the water supply ratio to total water resources (Water Exploitation Parameter (DPs)), the potential increase in the percentage of the population without safe drinking water (Safe Drinking Water Inaccessibility Parameter (DPd)) and without sanitation (Improved Sanitation inaccessibility (MCs)), and the volume of untreated wastewater (Pollution Parameter (EHp)). However, while the first and second impacts of the population could be assumed to be uniform across the countries of the region, the last three impacts will depend on the financial capabilities of these countries, which vary significantly in the region. Unlike most of the Mashriq countries and Yemen, it is not expected that the impacts of the size of the population on the three latter parameters would be significant in the GCC countries due to their energy and financial capability to provide desalination and treatment plants.

Figure 76 illustrates the projected water stress (RSs) for the countries of WA for the years 2020 and 2040. Trends in water stress indicate that threats from the water stress parameter will increase with different magnitudes during the projected period. Iraq, Lebanon, and Syria, with their relatively adequate surface water resources and higher rates of rainfall, seem to have lower water stress than the rest of WA, while the OPT, Jordan and Yemen will have extreme water stress due to the limited water

2. ACSAD estimates.

Figure 76: Water stress (RSs) estimates (scenario 1)

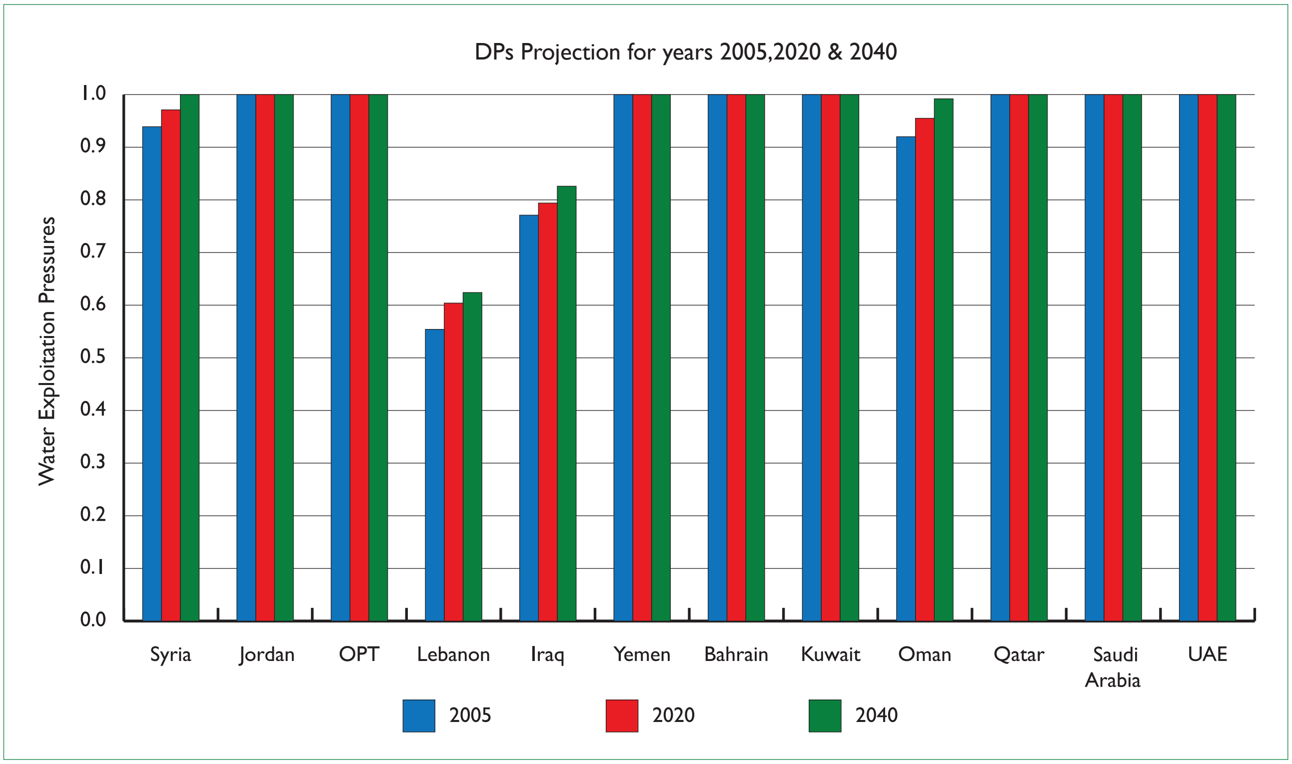


availability in view of the accelerated population growth. In most GCC countries, it is expected that expansion in desalination will alleviate water scarcity, particularly for the domestic water sector. While Syria and Iraq are expected to have low water scarcity, competition and conflict regarding shared water resources with upstream riparian countries could cause significant increases in water scarcity in these two countries in the future, since large amounts of their available water resources originate outside their territory.

The increase in the population will heighten pressures on the countries of the region to meet their water demands, particularly in the domestic and agriculture sectors, and would lead to further exploitation of their water resources. However, most of the countries of the region, with the exception of Lebanon, Iraq, Oman and Syria, have already developed their water to or beyond their capacity and are currently experiencing water deficits. In the GCC, total available water resources are expected to increase with the increase in desalination capacity and reuse of treated wastewater; however, mining groundwater resources would continue to meet primarily agricultural water demands. In countries like Lebanon, additional surface water development may not be possible due to financial constraints.

Figure 77 presents an estimation of the water exploitation parameter (DPs) projected for the countries of WA for the years 2020 and 2040 starting from the year 2005. As indicated above, the majority of the countries in the region are currently experiencing water deficits, where their water consumption exceeds available water resources, compensated by overdrafting and mining of freshwater resources.

Figure 77: Water exploitation pressure (DPs) (scenario 1)



An important aspect to be considered is that overdrafting of both surface and groundwater resources could have negative implications on freshwater-dependant ecosystems and the vegetation cover in the region (e.g., springs and their ecosystem habitats), either due to lowering water levels, depletion of resources or salinization. Thus, it is expected that development pressures would increase the threats of ecosystem deterioration (EHe) in the region. Moreover, while current domestic water supply coverage is generally adequate for most WA countries except for the OPT and Yemen, and is expected to improve with time, overdrafting of water resources might lead to the deterioration of the quality of these supplies in the future. Deterioration of the quality (salinization) of available water resources is expected to have a major impact on the productivity of the agricultural sector, thus impacting the agricultural sector contribution to the economy of WA countries (MCe). Finally, if the issue of shared water resources is not resolved and agreements between the riparian countries are not reached on the equitable utilization of these resources (MCs), the situation could be further complicated, and the threats emanating from such conditions will increase the level of vulnerability.

Although not fully quantified, in general, the vulnerability of freshwater resources in WA is expected to increase in the future if current trends of population growth and agricultural policies continue, and the issue of shared water resources is not resolved. Table 25 is an attempt to qualitatively estimate the trends of freshwater vulnerability in WA and the expected impacts of its main drivers. The table differentiates between GCC countries, Mashriq countries and Yemen based on the importance of the agriculture sector to their respective economies, the countries' financial capabilities and the importance of shared water resources. Analysis of the table indicates that the overall vulnerability of freshwater in WA countries will increase in the future due to population growth and agricultural policies (increasing water demands), and will be compounded by the unresolved issue of shared water resources. However, the magnitude of the increase in vulnerability will be less in the case of GCC countries due to their financial capabilities in providing water supply (desalination), sanitation services and treatment capacities, and also due to the limited volumes and dependence on shared water resources. Furthermore, it is anticipated that efforts to increase water use efficiency in the agricultural sector across WA countries will contribute to modifying the GDP produced per cubic meter (i.e., MCe).

6.2.2. Scenario 2: Impacts of Climate Change

At time of writing, the latest available IPCC report (Bates and others, 2008) provides an overview of projected impacts on water resources in different regions of the globe, which are solely based on Global Circulation Models (GCMs). The totality of GCMs carried out increased water scarcities in several semi-arid and arid regions of the world, including WA region. However, it should be noted that these global estimates and other GCMs are

Table 25: Estimated trends of freshwater vulnerability in West Asia

VI Parameter and Sub-Parameter		Sub-regions		Drivers			
		Mashriq & Yemen	GCC Countries	population growth	Financial Capabilities	Agricultural policies	Shared water resources
Resource Stresses *(RS)*	*RSs*	↗	↗	•			•
	RSv	↗	↗				
Development Pressures *(DP)*	*DPe*	↗	→	•	•	•	•
	DPd	↗	→	•	•	•	•
Ecological Health *(EH)*	*EHp*	↗	→	•	•		
	EHd	↗	→			•	
Management Challenges *(MC)*	*MCe*	↘	↘			•	
	MCs	↗	→	•	•		
	MCc	↗	→				•

Explanations

↗ increase, ↘ decrease, → stays the same or limited change, • has direct impact on the sub-parameter

RSs=f (per capita available water resources); RSv=f (rainfall variation); DPe=f (ratio of water supply to total water resources); DPd=f (population without safe drinking water); EHp=f (per cent of untreated wastewater to total water resources); EHd=f (% area without vegetation over to total basin area); MCe=f (GDP produced per cubic meter (agr) compared to world top world food producers); MCs=f (% population without sanitation); and MCc=f (level of shared management of shared water resources).

United Arab Emirates
Source: UNEP, LAS and CEDARE, 2010

not appropriate for downscaling to country or watershed level, since their results and implications can vary significantly between watersheds, and local data and information will be needed to estimate the changes on country or watershed level (Cap-Net, 2010).

In WA, detailed studies on the impacts of climate change on water resources are generally limited. They are available only for a few countries and are not comprehensive, in that they are limited to one or two impacts (e.g., sea level rise, temperature increase), which makes it difficult to quantitatively estimate the expected impacts at the country level. For the purposes of this study, the expected impacts of climate change are estimated qualitatively by relating the impacts to the VI parameters. For example, frequency of extreme events (floods and droughts) may increase with climate change, in turn affecting the water variation parameter (RSv). A possible decrease in rainfall and snow accumulation as well as an increase in temperatures and evaporation may occur, leading to a decrease in the overall water endowment of the region (Water Scarcity Parameter (RSs)).

In this scenario, the possible impacts of climate change are imposed on the previous scenario (Business as Usual). The estimated change in available water resources is gradually decreased by 7 per cent for all countries, except for Yemen which is expected to have an increase of 3 per cent, by the year 2040[3]. The result is that the decrease in available water under normal population growth in the region is expected to lead to a further increase in water stress and a general decrease in the amount of exploitable resources.

3. Data provided by ACSAD.

Figure 78: Water stress projection 2040 (scenario 2)

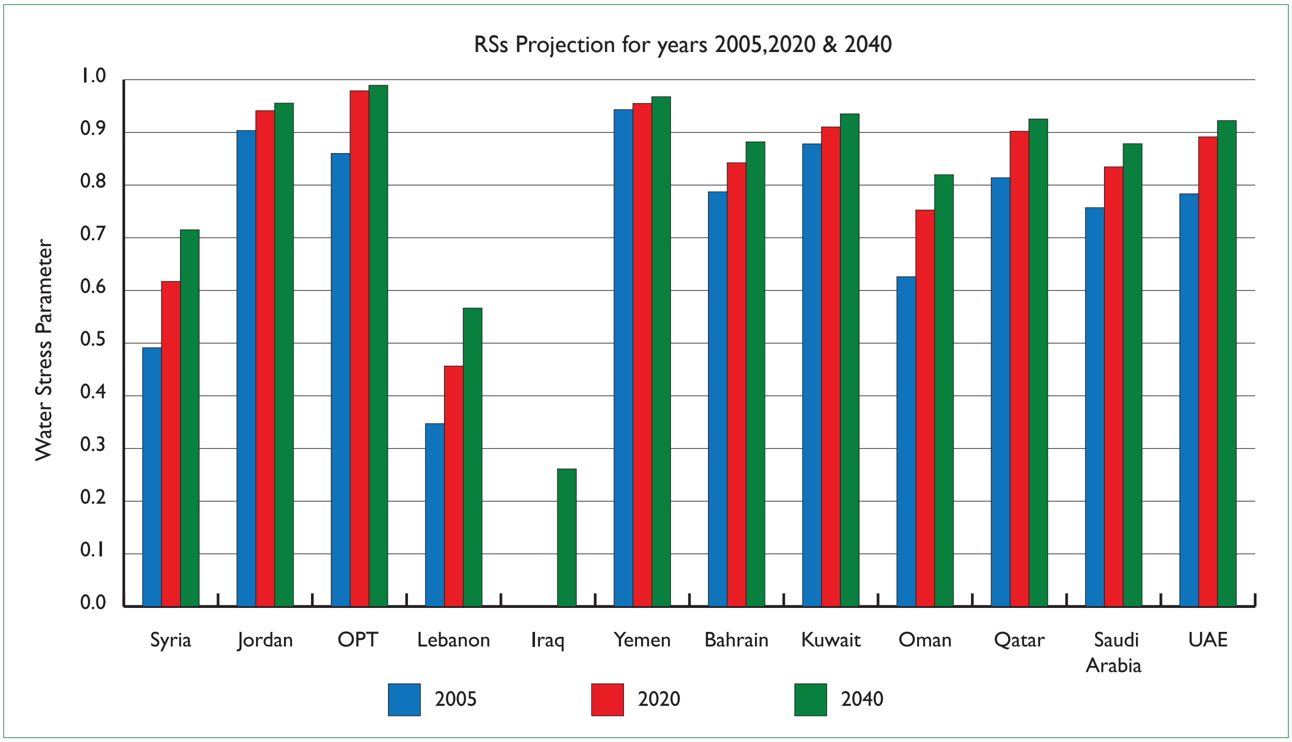


Figure 79: Water exploitation pressure parameter (scenario 2)

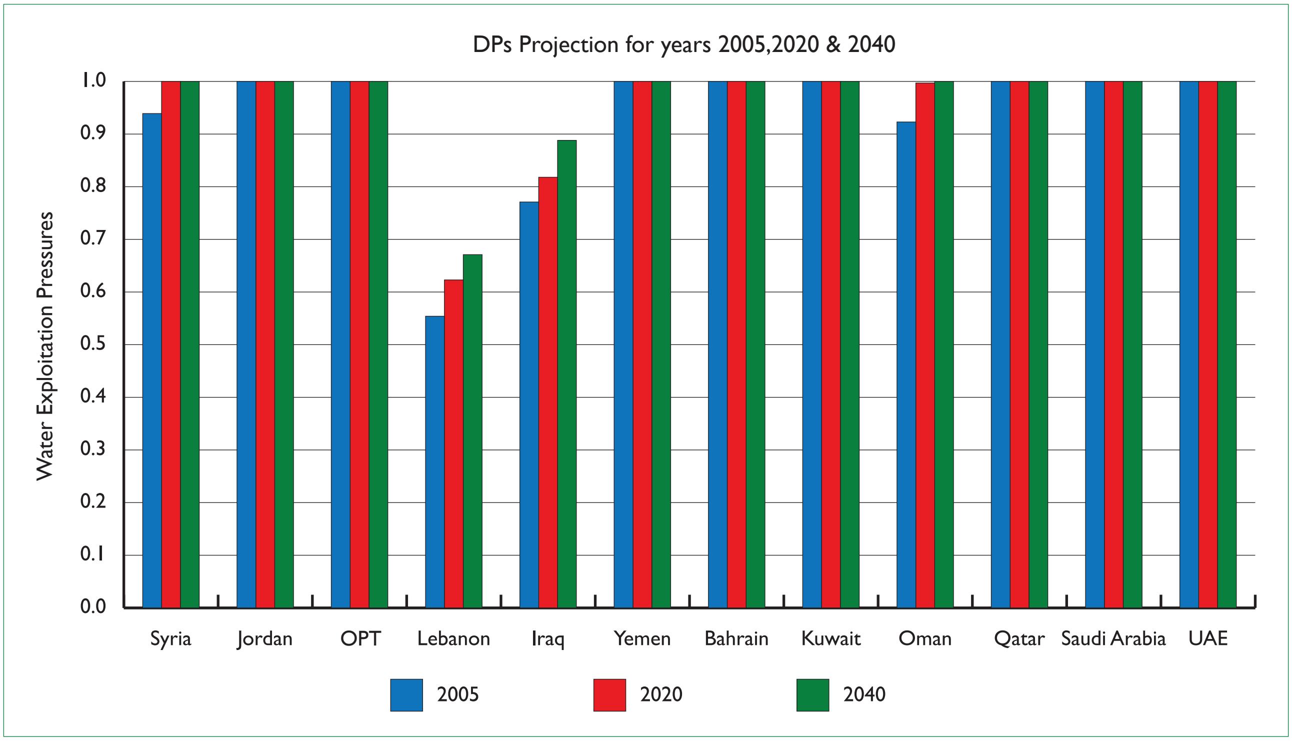


Figure 78 illustrates estimated water stress for WA countries. Climate change will increase threats to freshwater resources in the region (compared to the Business as Usual scenario in Figure 76) by reducing the per capita water share. When combined with the expected variation in water resources and population growth, the Resources Stress (RS) contribution to freshwater vulnerability in WA countries would be higher.

As in scenario 1, but more intensely in order to compensate for climate-change induced water shortages, water exploitation would increase as presented in Figure 79 for the years 2020 and 2040. By 2040, all WA countries, except Lebanon and Iraq, will have very high vulnerability due to over-exploitation of their water resources. Climate change is expected to lead to more water scarcity and deficits in the countries of the region. Under this scenario, it is expected that climate change will amplify the impacts of the overdrafting of water resources, as discussed above in the Business as Usual scenario. Furthermore, the unresolved issue of shared water resources might lead to conflicts between riparian countries when exacerbated by the expected impacts of climate change of reducing available water resources, thus increasing overall vulnerability.

6.3. CONCLUSION

In general, the vulnerability of freshwater resources in WA is expected to increase in the future if the current trends of population growth and agricultural policies persist, and the issue of shared water resources is not resolved. While still expected to increase, the vulnerability magnitude will be lessened in some countries due to their financial capacity to provide water supply and sanitation services and due to their very limited, or non-existent, dependence on shared water resources. It is expected that freshwater vulnerability in the region would be exacerbated by the impact of climate change, manifested by increasing water resources scarcity, variability and deficits between the available water resources and demands, and might lead to disputes between riparian countries.

Agricultural development, United Arab Emirates
Source: UNEP, LAS and CEDARE, 2010

It is therefore imperative that the countries of the region consider the potential impacts of climate change in their water resources planning by integrating appropriate adaptation measures in their water programmes. Furthermore, the issue of shared water resources with countries outside the region, as well as among the countries within the region, represents a major driver for the vulnerability of freshwater resources in the region, and a framework for cooperation in the management of shared water resources should be given the highest priority and developed.

CHAPTER SEVEN

CHALLENGES AND OPPORTUNITIES

Khaled Mubarak

Key Messages

The main water management challenge facing WA countries is the continuous increase in water scarcity and the increasing stresses on, and deterioration of, the region's limited natural water resources. This challenge poses major threats and implications not only for future development, but also for the sustainability of existing socio-economic achievements.

The absence of an enabling environment for integrated water management policies with an adequate legislative framework, institutional weakness and management practices focusing on 'supply-side' management without giving adequate attention to 'demand-side' management, have contributed to increasing freshwater vulnerability in most countries of the region. Policy reforms, emphasising demand management, conservation and protection and improvement of the legal and institutional provisions are all essential for the efficient development and management of water resources and must be given the utmost attention to minimise freshwater vulnerability.

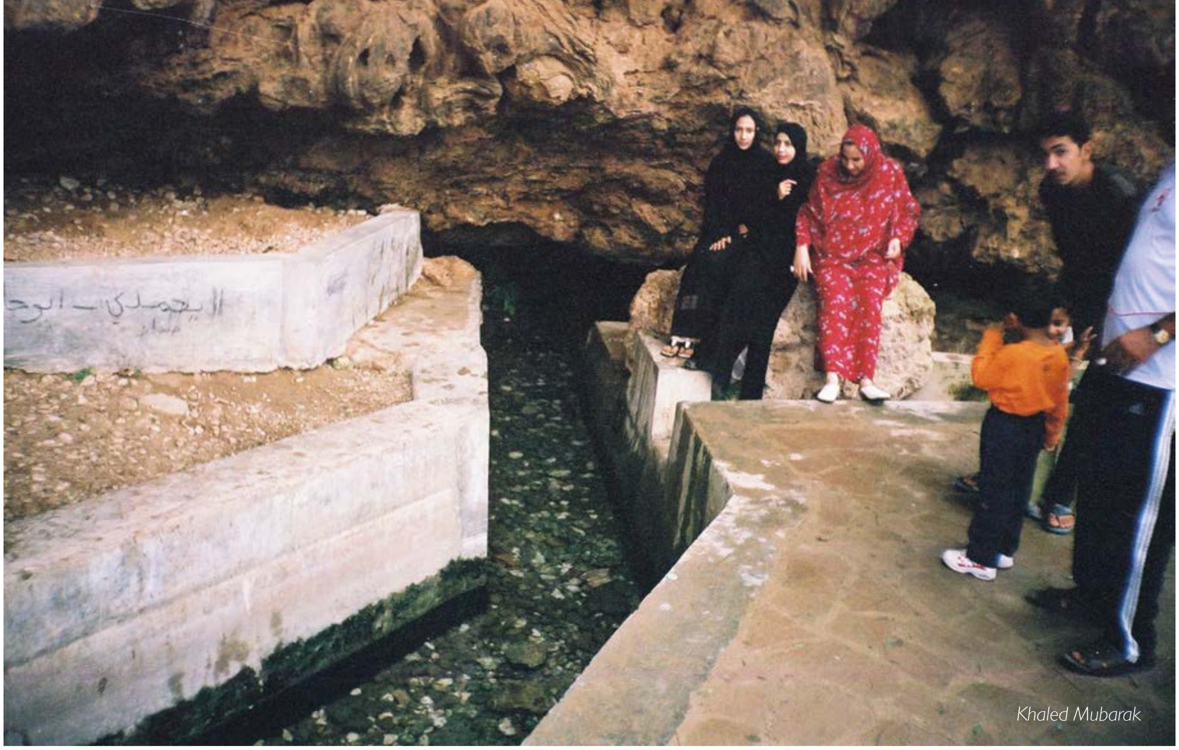
Climate change is expected to place further stresses on the limited freshwater resources of WA and intensify vulnerability, especially for those countries relying on shared water resources. In the absence of sharing agreements, this can potentially increase tensions between riparian countries. The issue of shared water resources should be given high priority by WA countries to finalize binding agreements in accordance with international laws.

Large water savings opportunities exist in the agricultural sector, which accounts for more than 80 per cent of total water consumption in the region and where most water wastage occurs. Savings are possible by increasing irrigation efficiency through the introduction of better irrigation and agricultural techniques, reuse of treated wastewater, augmentation by agricultural drainage water and implementation of incentive/disincentive systems.

Municipal wastewater has become an increasingly important source of water with considerable potential in alleviating water scarcity in the region, as its volume increases proportionally with increasing urban consumption. With proper treatment, it can be used to supplement water supply in the agricultural and industrial sectors, as well as in managed aquifer recharge (MAR) schemes.

While further reliance on desalinated water in the region is inevitable in the future and contributes to lessening water scarcity, especially for GCC countries, desalination technologies are capital and energy intensive, largely imported, provide limited added value to countries' economies, and have many negative environmental impacts. There is an urgent need for cooperation among WA countries, as well as with other Arab countries, to invest in Research & Development for these technologies, with the aim of acquiring and localizing them, to reduce costs and environmental impacts, and increase reliability and economic value.

The issue of water resources management should be placed high on the national priorities of WA countries. Political will is needed to take actions for the sustainable management of water resources and a necessary prerequisite to lower freshwater vulnerability in the countries of the region.



Oman

Khaled Mubarak

The main water management challenge facing WA countries is increasing water scarcity, as well as stresses on and deterioration of the region's limited natural water resources, due to increasing water demands. These conditions pose major threats and have many implications not only on the future development of the countries of the region, but also for the sustainability of their existing socio-economic achievements. Current water scarcity in the region is expected to reach more severe levels in the future due to high population growth rates, increasing salinization and pollution levels, which would further reduce available freshwater resources, and the anticipated impacts of climate change, which are expected to decrease the availability of freshwater resources in the region and would exacerbate the situation.

As previous chapters have indicated, the main drivers that impact the water sector and its vulnerability in WA are population growth, financial capacity, agricultural policies, uncertainty with regards to shared water resources and the incremental impacts of climate change. While in the short-term, relatively high financial capacity can lower freshwater vulnerability in some countries, such as the GCC countries, its success in reducing this vulnerability in the long-term is questionable. Despite the strenuous efforts of these financially capable countries to tackle their water scarcity by augmenting their water resources with additional desalination plants, a process associated with high economic and environmental costs, they still face serious water deficits due to continuously increasing water demands by rates that exceed their water supply development rates.

In fact, current water resources management approaches in WA countries coupled with an absence of clear comprehensive policies has led to an increase in freshwater depletion and quality deterioration, and thus has contributed to freshwater vulnerability in these countries. In the past three decades, the countries' efforts were concentrated principally on supply management and augmentation to meet ever-increasing water demands, without giving adequate attention to demand management, efficient allocation, conservation and protection. This has led to the emergence of many unsustainable practices such as poor water use efficiency, growing demands and per capita water use, increasing the costs of water production and distribution, as well as a wide spectrum of general and local water problems. The situation was further aggravated by the lack of integrated long-term water policies and strategies in most of the countries that take into account social, economic, health and environmental aspects, and to adequately address the problem of water scarcity in the region.

Furthermore, these conditions were compounded by institutional weakness, where many of the institutions concerned with water and water-related sectors are characterized by overlapping responsibilities, ineffective coordination, low financial performance, weak monitoring systems, outdated water legislation and enforcement of existing laws, in addition to poor scientific and technological capacities, particularly in the field of water management and planning.

Cooperation among the relevant ministries at all stages, including planning and investment, is critical. The main pillar of adequate water resources management for any country is the definition of a strategy that identifies and provides an appropriate legal, regulatory and administrative framework. The strategy should spell out priorities for water use, water rights, cost recovery policies, public investment strategies and the role of different stakeholders. Institutional capacity at the national and local levels needs strong legal and regulatory frameworks and should include community groups, non-governmental organizations (NGOs) and local associations.

Fortunately, most of the countries in the region have realized that efficient development and management of water resources requires policy reforms, to include more emphasis on demand management measures and the improvement of legal and institutional provisions. Addressing the immense challenges associated with water resources management in the region requires daring reforms to existing institutions and policies governing water resources. Far-reaching and multi-sectoral approaches are vital if countries are to overcome inefficiencies and achieve sustainable water use, thus lowering their societies' vulnerability to freshwater shortage.

With large percentages of water resources in the region shared either among other countries in the region or with neighbouring countries, the water resources situation can become further complicated in the future. Unfortunately, either there are no shared management agreements for these shared resources yet, or, where these agreements do exist, no implementation has taken place. With increasing water demands in the riparian countries, this situation is a potential source of conflict in the future. Furthermore, the expected impacts of climate change are likely to exacerbate this deterioration, thus inducing more pressure on natural water resources and increasing freshwater vulnerability. Based on the findings of international studies, the region will experience less, and more erratic, precipitation, increased drought frequency and an increase in average temperatures (IPCC, 2007; Hanson and others, 2007); water flow in the Euphrates may decrease by 30 per cent and that of Jordan by 80 per cent before the turn of the century. Such a situation would increase tensions between riparian countries sharing these rivers (Khordagui, 2007).

The issue of shared water resources, both surface and groundwater, should be given high priority by WA countries in order to finalize agreements and conclude treaties regarding water allocation, including quality considerations, according to international water laws. The conclusion of such agreements should be considered an urgent matter, particularly in view of the expected climate change impacts on the region's water resources. It would also alleviate tensions, which in themselves simply the potential costs of conflict, among competing riparian countries, and will help concerned countries in defining their water policies based on real figures about water share and not on estimated ones. This could also assist in achieving integrated basin management, which is the best way to ensure ecosystem integrity and enable better watershed management, providing benefits to the water body itself. It also encourages exchange of knowledge and expertise, which is much less costly than redeveloping best practices through trial and error.

Pollution of available freshwater resources remains the greatest threat to human health and aquatic ecosystems in the region, while at the same time significantly contributing to reducing available freshwater resources in the region. Most of the rivers in the region are receiving raw wastewater due to the absence of treatment plants. Groundwater is being polluted by a number of anthropogenic activities including agricultural (saline and contaminated irrigation return flows with pesticides, fertilizers, herbicides, etc.), industrial (discharge of hazardous and toxic industrial wastes, underground storage tanks, surface and deep disposal of oil and gas brines, etc.) and domestic activities (discharge of inadequately treated domestic wastewater, septic tanks, municipal landfills, etc.). Therefore, it is important to develop protection strategies for these limited freshwater resources to enhance their availability and sustainability.

It is expected that future scarcity will highly impact the agricultural sector, which consumes more than 80 per cent of available freshwater resources in the region (FAOSTAT, 2009), and where most water wastage occurs due to the use of traditional irrigation methods with low irrigation efficiencies. Innovative approaches in irrigation water management are highly recommended. These could include: increasing water use efficiency through savings from seepage and tail ends of irrigation systems, modern irrigation techniques, augmenting irrigation water supply by recycling of agricultural drainage water where feasible, reuse of treated wastewater in irrigation of appropriate crops, reducing demands through the adaptation of systems of incentives (for good practices) and disincentives (for poor practices), reducing irrigation water requirements and maximizing production using modern agricultural systems (e.g., soil-less cultures). These interventions are expected to result in large savings in irrigation water, higher economic values per unit of delivered water to the agricultural sector, significant reductions in freshwater stresses and freeing of large portions of freshwater resources for other sectors.

With escalating water consumption in the ever-expanding urban areas in WA countries, municipal wastewater has become an increasingly significant source of water with considerable potential in alleviating water scarcity. While these waters currently constitute a major challenge for many countries in the region in terms of freshwater resources pollution and health hazards; with proper treatment and management, they can be converted to an opportunity and can contribute to lowering freshwater vulnerability in the region, especially since the quantities of these waters increase proportionally with increasing population and domestic water consumption. If treated properly, reclaimed wastewater can be used to support water demands for some sectors, such as the agricultural and industrial sectors, and potentially prevent health concerns. Furthermore, surpluses of these waters can be used for artificial groundwater recharge under managed aquifer recharge (MAR) schemes depending on the quality of the reclaimed water and purpose of the recharge (i.e., Aquifer-Storage-Recovery (ASR), Soil-Aquifer-Treatment (SAT) when partially treated, or Aquifer Storage, Transfer and Recovery (ASTR) schemes).

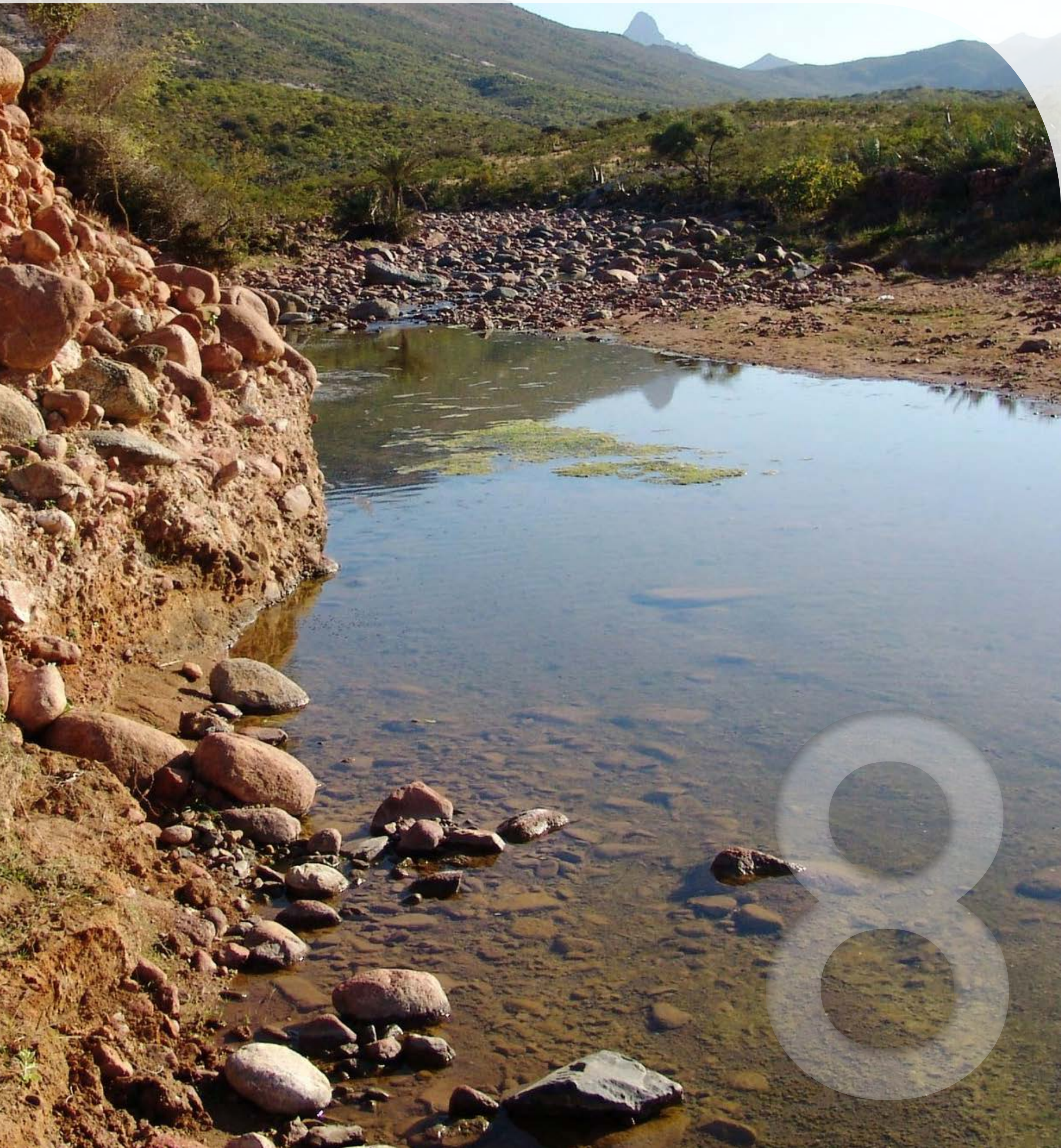
Socotra, Yemen
Source: UNEP, LAS and CEDARE, 2010

Desalination of sea water and brackish groundwater has become a strategic option for meeting increasing drinking water demands in many countries in the region, particularly in the GCC countries, due to their financial and energy capacities. West Asia countries own more than 50 per cent of world desalination capacity. Saudi Arabia, the UAE, Kuwait and Qatar are the top producers of desalinated water in the region, and total GCC countries' desalination capacity is about 9 500 mcm (AFED, 2010). While desalination is contributing to the alleviation of water scarcity in the region and lowering its freshwater vulnerability, and although its future expansion is inevitable for some countries to meet their domestic water demands (i.e., the GCC countries), desalination technologies are capital and energy intensive and have many negative environmental impacts. Furthermore, these technologies are still largely imported and the desalination industry and projects provide limited added value to countries' economies. There is an urgent need for cooperation among WA countries as well as with Arab countries to invest in R&D for these technologies, with the aim of acquiring and localizing these technologies in the region, to reduce their cost, increase their reliability, increase their economic value and mitigate their environmental impact.

Finally, in view of the immense freshwater challenges facing the countries of WA, as well as the available opportunities to alleviate the situation, the issue of water resources (and not simply water supply) management should be placed high on the respective lists of national priorities for each of these countries. In this regard, political will is needed to take concrete steps to achieve sustainable management of water resources, in itself a necessary prerequisite to lowering freshwater vulnerability in the region. Furthermore, public and community participation in the water management process has proved to be successful in increasing awareness regarding water scarcity and the necessity to move towards demand management. Therefore, such efforts should be strengthened to help increase recognition of water resources management problems and develop support for effective actions among stakeholders.

CHAPTER EIGHT

POLICY SOLUTIONS: THE WAY TOWARDS SUSTAINABLE WATER MANAGEMENT



8

Key Messages

There is an urgent need to put integrated water resources management (IWRM) high on the political agenda in WA in order to enable decision-makers to act effectively in the interest of sustainability. Taking an IWRM approach would also provide decision-makers with critical information to allow them to commit the necessary financial and human resources. An enabling environment (policies, legislations, organizational structures, institutional capacities and financing) for effective water resources management needs to be established.

Water policy reforms are urgently required in most WA countries to address the integrated management aspect, water governance, climate change impacts, food security, taking into consideration the specific requirements and prevailing social, economic and cultural conditions in the region.

In order to cope with water scarcity and lower freshwater vulnerability in the region, a major shift to demand management, water use efficiency and conservation needs to happen, and should focus on the agriculture sector where most water savings can be achieved. Furthermore, there is an urgent need to strengthen and reinforce the capacity of water institutions to deal effectively with water issues in a holistic approach through legal and institutional frameworks.

Vulnerability and adaptation to climate change need to be integrated into future water resources management policies at the national level. A key role for concerned institutions to achieve this goal is to provide knowledge and promote awareness.

Surface irrigation in Bahraina
Source: CEDARE and AWC, 2005

Freshwater vulnerability in WA that is a pressing concern for decision-makers now and in the future. It requires the development of policies that take into consideration the continuous increase in water demand under a changing environment, including climatic conditions and increased desertification. Solutions can be mapped along a continuum from those where proven solutions are available to those where the problem and its solution have yet to be fully comprehended. It is clear from the above analysis that the vulnerability of freshwater resources in WA countries is a result of inadequate management and will become exacerbated by the impacts of climate change. The following are the main policy options to deal with both issues.

8.1. WATER RESOURCES MANAGEMENT

- There is an urgent need to put IWRM high on the political agenda in order to enable decision-makers to act effectively in the interest of sustainability. Taking an IWRM approach will also provide decision-makers with critical information to allow them to commit the necessary financial and human resources to address this issue. An enabling environment (policies, legislations, organizational structures, institutional capacities, and financing) for effective water resources management needs to be established.
- Water policy reforms should address the integrated management aspect, water governance, climate change impacts and food security, taking into consideration the specific requirements and prevailing social, economic and cultural conditions of the region.
- Demand management measures should focus on the agriculture sector with emphasis on improving irrigation efficiency which consumes on average more than 85 per cent of available freshwater in some countries (UNEP, LAS and CEDARE, 2010). Increased efficiency would increase agriculture productivity and reduce water depletion from non-renewable sources. Water savings can meet, and exceed, the domestic water demand.
- There is an urgent need to strengthen and reinforce the capacity of water institutions to effectively deal with water issues in a holistic approach through the appropriate legal and institutional frameworks. Participatory approaches, involving relevant water stakeholders and the private sector should be considered. Coordination mechanisms within the

water sector and among water related and other development sectors, especially the agricultural sector, are needed.

- The decision making process should be changed from the currently practiced top-down approach to a more participatory approach, where users are transformed from part of the problem to part of the solution. Effective participation will require public education, information dissemination and the facilitation of local decision making processes.
- Surface water and groundwater resources shared between riparian states should be given a high priority in order to reach agreements and make treaties regarding water allocation for the shared groundwater resources according to international water laws. The existing agreements between Syria, Iraq and Turkey; Lebanon and Syria; and Syria and Jordan regarding shared surface water resources need to be implemented fairly and allow high flexibility to regulate and monitor flows in terms of quantity and quality as well as undergo periodic review to ensure effectiveness.
- Improved financial performance of the water sector calls for the design of a cost-recovery approach taking into consideration the poorest segments of society. Subsidies and loans to water-consuming sectors should be used as leverage to promote conservation and protection of water resources and ecosystems.

8.2. FRESHWATER VULNERABILITY TO CLIMATE CHANGE

- Vulnerability and adaptation to climate change must be integrated into future water resources management policies at the national level. A key role for concerned institutions to achieve this goal is to provide knowledge and promote awareness.
- The high vulnerability of the region›s water resources to climate change calls for the implementation of actions at present rather than waiting for better solutions to come along. This principle is also useful with regards to shared water resources: it is better to reach agreements concerning them at present than wait for the future.
- Existing policies need to be updated to include structural and non-structural adaptation measures to reduce vulnerability to climate change and put in place effective programmes to minimize the expected risks and impacts. Cooperation and exchange of data and information at the national and regional levels regarding the vulnerability of the region to climate change and measures for mitigation and adaptation could help in alleviating the negative impacts on the countries of the region.
- There is a need to formulate emergency plans for disasters and extreme climate events, such as floods and droughts, in order to increase the resilience of communities and water-consuming sectors. Water resources management planning processes need to account for the uncertainty of water variability and disaster risk management.
- The socio-economic impact of climate change on populations must be assessed and appropriate monitoring mechanisms and adaptive measures suitable for arid environments formulated and their effectiveness assessed.
- Support research, monitoring, and information networking regarding climate change issues at the national and regional levels and assess its impacts at the regional level.

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ANNEX:
VULNERABILITY INDEX (VI) ESTIMATION

According to UNEP methodology, vulnerability is a function of four main parameters: water availability, use and management. The vulnerability index (VI) can be assessed from the application of a number of governing equations to estimate the four parameters of: water resource availability stress (RS), development pressure (DP), use conflicts and ecological security (ES), and management (MC). The vulnerability of water resources index VI = f (RS, DP, ES, and MC) can be assessed from two perspectives:

- The main threats to the availability of water resources, its development and water utilization dynamics.
- Capacity to cope with the potential national and regional threats to water availability.

The governing equations to estimate the various vulnerability threats for each country of the Mashriq and AP sub-region as well as for the shared water resources (Euphrates River and Dammam aquifer) are presented below.

A.1. The Resource Stress (Rs) Parameter

The water stress indicator is influenced by renewable water resources availability and consumption patterns of the growing population (RSs) and water variation parameter resulting from long term rainfall variability (RSv). These two parameters are assessed to determine the water resources available to meet the pressure of water demands for the growing population, taking into consideration rainfall variability on surface water generated and the amount of groundwater recharge.

The general influence of the vulnerability of water resources will be the quantity and quality of water resources, with the pressures from them being expressed as the stress and variation on available water resources.

A.1.1. Water resources stress (RSs)

The water availability of renewable water resources (surface and groundwater) supplemented by desalination available over time in the past and the future will decide to what extent it can meet past and future water demands of the level of the population size. Thus, the water resources stress parameter can be expressed as per capita renewable national or regional water resources compared to the internationally agreed water poverty index of 1 700 m^3/person of water resources. However, as WA is characterized by scarce water sources, it would have been more appropriate to use a realistic value of 1 000 m^3/person. The available annual per capita of renewable water source at the national or the regional levels is estimated by the ratio of the renewable water resources to the size of the population for a given year. Thus, the water resources stress RSs can be expressed as follows:

Water resources stress (RSs)

$$RS_s = \frac{1000 - R}{1000} \quad (R<1000) \qquad (1)$$

$$RS_s = 0 \quad (R \geq 1000)$$

Where:

RSs : water resources stress

R : per capita water resources (m^3/person)

A.1.2. Water Variation (RSv)

Rain and snow are the dominant factors in the generation of surface water resources. For WA, rainfall amount and variability determine how much surface water will be available and its contribution to the groundwater recharge. In addition, surface water inflow from neighbouring countries is another component that must be considered. Thus, water resources variability is estimated by the coefficient of variation (CV) of a long rainfall record for a period of 20-50 years. The methodology guidelines

(UNEP, 2009) designate a set rainfall variation value for the CV as CV = 0.3 or as a CV > 0.3. When CV is > 0.3, the parameter is assigned a highest value of 1, thus indicating large rainfall variation in time and space while for a CV less than 0.3, it reflect low variability. The CV is estimated by the ratio of the standard deviation of the long rainfall record to the average rainfall as follows:

$$CV = \frac{\sigma}{\mu} \quad (2)$$

$$\mu = \frac{\sum_{i=1}^{n} P_i}{n}$$

$$\sigma = \frac{\sqrt{\sum_{i=1}^{n} (P_i - \mu)^2}}{n-1}$$

$$RS_v = \frac{CV}{0.3} \qquad (CV<0.3) \qquad (3)$$

$$RS_v = 1 \qquad (CV \geq 0.3) \qquad (4)$$

Where:

RS_v : water resources variation

P_i : rainfall of the i[th] year (mm)

μ : mean rainfall for the data record

σ : standard deviation

A.2. Water Development Pressures (Dp) Parameter

Freshwater resources in the region rely on rainfall and recharge patterns. The higher frequency of occurrence and amounts contribute to enhanced water availability and dependability. Water development may experience different degrees of pressures from increasing demand in different sectors and its pollution from different sources of wastes as these two factors can diminish the supply potential. Thus, the degree of water sector development can place stress on the available water resources. Also, the fragile arid environment is sensitive to development activities due to its low resiliency to restore its natural equilibrium. The water development parameter can be estimated by two variables designated as water exploitation (DPs) and safe drinking water accessibility (Dpd). The water development variable is estimated by the available water resources capacity to meet water demand in the domestic, industrial and irrigation sectors, while the water supply coverage is the percentage of the population covered by drinking water supply services. The water development parameter (Dp) is estimated as follow:

A.2.1. Water Exploitation (DPs)

Water supply development deals with the construction of water infrastructure (water abstraction from rivers, groundwater and desalination). The water exploitation variable is estimated by the ratio of total water demand (domestic, industrial and irrigation) (WRs) for a given year, to the available amount of renewable water resources (WR) that consist of: surface water and groundwater safe yield (river flow or run off and recharge). In the GCC sub-region, desalination, being a dependable water supply source, is considered an essential component of renewable sources for the sub-region. The degree of water exploitation is estimated by the following equation:

$$DP_S = \frac{WR_S}{WR} \qquad (5)$$

Where:

DPs : water resources exploitation

WRs : total water supply (water demands)

WR : total renewable water resources

A.2.2. Safe drinking water inaccessibility (DPd)

Supply coverage deals with the availability of water supply facilities to abstract the needed drinking supply and the distribution network and treatment to meet domestic water demand. Supply coverage depends on water resources development activities to provide the basic water needs for different segments of society. The lack of safe water accessibility is estimated by the ratio of the percentage of the population lacking accessibility (Pd) to the size of the population (P) at a given time as follows:

$$DP_d = \frac{P_d}{P} \quad (6)$$

Where:

DPd : safe drinking water

Pd : population without access to improved drinking water sources

P : total population

A.3. Ecological Health (EH)Parameter

The water ecological health (EH) parameter is a measure of the pollution impact from different sources on ecosystem equilibrium and protection. The arid ecosystem with low resiliency takes a long time to regenerate or adjust to a reasonable stage of sustainability. Water pollution in WA represents major threats to future water availability as well as poses a major health impact. These impacts can be assessed by two variables; namely, water pollution (EHp) and ecosystem deterioration (EHe). Water resources development to meet water demands especially in the domestic sector, generates wastewater that may receive treatment of different levels or disposed of untreated and can have different degrees of impacts on the environment. The ecosystem can also experience deterioration in terms of desertification from unsustainable land use management practices (loss of arable land to low rainfall, loss of productivity from rain-fed areas, overgrazing and urban expansion) and the impact of different hydrological processes, particularly rainfall and run off, on erosion and sedimentation.

A.3.1. Water pollution (EHp)

Pollution to water resources is estimated by the ratio of total untreated wastewater (WW) discharge in water-receiving systems to total available renewable water resources (WR). The amount of untreated wastewater is estimated as the difference between the generated wastewater collected by the system and amount of wastewater that received treatment. Untreated wastewater is the major cause of pollution in the region, as sewage with certain concentrations can make about 10 times its quantity of clear water totally unusable, thus wasting already limited water sources.

$$EH_p = \frac{WW/WR}{0.1} \qquad (WW<0.1*WR) \quad (7)$$

$$EH_p = 1 \qquad (WW \geq 0.1*WR) \quad (8)$$

Where:

EH_p : water pollution

WW : total wastewater

WR : total renewable water resources

A.3.2. Ecosystem deterioration (EHe)

Population growth and the associated urbanization and other socio-economic development activities impact surface and groundwater systems by increasing depletion and increasing pollution stresses. Increasing rates of urbanization, irrigation and overgrazing have contributed directly or indirectly to the vulnerability of the region's water resources.

The natural landscape is being modified by the removal of the vegetation cover, which, in turn, is contributing to the modification of the hydrological properties of the land surface with impact on the functioning of ecosystems. Land use negatively impacts water resources conservation and protection leading to higher vulnerability for water resources. Ecosystem deterioration is estimated as the ratio of land size without vegetation cover (Ad) to the total size of the country (A) assessed as follows:

$$EH_e = \frac{A_d}{A} \qquad (9)$$

Where:

EH_e : ecosystem deterioration parameter

A_d : land area without vegetation coverage (i.e., total land area except that covered with forests, pastures and cultivated areas)

A : total area of the country

A.4. Management Capacity (MC) Parameter

Freshwater vulnerability is improved by the implementation of effective management practices as it will contribute to water sustainability. Evaluation of the management capacity provides a means to evaluate how effective the water sector is being managed. The lack of good management practices in line with IWRM on the ground has contributed to the decrease in water availability. The lack of effective management practices can be assessed by the vulnerability of the management capacity (MC) of freshwater through the estimation by three variables namely: water use inefficiency (MCe), improved sanitation accessibility (MCs) and conflict management of the shared water sources (transboundary).

The efficiency of a water resources management systems can be evaluated by examining the gap between water use efficiency and a defined world standard average water use efficiency index related to the contribution to the GDP from the use of one cubic meter of water for selected countries. Accessibility to improved sanitation is used as a typical variable to measure the capacity of a management system to deal with livelihood improvement in terms of sanitation coverage. The sanitation impact (MCs) is estimated by the ratio of the population without accessibility to sanitation facilities to the population size at a given time. The conflict management variable assesses the capacity of the management of shared water sources such as a river or aquifer to reduce trans-boundary disputes. A good dispute management framework can be assessed by its effectiveness in enhancing institutional arrangements, policy formulation and implementation, effective communication mechanisms, and implementation efficiency. The final score of the conflict management capacity parameter (MCg) is determined by a matrix represented in the UNEP methodology guidelines (2009), but the selected values call for a judgment to be provided by a water expert familiar with the water situation, especially shared water resources, in the region. The UNEP management matrix is shown in Table A.1. The management capacity parameter influenced by the water use efficiency, sanitation coverage and trans-boundary conflict management variables are estimated as follows:

A.4.1. Water use inefficiency parameter (MCe)

Unsustainable water resources management practices in the absence of a comprehensive water sector plan and strategy can lead to reduced water availability and increased vulnerability. Efficiency in water use enhances water availability for food production and achievement of a better standard of living. Assessment of the management of the available water can be examined in terms of water use efficiency and the financial return generated from the use of a unit of water. This can be estimated by the economic return (GDP) of the use of one cubic meter compared to an average for selected countries as follows:

$$MC_e = \frac{WE_{wm} - WE}{WE_{wm}} \qquad (WE < WEwm) \qquad (10)$$

$$MC_e = 0 \qquad (WE \geq WEwm) \qquad (11)$$

Table A.1: Conflict management capacity parameter matrix

Category of capacity	Description	Scoring criteria 0.00 ◄──► 0.25		
Institutional capacity	Trans-boundary institutional arrangement for coordinated water resources management	Solid institutional arrangements	Loose institutional arrangements	No existing institutions
Agreement capacity	Writing/ signed policy/ agreement for water resources management	Concrete / detailed agreement	General agreement only	No agreement
Communication capacity	Routine communication mechanism for water resources management (annual conferences, etc.)	Communications at policy and operational levels	Communications only at policy level or operational level	No communication mechanism
Implementation capacity	Water resources management cooperation actions	Effective implementation of basin-wide river projects/programs	With joint project/ program, but poor management	No joint project program

Where:

MCe : water use inefficiency

WE : GDP value produced from one m^3 of water

WEwm : mean WE of selected countries

A.4.2. Improved Sanitation Inaccessibility (MCs)

Availability of an adequate sanitation services infrastructure reduces pollution levels and preserves the water resources.

Accessibility to improved sanitation is used as a typical value to measure the capacity of a management system to deal with likelihood improvement in reducing pollution level. The variable is estimated as the ratio of the proportion of the population without accessibility to improved sanitation facilities to the total population as follows:

$$MC_s = \frac{P_d}{P} \qquad (12)$$

Where:

MCs : improved sanitation inaccessibility

Pd : population without access to improved sanitation

P : total population

A.4.3. Conflict Management Capacity (MCg)

Water resources are being used to meet domestic water demand and socio-economic and ecosystem requirements. Competition over water utilization among different consuming sectors at the national and regional levels, including neighbouring countries that are sharing surface and groundwater resources, can lead to social and political tensions. Assessing the management of disputes evaluates the institutional arrangements, communication and implementation of a viable water sharing agreement. According to the assessment guidelines (UNEP, 2009), the conflict management capacity can be assessed utilizing the matrix of Table A.1 by selecting different capacity values (institution, agreement, communication and implementation) with a designated scoring criteria ranging from 0.0 to 0.25. The assessment of a conflict management coefficient must take into consideration the interrelation of all the variables presented in Table A.1. These aspects are assigned scoring criteria ranging from 0 to 1, giving weights to each parameter.

B. FRESHWATER VULNERABILITY INDEX ESTIMATION

It is estimated based on the consolidation of the values of the four main parameters estimated by the abovementioned equations (1-12). The vulnerability index can be calculated as follows:

$$VI = \sum_{i=1}^{n}\left[\left(\sum_{j=1}^{m_i} x_{ij} * w_{ij}\right) * w_i\right] \quad (13)$$

Where:

VI : Vulnerability Index

n : number of parameter category

m_i : number of parameters in ith category

x_{ij} : value of jth parameter in ith category

w_{ij} : weight given to jth parameter in ith category (the four parameters)

w_i : weight given to ith category

The VI equation provides an estimated value for a given year ranging from zero to one with the higher value representing extreme vulnerability. The rules highlighted below can be used to determine the relative weights:

- The total weights given to all parameters in each category should be equal to 1.
- The total of weights given to all categories should be equal to 1.

Table A.2: Weight given to each parameter in the calculation of the Vulnerability Index

Category	Resource Stress		Development Pressure		Ecological Health		Management Capacity		
Parameter	**RSs**	**RSv**	**DPs**	**DPd**	**Ehp**	**EHe**	**MCe**	**MCs**	**MCg**
Calculated	A	B	C	D	E	F	G	H	K
Weight in Category	0.5	0.5	0.5	0.5	0.5	0.5	0.33	0.33	0.33
Weighted	0.5*A	0.5*B	0.5*C	0.5*D	0.5*E	0.5*F	0.33*G	0.33*H	0.33*K
Component Total	0.5*A+0.5*B		0.5*C+0.5*D		0.5*E+0.5*F		0.33*G+0.33*H+0.33*K		
Weight for Category	0.25		0.25		0.25		0.25		
Weighted	0.25*(0.5*A+0.5*B)		0.25*(0.5*C+0.5*D)		0.25*(0.5*E+0.5*F)		0.25*(0.5*G+0.5*H+0.5*K)		
Overall Score	0.25*(0.5*A+0.5*B)+0.25*(0.5*C+0.5*D)+0.25*(0.5*E+0.5*F)+0.25*(0.33*G+0.33*H+0.33*K)								

Because the process of determining relative weights can be biased, which can make the final results difficult to compare, it is recommended that equal weights should be assigned among the parameters in the same category, and also among different categories, as shown in Table A.2.

Further explanations are needed to prove policy recommendations in line with the criteria presented in Table A.3.

Table A.3: Reference sheet for interpretation of Vulnerability Index

Vulnerability Index	Interpretation
Low (0-0.2)	This indicates a healthy basin, in terms of resource richness, development practices, ecological state, and management capacity. No serious policy change is needed. It is still possible, however, that moderate problems exist in the basin in regard to one or two aspects of the assessed components, and policy adjustments should be taken into account after examining the VI structure.
Moderate (0.2-0.4)	This indicates the river basin is generally in a good condition in regard to realization of sustainable water resources management. It may still face major challenges, however, in regard to either technical support or management capacity building. Thus the basin's policy design should focus on the main challenges identified after examining the VI structure, and strong policy interventions should be designed to overcome key constraints for the river basin.
HIGH (04-0.7)	This indicates the river basin is experiencing high stresses, and great efforts should be made to design policy to provide technical support and policy backup to mitigate the pressures. A longer term and appropriate strategic development plan should be made, with a focus on rebuilding management capacity to deal with the main threatening factors.
Severe (0.7-1)	This indicates the river basin is highly degraded in regard to being a water resources system with a poor management structure. Restoration of the river basin's water resources management will require major commitment from both government and general public. Restoration will be a long process, and an integrated plan should be made at the basin level, with involvement from international, national and local level agencies.

Acronyms and Abbreviations

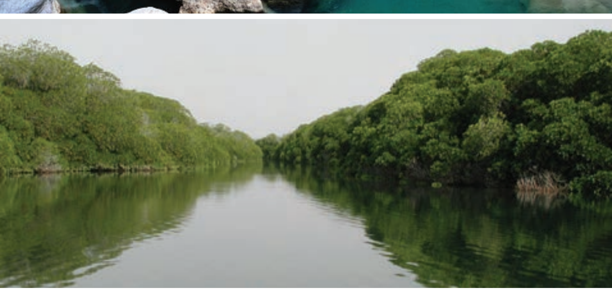
ACSAD	Arab Center for the Studies of Arid and Dry Lands
AFED	Arab Forum for Environment and Development
AGU	Arabian Gulf University
AP	Arabian Peninsula
API	Arab Planning Institute
ASR	Aquifer Storage Recovery
AWC	Arab Water Council
BGR	Federal Institute for Geosciences and Natural Resources (in German)
CEDARE	Centre for Environment and Development for the Arab Region and Europe
CV	Coefficient of Variation
DEM	Digital Elevation Model
DP	Development Pressure
DPd	Safe Drinking water inaccessibility
DPs	Water exploitation
DPSIR	Driver, Pressure, State, Impact and Response
EH	Ecological Health
EHe	Ecosystem deterioration
EHp	Water pollution
ESCWA	Economic and Social Commission for Western Asia
GCC	Gulf Cooperation Council
GCMs	Global Circulation Models
GDC	Groundwater Development Consultants
GDP	Gross Domestic Product
GHG	Green House Gases
GTZ	German Technical Cooperation (in German)
IPCC	Intergovernmental Panel on Climate Change
IWR	Integrated Water Resources Management
LAS	League of Arab States
MAR	Managed aquifer recharge
MAW	Ministry of Agriculture and Water
MC	Management Capacity
MCe	Water use inefficiency
MCg	Conflict Management Capacity
mcm	million cubic meters
MCs	Improved sanitation inaccessibility
MDG	Millennium Development Goals
NGOs	Non-Governmental Organizations
OPT	Occupied Palestinian Territories
ppm	part per million
R&D	Research and Development
ROWA	Regional Office for West Asia
ROPME	Regional Organization for the Protection of the Marine Environment
RS	Resources Stress

RSs	Water Resources Stress
RSv	Water Variation
SAT	Soil Aquifer Treatment
TDS	Total Dissolved Salts
TSE	Treated Sewage Effluent
UAE	United Arab Emirates
UN	United Nations
UNEP	United Nations Environment Programme
UNICEF	United Nations Children's Fund
UNU	United Nations University
VI	Vulnerability Index
WA	West Asia
WEC	Water and Environment Center
WHO	World Health Organization
WR	Water Resources
WW	Wastewater










Vulnerability Assessment of Freshwater Resources to Climate Change: Implications for Shared Water Resources in the West Asia Region provides a useful tool for decision-makers to identify potential risks to freshwater resources in the region from the impacts of climate change.

Already a major constraint to socio-economic development, water stress in West Asia is expected to deepen due to the impacts of climate change. Understanding the vulnerability of water systems in West Asia, therefore, is vital to sustainable water resource management in the region.

The approach employed in this assessment recognizes that a sustainable freshwater system can only function within an integrative operational framework that combines both the natural and management processes.

The assessment concludes that political action is needed to ensure sustainable management of water resources, with vulnerability and adaptation to climate change integrated into future national plans. It recommends that resource management policies shift to demand management, water use efficiency and conservation.

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