Assessment of Freshwater Resources Vulnerability To Climate Change

Implication for Shared Water Resources

in West Asia Region

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UNEP coordination
Dr. Adel Abdelkader

Lead Coordinating Authors
Dr. Abdulla Droubi, ACSAD
Dr. Waleed K Al-Zubari, AGU

Co-authors

ACSAD
Dr. Mahmoud Al-Sibai
Ms. Hiam Al-Ashqar
AGU
Dr. Alaa Abdallah El-Sadek
Dr. Mohammad Jameel Abdulrazzak
Dr. Mona Radwan
Reviewers
Dr. Fatma Attia Abdulrahman
Dr. Yousif Al-Mooji
Production

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Acronyms and Abbreviations

ACSAD:	Arab Centre for the Studies of Arid and Dry Lands
AFED:	Arab Forum for Environment and Development
AGFUND:	Arab Gulf Program for United Nations 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:	Center 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
EOAR:	Environment Outlook for the Arab Region
ESCWA:	Economic and Social Commission for Western Asia
GCC:	Gulf Cooperation Council
GCMs:	Global Circulation Models
GDC:	Groundwater Development Consultants
GDP:	Gross Domestic Product
GEO:	Global Environmental Outlook
GHG:	Green House Gases
GTZ:	German Technical Cooperation (in German)
IPPC:	Intergovernmental Panel on Climate Change
IWRM:	Integrated Water Resources Management
LAS:	League of Arab States
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
ppm:	part per million
R&D:	Research and Development
ROWA:	Regional Office for West Asia
RS:	Resources Stress
RSs:	Water Resources Stress
RSv:	Water Variation

SAT:	Soil Aquifer Treatment
UAE:	United Arab of Emirates
UN:	United Nations
UNEP:	United Nations Environment Program
UNICEF:	United Nations Children's Fund
UNU:	United Nations University
VI:	Vulnerability Index
WA:	West Asia
WB:	World Bank
WEC:	Water and Environment Center
WHO:	World Health Organization
WR:	Water Resources
WW:	Wastewater

Executive Summary

Countries of the West Asia region have been experiencing different degrees of natural and anthropogenic water risk regarding 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 human activities, including the expected impacts from climate change, presents a major challenge to decision makers. They have to achieve adequate, safe and dependable water sources and food supply in the future for improving the well-being of the society as well as meeting the requirements of the future generations.

The West Asia 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, Occupied Palestinian Territories, Syria and Yemen) and the Gulf Cooperation Council (GCC) countries (Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, UAE). The whole region, however, is suffering from water scarcity; which is attributed to large temporal and spatial variations in most of the hydrological parameters, especially the rates of precipitation and evaporation. The most significant parameter causing environmental stress is the rainfall pattern, which influences the generation and dependability of freshwater availability in terms of its amount, frequency and distribution. Climate change will further increase the variability of rainfall adding more uncertainty and complication to the planning and management process 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 West Asia is therefore vital to ensure sustainable water management in the region. Undertaking a vulnerability assessment of fresh water will distinguish 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 which is based on the premise that the vulnerability assessment must have a precise understanding of four components of the water resource system, including: total water resources; water resource development and use; ecological health; and 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 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 understanding of the problem and its solution are still emerging. It is clear from the above analysis that the vulnerability of freshwater resources in West Asia countries is a result of inadequate management levels and will be exacerbated by the effects of climate change.

The main water management challenge facing the countries of West Asia region is the increasing stresses and deterioration placed on 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, adequate legislative framework, 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, and 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 the countries of West Asia 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 tension between riparian countries. The issue of shared water resources should be given high priority by the countries of West Asia to finalize water resource sharing agreements according to the international water law. Large water saving opportunities exists in the agricultural sector, which uses more than 80 per cent of the total water consumption in the region and where most of water wastage occurs. Savings are possible through increasing irrigation efficiency by 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 increasing source of water with considerable potential in alleviating water scarcity in the region, particularly since the volume available increases proportionally with increasing urban consumptions. 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 schemes. While increasing reliance on desalinated water in the region is inevitable in the future and contributes in lessening water scarcity, especially for the GCC countries, desalination technology has many drawbacks: it is capital and energy intensive; is largely imported; provides limited added value to the countries' economies; and has many negative environmental impacts. There is an urgent need for cooperation among the West Asia countries and with the Arab Countries for investment in R&D for desalination technology, with the aim of acquiring and localizing these technologies in the region. This would see many advantages, including reducing costs, increasing the reliability of supply, increasing value for the countries' economies, and a reduction in the environmental impacts of desalination.

The issue of water resources management should be placed high on the national priorities list of the countries of West Asia. Political action is needed for the sustainable management of water resources and is a necessary pre-requisite to reduce freshwater vulnerability in the countries of the region.

In order to cope with the water scarcity and lower the freshwater vulnerability in the region, a major shift to demand management, water use efficiency, and conservation need to be made. This should focus on the agricultural sector where most of the 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 framework. 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 1

Introduction

Chapter Key messages

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

In addition to the prevailing arid climate, freshwater availability is expected to suffer from the impact 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.

Litani River in Lebanon (ACSAD, 2010)

1.1. Background

Countries of the West Asia region have been experiencing different degrees of natural and anthropogenic risk regarding 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 human activities, including the expected impacts from climate change, presents a major challenge to decision makers. They have to achieve adequate, safe and dependable water sources and food supply in the future for improving the well-being of the society as well as meeting the requirements of the future generations.

The West Asia region (according to the United Nations Environment Program, UNEP, classification) 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, Occupied Palestinian Territories, Syria and Yemen) and the Gulf Cooperation Council (GCC) countries (Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, UAE). The whole region, however, is suffering from water scarcity which is attributed to large temporal and spatial variations in most of the hydrological parameters, especially the rates of precipitation and evaporation. The most significant parameter causing environmental stress is the rainfall pattern, which influences the generation and dependability of freshwater availability in terms of its amount, frequency and distribution. Rainfall and snow-accumulation are the sources of river flow, runoff in major wadis, rain-fed agriculture, recharge to groundwater and hazardous flooding and drought events. The 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 sub-region influences the amount of sporadic drainage through wadis, flash floods and groundwater recharge. Climate change will further increase the variability of rainfall, contributing to greater uncertainty and complication in the planning and management processes of the water sector.

In addition to natural water scarcity, human activities are contributing to the depletion and deterioration of resources through increases in water demand in all sectors and pollution. The high population growth increasing rates of urbanization and economic activities have placed extensive pressure on the already limited water resources. The achievement of the Millennium Development Goals (MDG) of adequate and safe water supply and sanitation has added additional pressure on the limited water resources as well the satisfaction of food security. Increases in water demand, especially in the irrigation sector, have contributed to further depletion of surface water and groundwater resources, many places in excess of potential recharge. Pollution from domestic, industrial and agricultural wastes is further contributing to the loss of already limited resources.

There are many shared surface and groundwater resources between countries of the and with neighboring countries. Many of the deep aquifers are shared among countries of the Arabia Peninsula sub-region and also with Jordan. Freshwater status is further complicated by the fact that substantial portions of surface water originate from outside the region, with no binding agreement for sharing water resources between the riparian countries, or the implementation and monitoring of the existing agreements. The control of shared surface and groundwater flows from up- and down-stream countries has increased water disputes and could impact regional stability.

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

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.). Therefore, the United Nations Environment Program (UNEP) Regional Office for West Asia (ROWA) in Bahrain, within its mandate to help its member states to enhance their capacities to address priority and emerging issues such as freshwater vulnerability, has commissioned the Arabian Gulf University (AGU) and the Arab Centre for the Studies of Arid and Dry Lands (ACSAD) to undertake a desk study assessing the current and future freshwater resource vulnerability. This study examines water vulnerability for national and shared resources in the face of climate change.

1.2. Objectives

Freshwater vulnerability assessment is a tool to identify potential risks, providing decision makers with an early warning signal about the need to monitor potential variation over time. This is important in order to detect the occurrence of threats early as well as formulate and implement measures to reduce negative impacts. Vulnerability assessment of freshwater will also identify gaps in existing information and the appropriate indicators and management measures required for the government to gather such information by committing the necessary financial and human resources to the issue. Moreover, the assessment enhances public awareness about the threat that society may face.

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 implement measures to improve water resource management. The specific objectives will focus on the following tasks:

- Assess the vulnerability of the freshwater to threats and its impacts 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 water demand of different sector,
- Evaluate impacts of environmental change in terms of water resource stress and identify management challenges;
- Develop knowledge, policy options, and understanding the 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.
- 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 was 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 crisis, since any variation in precipitation will have direct negative impact on the limited water resources in these areas. Thus, this analysis is based on the premise that the vulnerability assessment must be based on a precise understanding of four components of the water resource system, including their states and relationships, these are:

- Total water resources
- Water resource development and use
- Ecological health
- 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, 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 Driver, Pressure, State, Impact and Response (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 that stress is being placed on the water sector by water scarcity, increasing water demand and the requirements of socioeconomic activities and ecological conditions will be evaluated by the vulnerability assessment.

Although such studies require advanced modeling 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 2

Water Resources in West Asia: An Overview

Chapter 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 the available water resources and agricultural productivity. Moreover, under these unfavorable and uncertain conditions, it is expected that food self-sufficiency will decrease with time, resulting in the failure of the 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.

Men using boats to restore the marshlands of the Shatt al Arab, Iraq. Photo credit: USAID

Shat el Arab –Iraq (Photo found in UNEP 2009 after credit from USAID Photo credit: USAID)

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 the West Asia region, 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 regions (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 GEO-4, 2007). The region has two shared rivers originating outside the area (Euphrates and Tigris) and many smaller ones. The Arabian Peninsula (AP) is characterized by an arid climate with annual rainfall of less than 100 mm, with no reliable surface water supplies. The region depends entirely on groundwater and desalinated water to meet its water requirements (UNEP GEO-4, 2007).

These two sub-regions can be differentiated by 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 desired socioeconomic development, and both sub-regions are highly vulnerable to external natural and man-made stresses, such as the rainfall amount and variability, population growth, pollution levels, and water management practices (UN-ESCWA, 2005).

In the last three decades, most of the countries in the WA region have undergone major demographic development 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 (LAS-UNEP/EOAR, 2010).

Water scarcity in the region is further aggravated by the continuous deterioration in the quality of surface and groundwater resources by industrial, domestic, and agricultural effluent discharges, which is also impacting the human health (LAS –UNEP/EOAR, 2010).

Another major challenge facing the countries of the region is the management of shared water resources among countries within the region as well as those shared with countries outside of the region. As more than 60 per cent of surface water resources originate from outside the region, this issue remains a major concern threatening the region's stability, food security, and water resource planning (LAS –UNEP/EOAR, 2010; ACSAD 2009). Conventions and agreements on equitable sharing and management of water resources have not been signed by riparian countries for some shared rivers such as the Euphrates and Tigris. For others such as Orontes a convention has been signed. Furthermore, some of the countries of the region (Palestinian Occupied Territories, Syria, and Lebanon) are deprived of their water resources due to Israeli occupation of part of their territories, by occupying powers which constitute another major issue in the region and is constraining the development of its populations (ACSAD, 2009; LAS –UNEP/EOAR, 2010).

The critical nature of the current water situation in the region is expected to be further aggravated by the impacts of climate change, where it is anticipated that water scarcity and quality deterioration in the region will increase due to the reduction of precipitation, increase of domestic and agricultural water demands and seawater intrusion in 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 WA 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 land for agriculture (UNEP, 2000). The percentage of land cover by desert areas varies among countries. A large proportion of the GCC is covered by desert, with only small areas of land are considered as having a reasonable natural resources base endowment. In the Mashriq sub-region 50.6 per cent is covered by desert areas with 36.4 per cent covered by areas vulnerable to desertification and just 13 per cent considered suitable land for agriculture. In the Arabian Peninsula, about 88.8 per cent is desert, 8.8 per cent is vulnerable to desertification and only 2.4 per cent suitable land for agriculture (UNEP GEO-3, 2002). The desertification process is influenced by the temporal and spatial distribution of rainfall pattern and the frequency of drought cycles. The large percentage of the lands of West Asia region being arid and semi-arid areas is attributed to the extreme random nature of the rainfall characteristics that influence 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, have characterized this part of the world. Rainfall distribution in the region exhibits large variation in the amount and frequency as 72 per cent of the region receives on the average less than 100 mm per year mainly in the GCC countries, 18 percent of its area receives 100-300 mm per year and only 10 per cent of the region receives more than 300 mm per year (analysis in present study). Annual rainfall distribution in WA is shown in Figure 1.

Areas that have relatively high rainfall rates of more than 300 mm are limited to locations in the 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 the renewable ground water in the region.

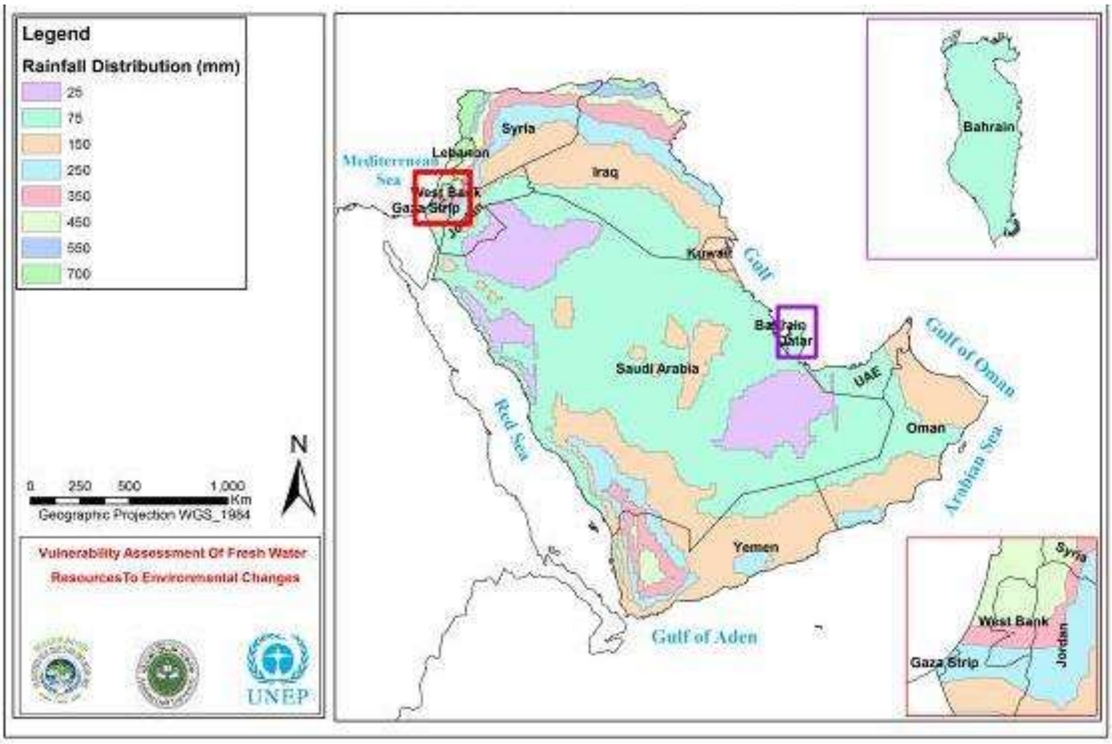


Figure 1: Rainfall distribution in West Asia.

2.2.2. Water resources

The West Asia 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 river flows, are estimated at 93 100 million cubic meters (mcm) concentrated mainly in the Mashriq sub-region with 80100 mcm available from the major shared rivers and the remaining 13000 mcm from small rivers, springs and intermittent wadi flow(UNESWCA 2007). The Mashriq countries, such as Iraq, Lebanon and Syria, rely on river flows supplemented by limited groundwater sources, while the remaining countries have been relying on flood and shallow and deep groundwater sources. The total annual internal renewable water resources account for only 6.3 per cent average annual precipitation, against a world average of 40.6per cent, due to the high rate of evaporation. While renewable water resources are the main dependable sources in the countries of the region, resource renewal is expected to experience uncertainty due to climate change.

Renewable groundwater in the region is generally present in 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. The renewable groundwater source is estimated at 15 500 mcm (UN-ESCWA, 2007), representing the amount of the groundwater recharge (UN-ESCWA, 2007). In the Mashriq sub-region the amount and the frequency of recharge is much greater than in the Arabian Peninsula sub-region, due to the higher amount of rainfall and its frequent occurrences. The degree of groundwater exploitation in most countries of the West Asia region 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 (LAS –UNEP/EOAR, 2010).

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

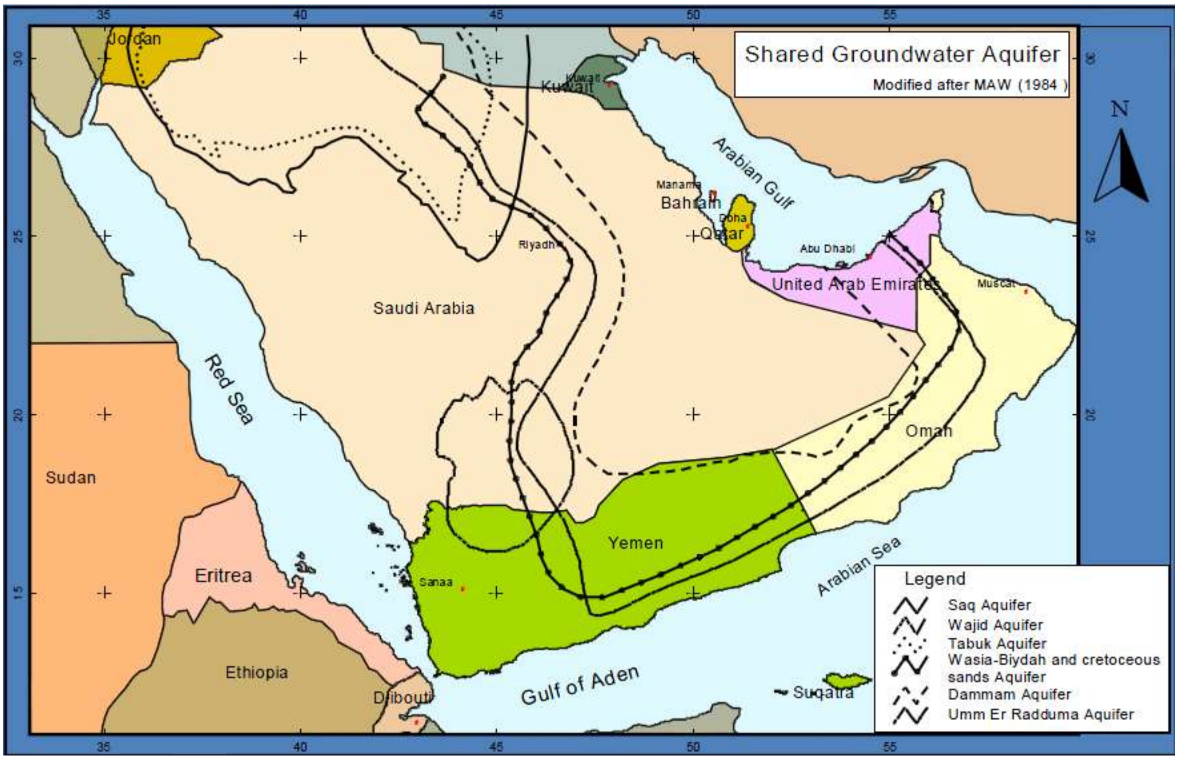


Figure 2: Shared groundwater aquifers in Arabian Peninsula (MAW, 1984).

A large portion of shared surface water, estimated at 56000 mcm of the total flow, originates outside the region (UN-ESCWA, 2007; UNEP GEO 4, 2007). The 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, OPT and Israel.

The water dependency ratio in the Middle East indicates the proportion of renewable freshwater resources that originate outside the country in question. 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).

Figure 3: Water Dependency Ratio in the Middle East by Country.

(Source: Strategic Foresight Group, 2009)

Countries such Iraq, Syria and OPT have been experiencing reduced surface water flow resulting from disputes about water sharing. Currently, the majority of shared water resources do not have a binding agreement to regulate their utilization and management (LAS – UNEP/EOAR, 2010). Cooperation among the countries is effected by the prevailing political situation. Political tension in the past has resulted in reduction of upstream releases. Increased competition for the limited water sources to meet the demand of socio-economic activities could lead to regional instability; however it could also be used as a catalyst to agree on fair allocation and improve management measures, especially from the 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 a sustainable condition. In addition, neglecting to address the issue will not make the problem to disappear but further exacerbate the situation and increase tension among the countries of the region as well as with neighboring countries.

Other complimentary water sources are available from desalination of seawater and brackish water and reuse of treated wastewater. Desalinated water with very low total dissolved solid has become the main source of water for the domestic sector in most of the GCC countries (World Bank, 2005). The 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 3300 mcm per year equivalent to 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).

Treated wastewater at desirable quality standards represents a potential non-conventional source of water to augment the irrigation water supply. Countries of the Arabian Peninsula sub-region and also Jordan and Syria have initiated reuse of treated wastewater for landscaping and agriculture, estimated at 640 mcm per 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 (LAS –UNEP/EOAR, 2010).

2.3. Socio-economic context

Social, economic and environmental factors influence the well-being of society of each country in the WA region. Countries of the region have been formulating and implementing policies to improve the standards of living through the provision of improved water supply and sanitation coverage and services and promoting economic activities to generate higher income.

The economy in the past has been relying on a mixture of mechanisms mainly regulatory. However, in the last two decades a trend has emerged towards 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. During the last two decades demographic changes and socio-economic development, especially in the GCC countries, have lead to increasing domestic water demands in the region. The main drivers impacting water availability are high population growth and urbanization, which increase demand for water. Population growth exerts two types of pressures to meet MDG goal–the first providing adequate drinking water and sanitation services and the second producing enough food. The population growth in all countries of West Asia has been increasing at a faster pace than the development of services (UN-ESCWA, 2009).

The high population growth can be attributed to improved health care, large family size and change in lifestyle, especially in the GCC countries. The total West Asia population increased from less than 20 million in 1950 to 98 million in 2000, a fivefold increase. It reached 116 million in 2005 and is expected to reach 146 million in 2015 (UNDP, 2009). During the period 1985-2005 the population size varied among the two West Asia sub-regions. In the Mashriq sub-region population was at 25.4 million in 1975 and reached 82 million in 2005 and is projected at about 159 million in 2040, while for the GCC it was at 7.1 million in 1975, 35 million in 2005 and is expected to reach about 61 million in 2040. Figure 4 below illustrates the difference in population growth rates between the countries of WA (this study).

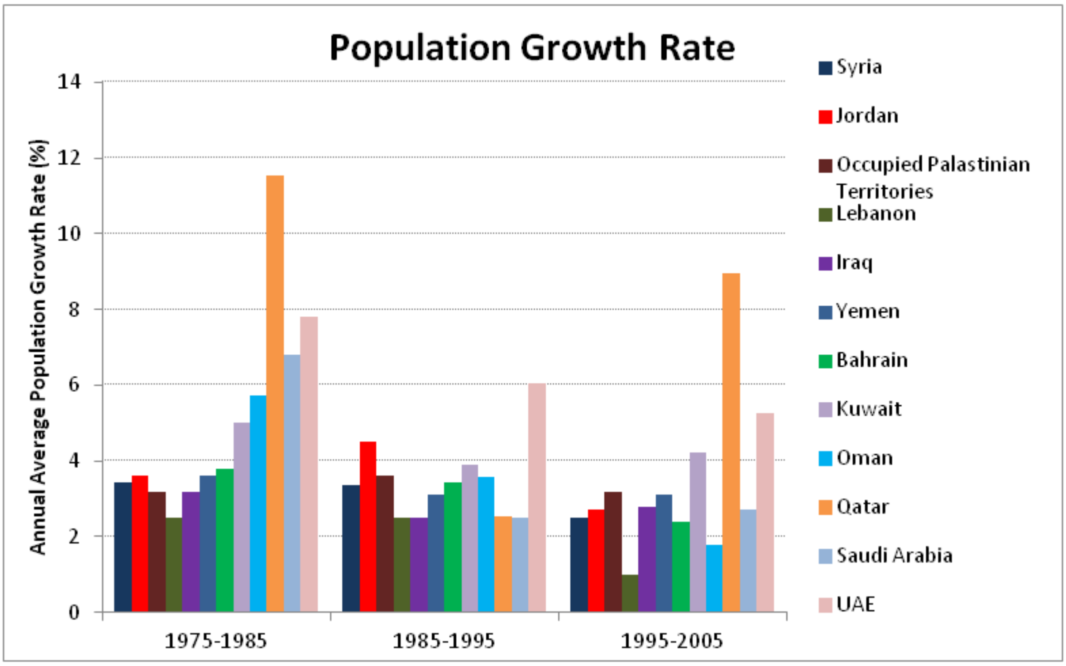


Figure 4: Population Growth for WA countries 1975 – 2005. Bars show the average population growth per annum for the decades preceding 1885, 1995 and 2005.

The per capita share of water resources has decreased due to the rapid population growth, as evident by the decreasing trends of renewable water resources per capita (Figure 5). Some countries show severe water stress, with values below the water poverty threshold. The annual per capita of renewable sources provides an indication of the freshwater vulnerability to natural and man-made activities expressed in cubic meters (m^3) of renewable water resource per capita. The West Asia region's annual per capita freshwater share fell from 1700 m^3 in 1985, to 907 m^3 in 2005 (UNEP GEO 4, 2007). The region's annual per capita freshwater availability (Figure 5) is very low compared to the world average of 7243 m^3 (CEDARE AWC, 2006). Sub-regionally, the per capita water availability for the Mashriq fell from 2844 m^3 in 1985 to 1608 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 1500 m^3 while for the AP is estimated at 125 m^3 (UN-ESCWA, 2007). Future per capita share in renewable water in WA region is expected to decrease to reach 650 m^3 in 2025 and 420 m^3 in 2050 due to anticipated population increase as shown in Figure 6.

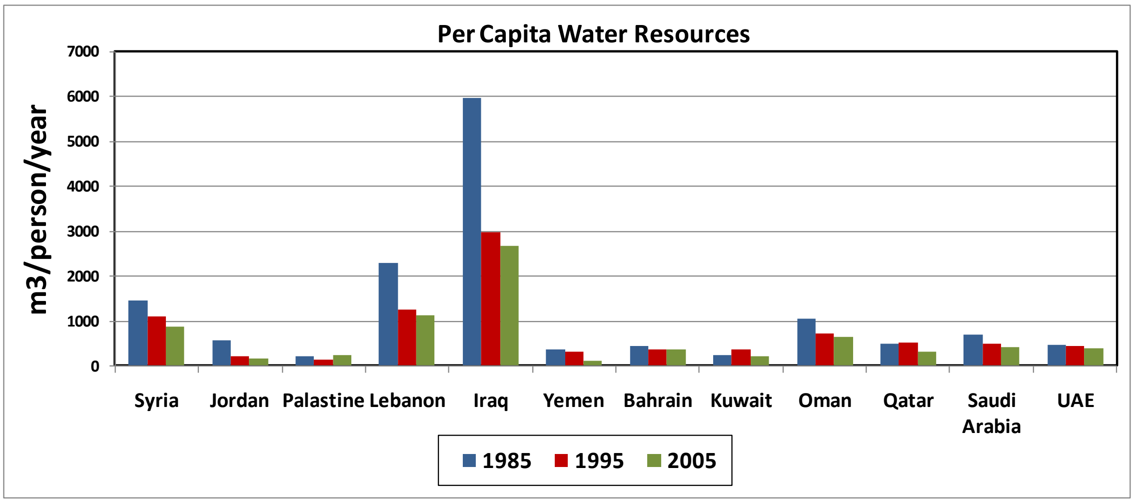


Figure 5: Per capita freshwater availability trend (this study).

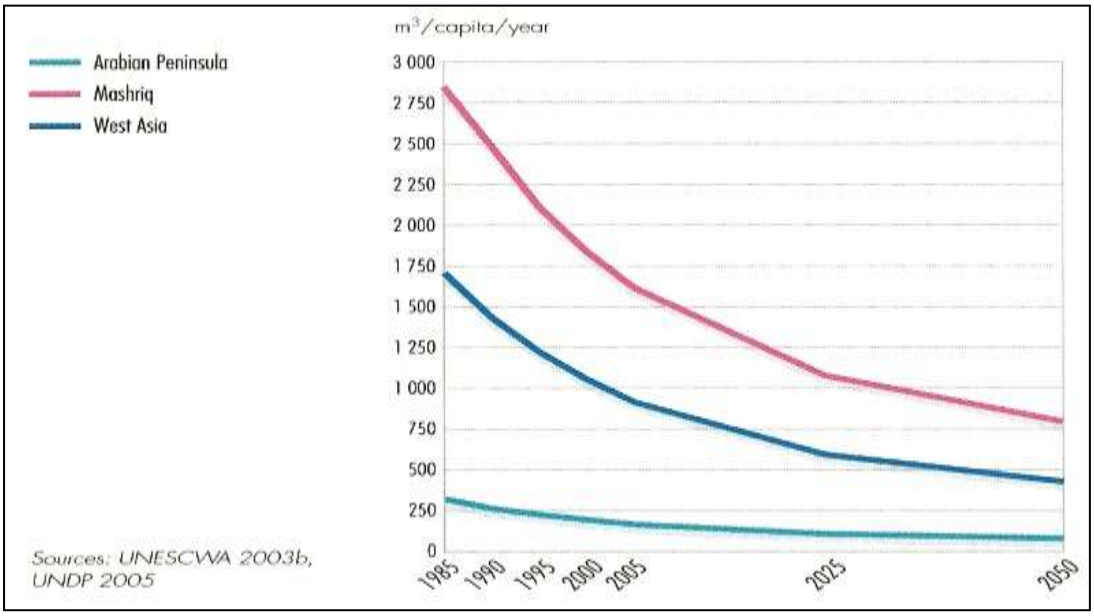


Figure 6: Trends and projection of share of renewable sources in West Asia.

Source (UNEP-GEO-4, 2007)

2.3.2.Urbanization

The increase in the population growth rate was accompanied by high urbanization rates resulting from the increased economic activities, migration from rural areas and an influx of foreign labor. Push factors from rural areas include: decreases in water availability due to depletion; the frequent occurrence of drought events; 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-ESWCWA, 2009). The urban population rate in WA increased from 23.7 per cent in 1950 to 55 per cent in 1980, reaching 66.5 per cent by 1995 and 69 per cent in 2000 (UNEP, 2000 GEO2). In 2005, it reached 85 per cent in the GCC and 71.6 per cent in the Mashriq (UNDP, 2009). Moreover, the change in the consumption pattern has resulted in increased per capita water consumption and the generation of more waste.

Urbanization process has created many urban centres in excess of more than million people putting more pressure on the government budget to expand water supply and sanitation infrastructure to 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). In Amman, Jordan, shortages have reached a critical point forcing the government to make a major undertaking by piping 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 reached 3.8 million in 2000 water shortages started to be felt, leading to the implementation of water rationing. Water shortages are also experienced in Palestine and some cities in Saudi Arabia.

The housing sector expansion in newly developed areas is taking place at a faster rate than the installation of water and sanitation infrastructures. Many newly built areas lack water supply and wastewater collection systems. There was an increase in the number of slums during 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 loss of fertile agriculture lands (encroachment) and sensitive coastal shorelines around some of the major cities (land reclamation).

2.3.3. Water related MDGs

In general, there has been major progress in the last two decades in expanding access to water supply and sanitation services in WA, despite the financial limitation of some of the countries. This progress was undertaken not only to achieve the Millennium Development Goals (MDGs), but also because water supplies and sanitation had 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, there are still some countries lagging behind (Figures 7 and 8).

In the WA region, there are approximately 37 million people that do not have access to safe drinking water and about 40 million people that need access to sanitation services (CEDARE and AWC, 2006). This is largely because these people live in lower income countries, are under occupation, or are riddled by war and conflict. It is estimated that the total financial cost of providing the 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, under MDG7, would be about 100 000 million and 62 000 million US dollars, respectively (CEDARE and AWC, 2006). At this point, the lower income countries do not have the financial resources to make this sort of investment. Investment in providing clean water supply has the potential to generate a high return in reducing health care costs. If current practices and trends continue, large investments in water and sanitation treatment facilities will be required in the future for the protection of general public health, particularly given the high population growth and 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 in many countries in the region hinders increased reuse, even in countries that have achieved the treatment of their wastewater to the level of well recognized standards (third degree of treatment) that allow for its use in the irrigation sector. This opposition can be attributed to farmers' personal and religious beliefs.

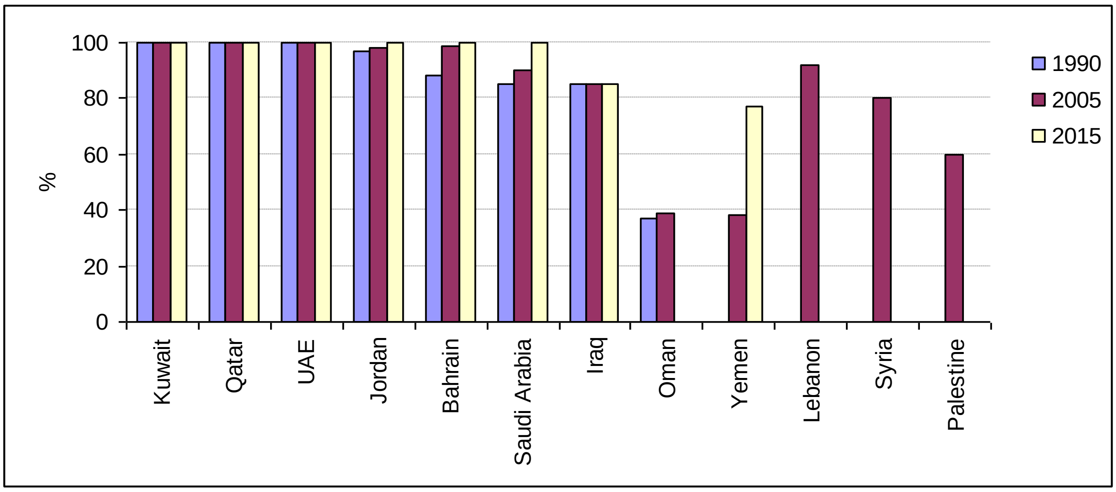


Figure 7: Trends of population with access to safe drinking water for the periods1990, 2005, and 2015 (CEDARE and AWC, 2005)

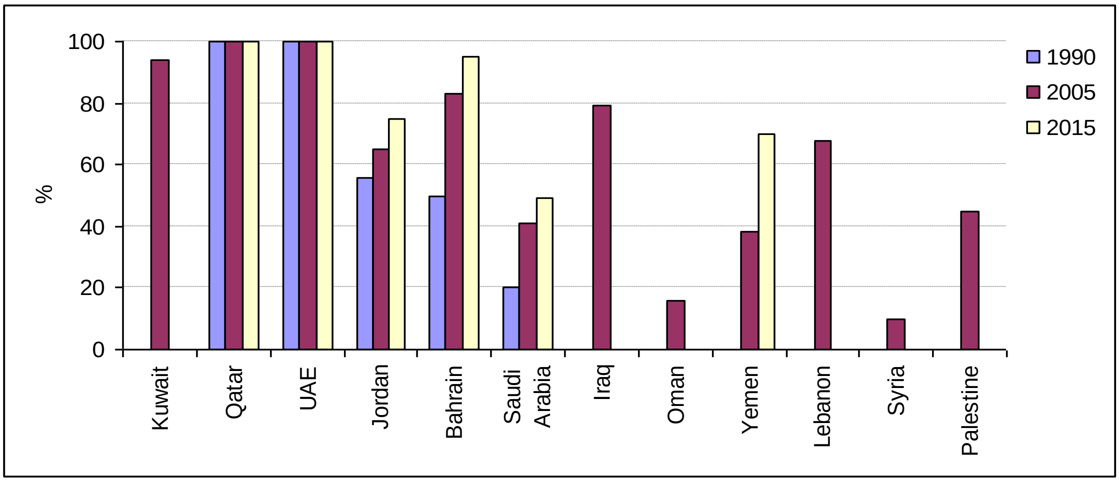


Figure 8: Trends of population with access to sanitation for the periods 1990, 2005 and 2015 (CEDARE and AWC, 2005)

2.3.4. Economic activities and Water Demands

The oil, agricultural and industrial sectors provide a diverse source of income for the region and are contributing by different degrees to the gross domestic product (GDP) of the individual countries. The main source of income for the GCC countries is oil and the associated petrochemical industries, while for the Mashriq sub-region it is a mixture of agriculture, industry and labor 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 of the countries of the WA region are experiencing different degrees of water stress to meet the increasing water demands especially in the irrigation sector. The increases in water consumption in the domestic and irrigation sectors is due to high population growth, improved standard of living and improved water supply and sanitation infrastructures, increased irrigated areas and overall increased industrial activities. Municipal water consumption escalated from 7 800 mcm in 1990 to about 11 000 mcm in 2000, and is currently approximately estimated at 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 used (Figure 10). During the past few decades, economic policies favoring 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 increased from approximately 73 000 mcm in 1990 to more than 85 000 mcm by 2002 period (UN-ESCWA, 2003), and reached about 87 000 mcm in 2007 (UN-ESCWA, 2007), exerting 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 countries, 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 investment could be beyond the financial capacity for most of the countries of the Mashriq sub-region. The percentage of water availability according to the supply sources and consumption of different sectors for the Mashriq sub-region is shown in (Figure 12).

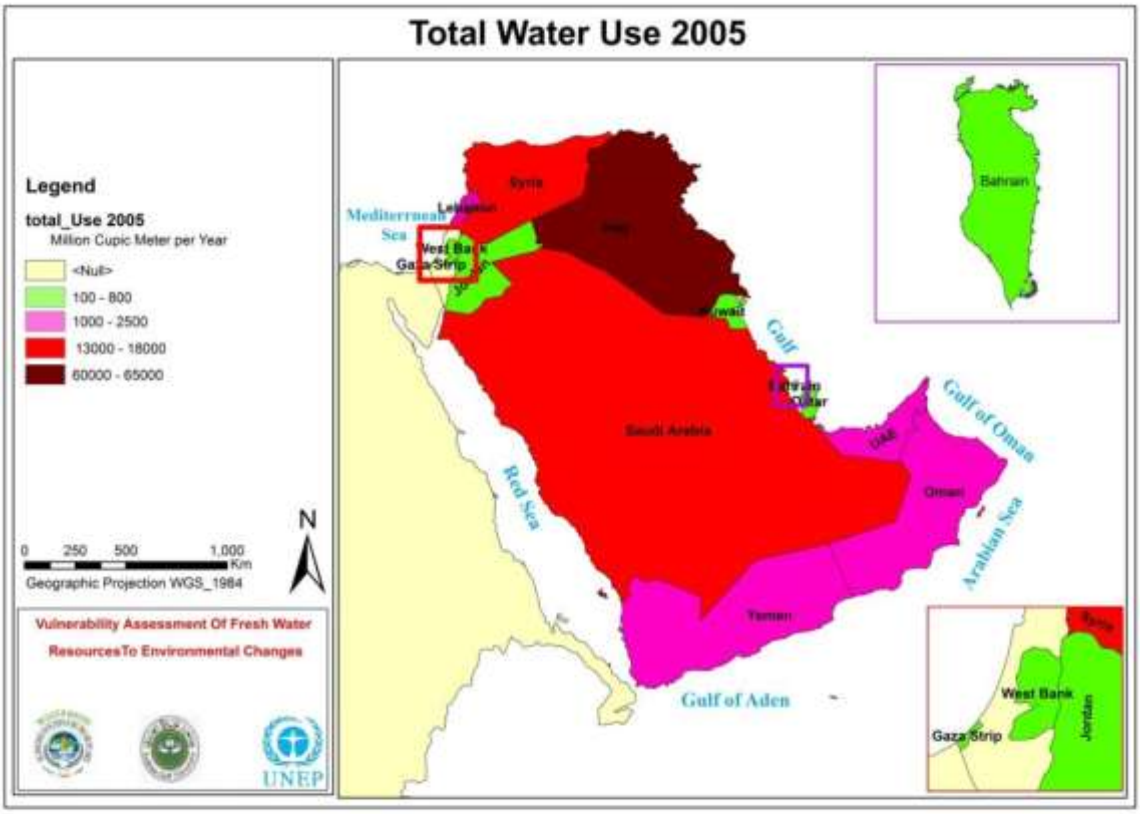


Figure 9: Total water use of West Asia countries.

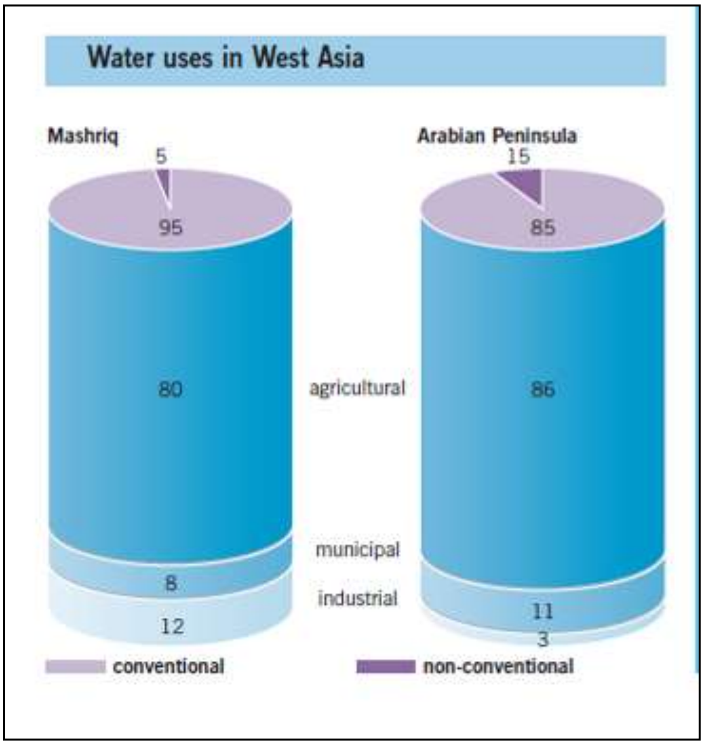


Figure 10: Water consumption percentage in West Asia (UNEP/GEO3, 2002).

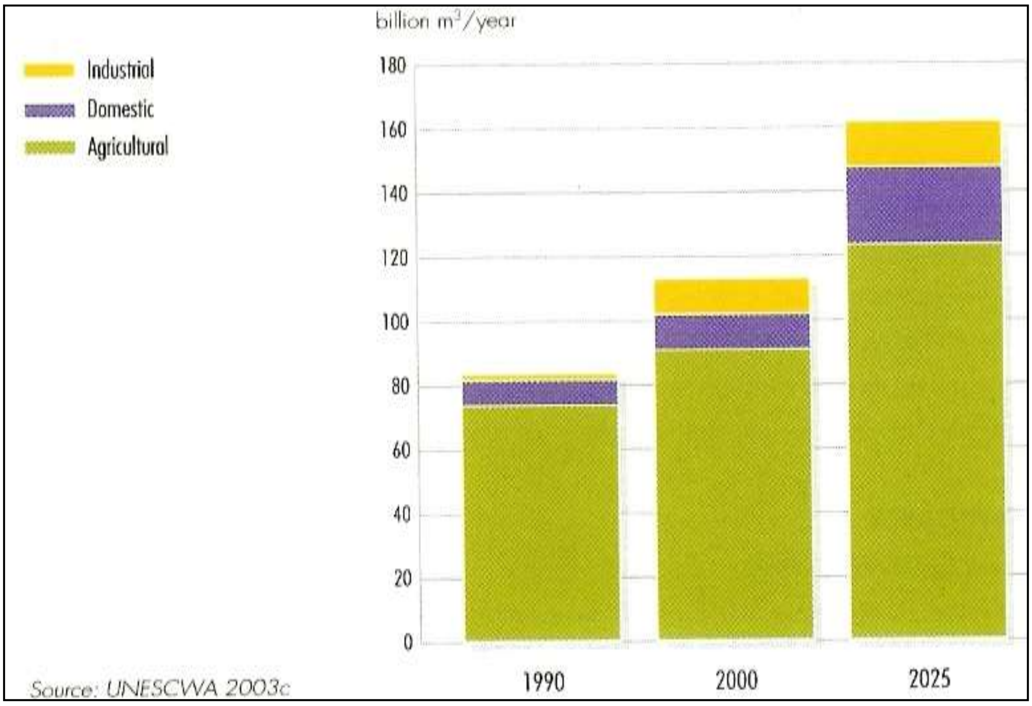


Figure 11: Trend and projection in water demand in West Asia (UNEP/GEO 4, 2007).

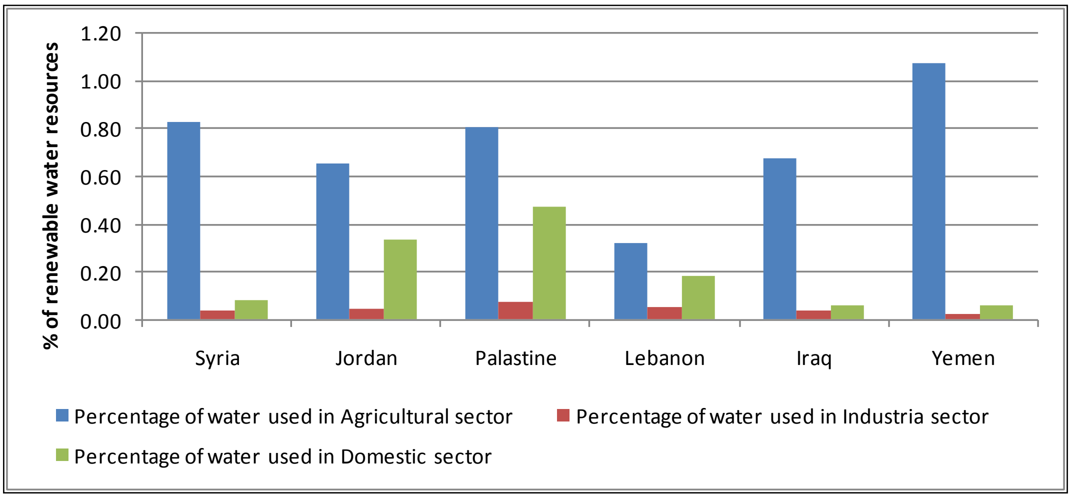


Figure 12: Percentage of water use in different sectors in the Mashriq sub-region.

2.3.5. Water Sector Financing and Contribution

Government budget, influenced by the magnitude of GDP, is the main source of funding for the development and management of the water sector. Annual budget allocation contribution to the water sector varies among countries of the region with higher allocation the GCC while some countries, mainly 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 with the volatile price of oil, contributing US$258000 million in 1995 and US$693 000 million in 2005 with the intention to invest in the water sector and improvement of social benefits (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 remaining countries of West Asia region was estimated at US$92 600 million. During the period 2004 to 2008, the GDP growth rates in the GCC fluctuated from as low as 5.3 per cent in Saudi Arabia to a 20.8 per cent in Qatar in 2004, while for 2008 it ranged from 4.1 per cent in Saudi Arabia to 9.7 per cent in Qatar. For the remaining countries, it ranged from 2 per cent in Palestine to 23 per cent in Iraq in 2004 compared to 1 per cent in Palestine 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 from some of the ESCWA countries and other parts of the world, putting more pressure on the water supply sector. The growth in tourism also contributed to a small increase in the water demands. This sector employed 20-30 per cent of the total population contributing 8-15 per cent to the total GDP.

The irrigation sector has contributed lower relative value to the GDP than the industrial and oil sectors. Agriculture contributed 20-30 per cent of GDP in the Mashriq sub-region and Yemen and 2 per cent in the GCC countries in 2005 (UNDP, 2005). During the period 1995-2005, the sector employed 16-54 per cent of the labour forces mainly in Yemen, Syria, and Palestine, with a small 5 per cent in GCC (UNDP, 2009). Agriculture has still made relatively good economic contribution for some of the countries such Lebanon, Syria, Iraq, Oman, Saudi Arabia and Yemen. However in many countries, agricultural production has not kept pace with the rapidly increasing demand for food, resulting in a widening food gap that is filled by imports.

GDP per capita data indicates that most countries experienced higher per capita improvements to the standard of living with this GDP growth. This has resulted in higher water consumption, estimated at 350-600 liters per day for most of GCC countries (LAS –UNEP, 2010). The recently high food prices have influenced the agriculture policy to achieve food security goal (e.g. by investing abroad and preserving water in order to meet the MDGs related to water supply and sanitation requirements). Furthermore, increases in commodity prices, especially the recent food price crises, have eroded individual incomes, especially the poor, leading to the maintenance of government subsidies of the water supply and the irrigation sectors. Prevailing inflation situations during the last five years especially have forced many governments of the region to maintain subsidies to establish a safety net for the well-being of the general public.

Social safety nets in term of subsidies have been justified on equity grounds, especially for the poor, to enhance water provision in all countries of the region. The water supply provision in all countries was subsidized through low water tariffs estimated at much less than water production and distribution cost. The production of desalinated water generally has higher production cost than that from surface and groundwater sources. Significant financial subsidies are being provided by the GCC countries for the provision of excellent water supply quality and adequate quantities, where the cost of the desalinated water production is estimated at US$ 1-2 per cubic meter (World Bank, 2005) compared to a very low water tariff rates in the local currency. Extensive agricultural subsidies were provided by the GCC countries, Syria, Iraq and Yemen. Moreover, the remaining countries provide different types of subsidies to the agriculture sector to enhance farm income and increase productivity.

2.3.6. Social benefits

Water availability, dependability and quality has implications for enhancing human welfare in regards to human health and the satisfaction of the human right to adequate and clean water supply and appropriate sanitation coverage. The most important social dimension is to provide real opportunity for the 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 the social well-being for all segments of the society to provide adequate and safe water sources, and the collection and treatment of domestic waste which is considered a part of the MDGs.

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 level being experienced in many parts of the region, especially the Mashriq sub-region, is posing high health risks to the communities, reducing water supplies and damaging the fragile ecosystem regimes. As the quality of water resources deteriorate, the health risk level is increased as well as the cost of health care and the treatments costs of highly polluted water is increased. Pollution sources are taking place from either over-exploitation of the 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 rivers courses and wadi beds (Hamad *et al.*, 1996). The percolation of such wastes into shallow aquifers represents a major health risk from especially nitrate, fecal coliforms, undetected viruses and heavy metals. Contamination in this way poses a significant health risk and can cause malaria, nutritional defects, water-borne diseases such as Giardiasis and Cryptosporidiosis, and respiratory illness. Nitrate contamination of groundwater sources in the Mashriq countries poses a serious source of illness for infants. Nitrate 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, residual metals emitted during production of desalinated water also pose health risk 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.

Despite the generous subsidies, the agricultural policies adopted in many countries have not achieved their desired goals, as the sector performance indicators are very low in achieving food security with major negative impacts during the period 1995-2008 on the depletion and deterioration of limited water resource. Agricultural performance and food production in the region remains unsatisfactory (Dabour, 2006; LAS-UNEP/EOAR, 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 sources through 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. There has also been increased pollution from pesticide and domestic wastes. Over the last two decades, the net irrigated area tripled across all GCC countries (LAS-UNEP/EOAR, 2010).

2.4. Water Governance

During the past few decades, economic policies favoring 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 health systems, it has had some adverse environmental effects related to urban and irrigated agriculture 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 the future challenges and constraints. The current situation reveals that depletion of water resources and deterioration of their quality poses a human security challenge for future generations. The current water problem is associated with the absence of holistic planning in line with the integrated water resources management (IWRM) framework in many countries. The main pillar of IWRM is good water governance. Integrated water resources management 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, policy makers, politicians, and community leaders. All of these partners form the water governance. It includes, enabling environment (integrating policy), water legislation (a legal framework) to set the implementation of policy, water institutions and building capacity, stakeholder participation and financing structure. Indicators of governance consist of accountability, effectiveness, regulatory quality, rule of law, control of corruption, and institutional quality (UN-ESCWA/ BGR and GTZ, 2004).

Currently, the water sector in many countries lacks appropriate governance owing to the difficulty of the required reform and integration of water policy with socio-economic development policy, as well as inadequate institutional arrangements. As a result existing water policies are fragmented and focus on the issue of water development for increasing water resources with little attention to an integrated management approach. Past practice neglected addressing the institutional arrangements to delineate overlapping function, jurisdiction in water and water related sectors, and legal enforcement for the implementation of water policy. 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 management of water resources, economic efficiency, social equality and environmental justice call for better governance practice. 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 West Asia:

- Application of strong water governance measures can contribute towards policy integration,
- Enhanced institutional arrangement,
- Improve the legal framework and its enforcement,
- Increase coordination,
- Transparency and accountability, financial efficiency,
- Decentralized decision making process,
- Encouragement of public participation, protecting individual rights, sharing experiences and promotes riparian cooperation.

Evaluation of the current state of these indicators in the water sector in the region is difficult; however the prevailing trends do vary among countries. There is evidence of with better performance on the rule of law, institutional set up and regulation and less on accountability for water distribution, cost recovery of water structure and effectiveness in water use and management.

2.5. Climate change and water resources

Anthropogenic climate change due to increasing man-made emissions is now an agreed upon reality being debated at the international levels by the UN, other international organizations and scientific communities. Fossil fuel combustion is the main source for the increase of the greenhouse gas emissions caused by increased socio-economic development activities and mismanagement of natural resources, such as overgrazing and accelerated development of urbanization centers. Other emissions include nitrous oxides, methane, ozone and chlorofluorocarbons. The Fourth Assessment Report of the Intergovernmental Panel on Climate Change indicated that the global average surface temperature has increased by 0.74^{o}C during the last century (IPCC, 2007). The change in temperature regimes during the 19thcentury was an increase in the range of 0.3-0.6 ^{0}C, while for the past 40 years the increase was within the range of 0.2-0.3 ^{o}C since 1970 (IPCC, 2007). This temperature change was accompanied -depending on the emission scenario- by increases or decreases in rainfall with heavy amounts in some regions of the world, increased evapo-transpiration rates, and a sea level rise of 0.17 m during the same period. Projections indicate that by 2100, global temperature is expected to increase by 3 - 4°C and the 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, poor and disadvantaged as well as the natural system. The impacts are expected to vary in space and time. Climate change could have major implications for human health. There are emerging new diseases in many regions of the world that may be attributed to changing weather patterns (UNPD, 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 the belt of these species up to higher elevation. Low land coastal zones, especially along the Gulf and small islands, will be exposed to sea level rise, and the increased temperature and changed 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 increases in weather related disasters, it was reported that in the year 2000 there were 500 events compared to 120 events in 1980, with a six-fold increase in flooding events (UNEP/GEO 4, 2007). Extreme events such as flooding will increase surface runoff with increases in sediment load, nutrient, pesticides, heavy metals into 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 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 a challenge to produce enough food, is expected to be impacted by the climate change resulting from changes in temperature and precipitation regimes. 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 productivities. 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 agriculture potential could be boosted by 8 per cent in the developed countries resulting from a longer growing season, while developed 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 requirement by focusing on food availability, accessibility, utilization and the system stability, and thus intensifying food production. Food shortages will force many countries to be dependent on foreign imports. Climate change could impact the production from rain-fed agriculture and decreases the productivity per hectare due to variable and reduced rainfall and soil moisture.

2.5.2. Potential impacts on West Asia region

Although the Arab region doesn't contribute more than 5 per cent of total emissions of Greenhouse gases (GHG), the climate change impact on the region is huge (AFED, 2010). GCC countries are shouldering the biggest share of the whole region. The countries of the region are expected to be impacted by the climate change phenomena. Recent studies indicated that the degree of the expected impacts will vary among countries of West Asia region, and the 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 countries of West Asia may experience different degrees of impacts ranging from extreme, significant to highly vulnerable to the impacts of climate change. This Index classified Iraq globally as the fifth country that is extremely vulnerable to decreased water and food availability and extreme temperature and its associated health problem. Bahrain and Qatar were ranked eleven and are projected to suffer significant impacts because of their small area and low elevation coastal zones will be exposed to sea level rise. The rest of the GCC counties are rated as highly vulnerable and Yemen as extremely vulnerable (Abdel Hamid, 2009).Climate change and environmental degradation could threaten the progress made toward achieving the MDGs from reduced water availability coupled with high population growth. Studies dealing with the analyses of the impacts of climate change for West Asia region are very limited due to data availability coverage and lack of its dissemination.

The change in precipitation regime (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). The Mashriq region rainfall may be decreased 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 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 *et al.*, 2007). The project also suggested that Lebanon, Syria, Jordan and Palestine may experience high reduction in the rainfall due to the expected changes in the general weather system pattern.

The increases in the temperature 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).

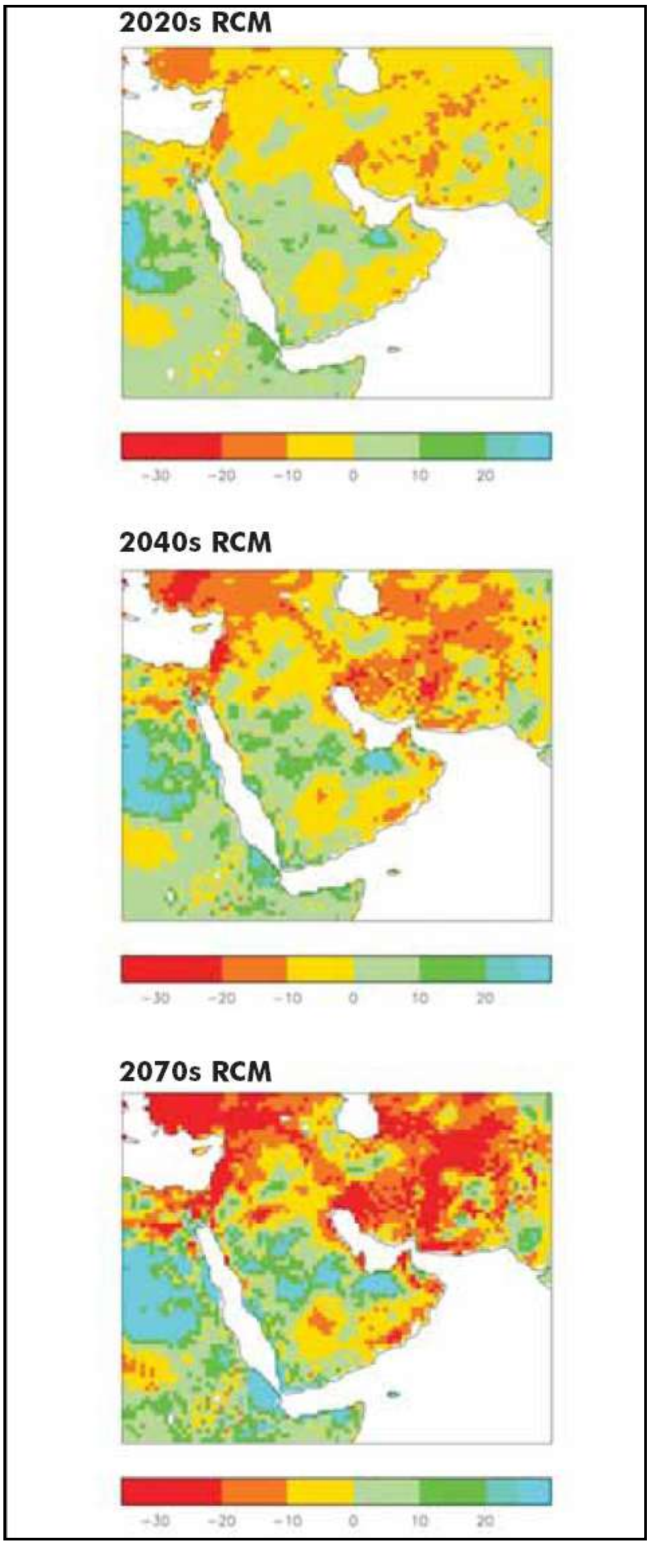


Figure 13: Regional climate model projections of precipitation changes (per cent) for 2020, 2040 and 2070 relative to 1990 (AFED, 2009).

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 Arabian Peninsula sub-region as many wadis are drained into the long coastal zones. Intake of desalination may be impacted with the potential of additional engineering redesign works and environmental assessment to accommodate the expected increase in seawater temperature and salinity concentration.

In regard 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 (LAS-UNEP, EOAR, 2010).

Weather events experienced during the last five years in the region such as the flooding Guno in Oman in 2007, Yemen and UAE in 2008 could be attributed to climate change. Cyclone Guno caused major flooding with significant increases in recharge rates to the 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 the rainfall regimes are the Mediterranean winter system affecting Lebanon, Syria, Jordan and Palestine and the Indian monsoon effecting south western parts of Saudi Arabia, Yemen and eastern part of Oman.

Chapter 3

Methodology

Chapter Key messages

- The aim of the Freshwater Vulnerability Assessment is: to provide a vulnerability assessment at different scales in order to generate information for decision makers.
- Data is collected in the form of an intensive literature review to provide a general trend of the parameters of the vulnerability index. From this a conceptual framework of analysis is formulated which facilitates the development of a detailed work plan.
- The methodology relies on the application of the DPSIR framework. Drivers include population growth and urbanization; water resource availability or deficit; and pollution. Impacts include the change in state of water sector performance and adaptability as a result of climate change, in addition to other socio-economic activities. Responses are 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 delineate severity of the stress being experienced by the water sector.

Damage of road structures by flood in South Western Saudi Arabia (ACSAD, 2008)

3.1. Introduction

An appropriate tool to assess freshwater vulnerability is the simplified approach developed by UNEP in 2009 under the title Methodologies Guidelines-Vulnerability Assessment of Freshwater Resources to Environmental Change- using the data availability and its coverage at the national and regional levels. The guideline objectives are to provide a vulnerability assessment at different scales (basin, sub-basin, national and regional levels) for generating timely and adequate information for decision makers. Also it allows the analysis of the state, trends and interrelationship between the following components: water resources availability from natural hydrological regimes, resources development and utilization for maintaining human well being for meeting MDG goals and socioeconomic development, water availability for the maintenance of ecosystem equilibrium and existing management capacity.

According to the assessment guidelines, assessment of the vulnerability of freshwater will consist of the following tasks;

I. A desk study to evaluate existing literature and collect water and water related information needed to define the most influencing parameters that can delineate potential threats and evaluate their impact
II. Analysis of the status of water resources availability from the prevailing natural conditions, development, use and management practices as well as identification of key issues that influence resources vulnerability.
III. Analysis of the Drivers-Pressures-State-Impacts-Responses (DPSIR) for the water sector in order to identify and evaluate the impact of the main drivers and the pressure parameters, 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 guideline taking into consideration the DPSIR parameters and preparation of maps showing the degree and the coverage of the threats including hot spots at basin, national or regional levels
V. Drawing a general conclusion on the freshwater vulnerability that may result from natural phenomena and man-made activities such un-proper utilization of the resource, pollution and climate change impacts and, finally drawing conclusions and recommendations to cope with future vulnerability.

3.2. Data Acquisition and Assessment process

Following the procedures of vulnerability assessment outlined in the "Methodological Guidelines," developed by UNEP and Peking University (UNEP, 2009), two research teams from AGU and ACSAD were formed to conduct an assessment of the West Asia 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 centers, UN and international organizations databases, research papers, policy reports, maps, etc. These data were sometime insufficient, incomplete and contradicted. 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 these data. 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) relies on the application of DPSIR framework to evaluate the integrated effect of the most dominant factors in order to delineate 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. The methodology based on DPSIR principles evaluates the main drivers, including population growth and the associated urbanization; the pressure parameters; water resource availability and deficit due to natural and anthropogenic activities; and 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 socioeconomic activities; while the response parameter is estimated by the adaptive capacity of the ecosystem and human being 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 regimes, degree of socioeconomic activities and environmental conditions. This study, undertaken at the national scale can form 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 of the West Asia region was calculated for a ten-year period interval starting 1985, 1995 and 2005, and was then predicted for the years 2020 and 2040.

The expected environmental impacts from water depletion, pollution and climate change are evaluated for two case studies in the shared water sources in the Western Asia region. Evaluation was made for the shared; surface water of the Euphrates River and the non-renewable groundwater Dammam aquifer.

The future vulnerability indices in relation to the associated four main parameters have been assessed for two scenarios (up to 2040), with and without the impacts of climate change:
Scenario (1) Normal population growth
It is assumed that the population growth rate will be based on the United Nations population projection trends reported in its publication for the countries of the region
Scenario (2) Normal population growth and reduced water sources

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 results 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. 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 resources in the region depend on rainfall and recharge distributions. The higher frequency of occurrence and the amount contributed to an 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 supply potential.

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 the Western Asia region represents a major threat to future water availability and as 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 vulnerability index estimation

It is estimated based the consolidation of the values of the four main parameters estimated by the above mentioned VI = f (RS, DP, ES, and MC) 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 an estimated value for a given year ranging from zero (non vulnerable) to one (most vulnerable) to delineate severity of the stress being experienced by the water sector. All the governing equations to estimate the above mentioned parameters are presented in annex.

Chapter 4

Assessment of freshwater vulnerability to climate change

Chapter 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 specially 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 of the Mashriq countries as well since any variation in precipitation will affect the 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 requirement for plans to providing technical support and policy backup to mitigate these pressures. A longer-term and appropriate strategic development plan should be adopted, with a focus on rebuilding capacity management to deal with the main threatening factors.

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

(Syrian Dutch cooperation annual report, 2008)

4.1. Introduction

The freshwater vulnerability index (VI) for each country of the West Asia region 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) depending on water renewability and water variation,
- Water Development Pressure (DP) depending on exploitation and safe drinking inaccessibility,
- Ecological Health (EH) depending on water pollution and ecological deterioration,
- Management Capacity (MC) depending 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 fresh water 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)

The water stress for each country was estimated based on per capita water resources. The water availability stress was calculated for three different years (1985, 1995 and 2005), as shown in Table 1. The 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 general increase in water stress with time for all countries of the region (Figure 14). Based on the 2005 Figures, critical water stress in the range of 0.7 - 0.95 is being experienced by Yemen, Jordan and Palestine and high water stress is being experienced by most of the 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 the freshwater stress parameters for each country for the year 2005 is shown in Figure 15.

Table 1: Water Resources Stress (RSs) parameters for West Asia countries. 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
Palastine	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

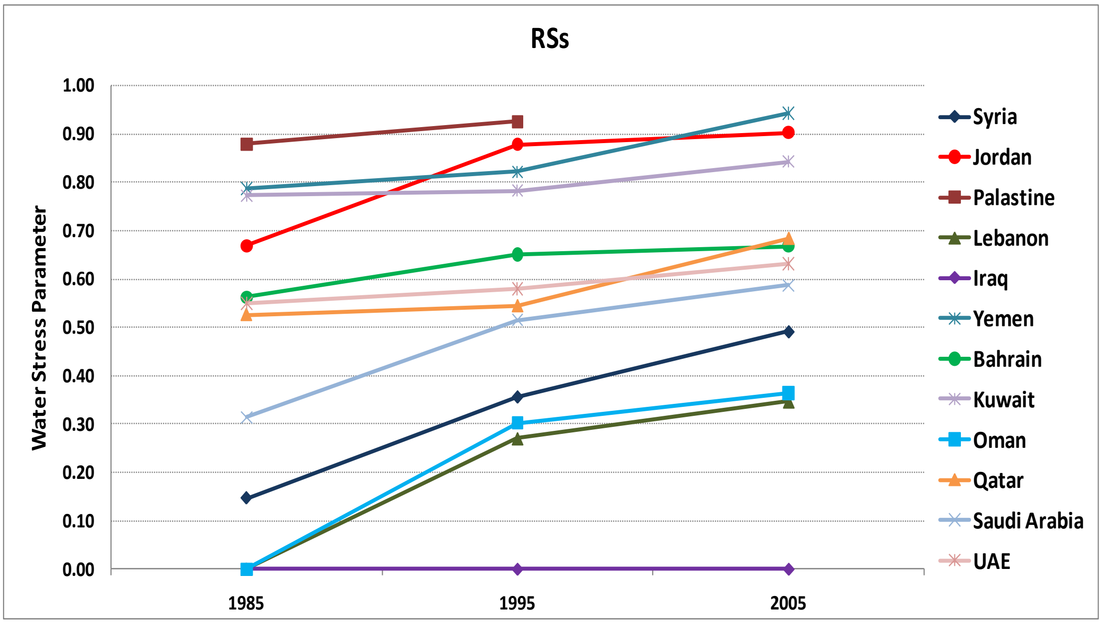


Figure 14: Trends of water stress parameters (RSs) for different countries.

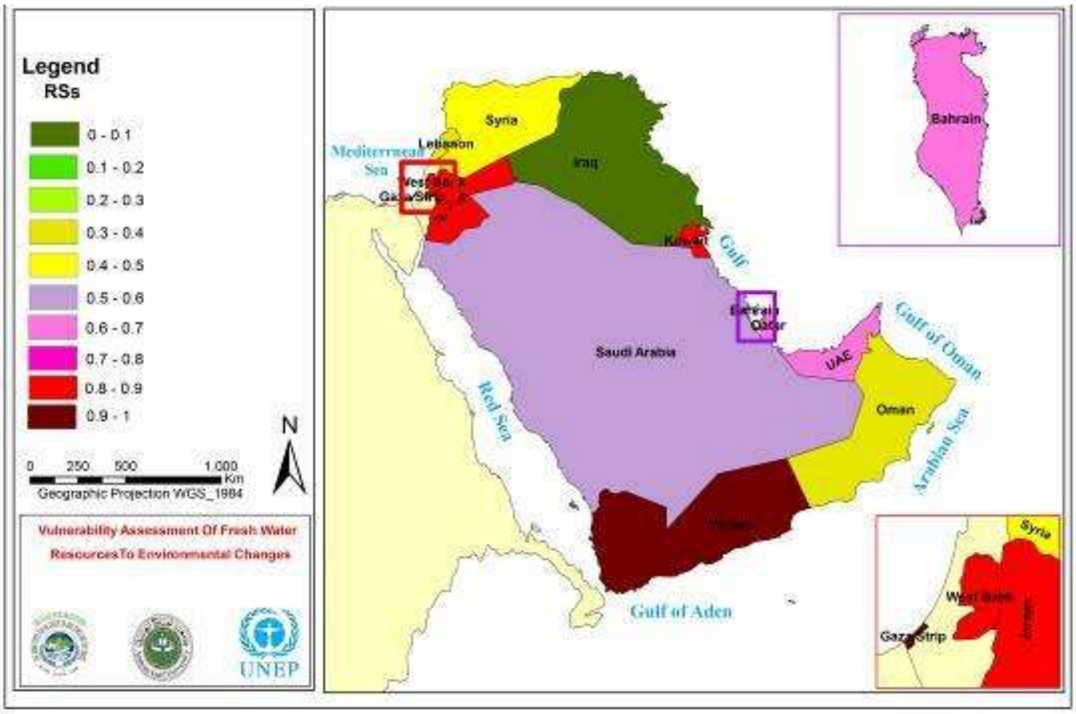


Figure 15: Water stress parameter (RSs) for the year 2005.

Water variation (RSv):

Water variation can be estimated by the coefficient of variation (CV) of the long-term average precipitation over a long period of observation preferably covering 50 years. It is known that 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.

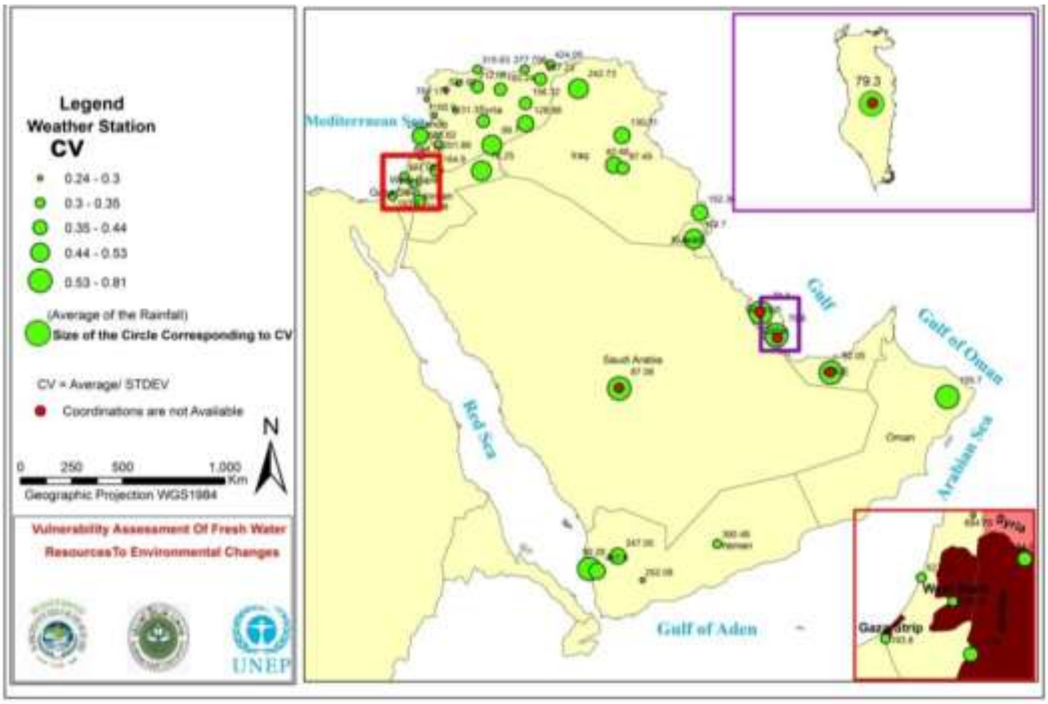


Figure 16: Coefficient of Variation (CV) of precipitation for West Asia region. A higher CV of precipitation indicates a higher vulnerability to climate change

Table 2: Water variation parameter (RSv) for WA countries

Country	CV	S	ρ	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
Palastine**	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 Arab	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 of the rainfall, ρ: standard deviation

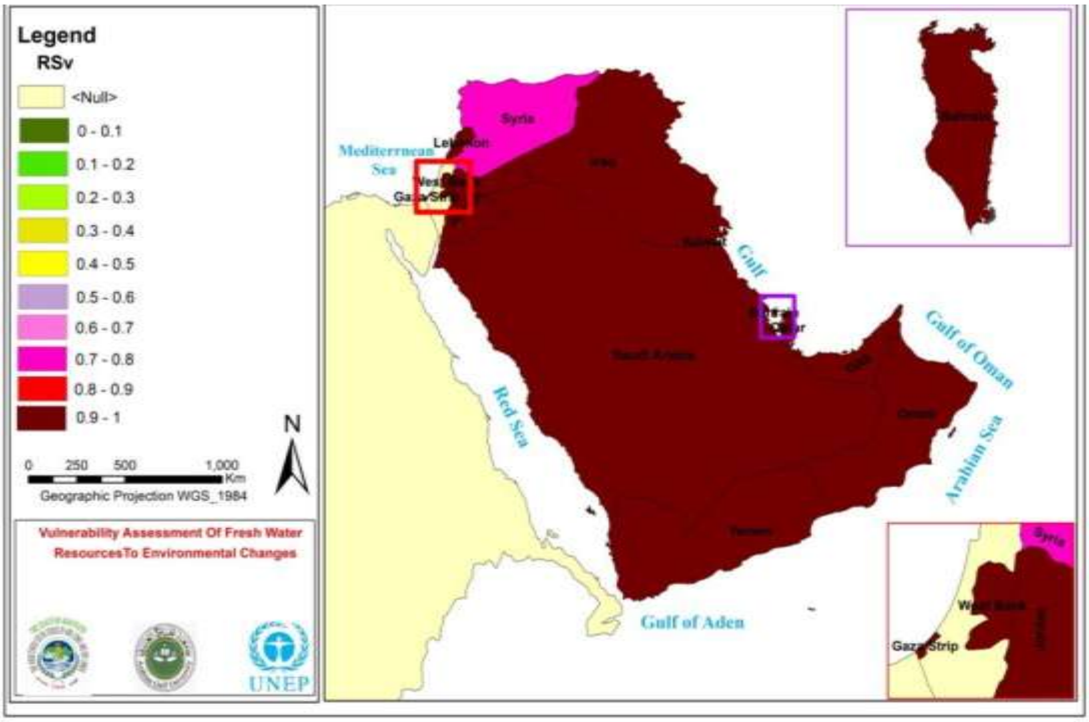


Figure 17: Water variation parameter (RSv) for WA region.

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 neighboring countries.

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 snow melt. 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 the basic needs for the social well being of the society is a further factor in calculating this parameter. It represents social adaptation to the degree of freshwater shortage, in regards to how the development facilities address the population needs (UNEP 2009). The water development pressure can be estimated from the available renewable freshwater sources, total water requirement, water supply coverage and the total population.

Water exploitation (DPs)

The analysis indicates that Jordan, Palestine, Yemen and most of the GCC suffer from critical conditions in the development of their water sources since water demands exceed the available water resources. Other countries are approaching this stage, with Syria displaying a significant increasing trend. In the GCC, water demands for the domestic sector are relying on investment in desalination facilities. The expected increase in the population growth for the region will lead to higher water demand in the absence of the implementation of 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 WA countries for the period 1985-2005. Values of 1 indicate the high stress and 0 indicate the least stress.

DPs			
Country	**1985**	**1995**	**2005**
Syria	0.36	0.64	0.94
Jordan	0.82	1.00	1.00
Palastine	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

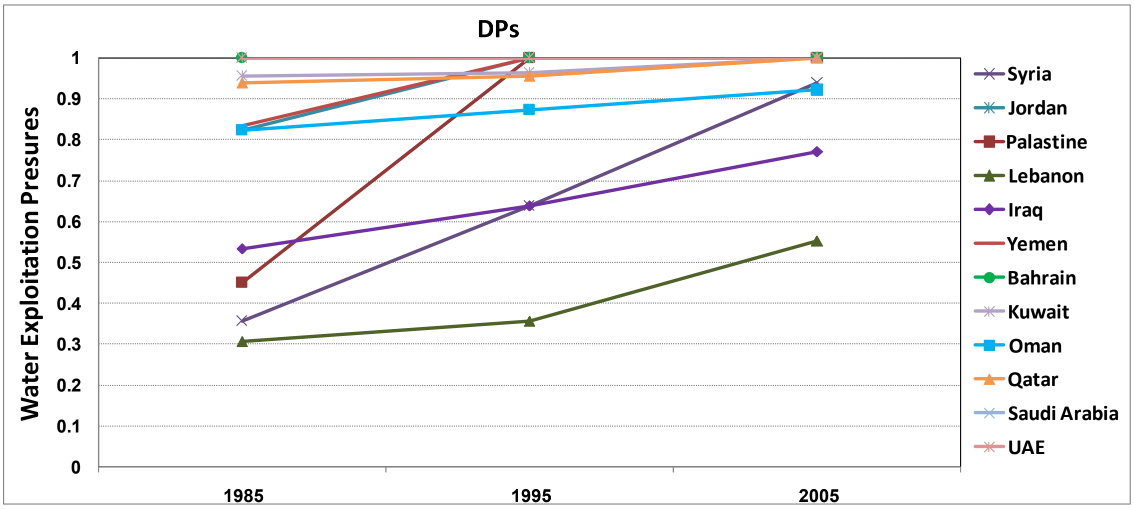


Figure 18: Trends of water exploitation pressure (DPs) in WA, 1985 -2005.

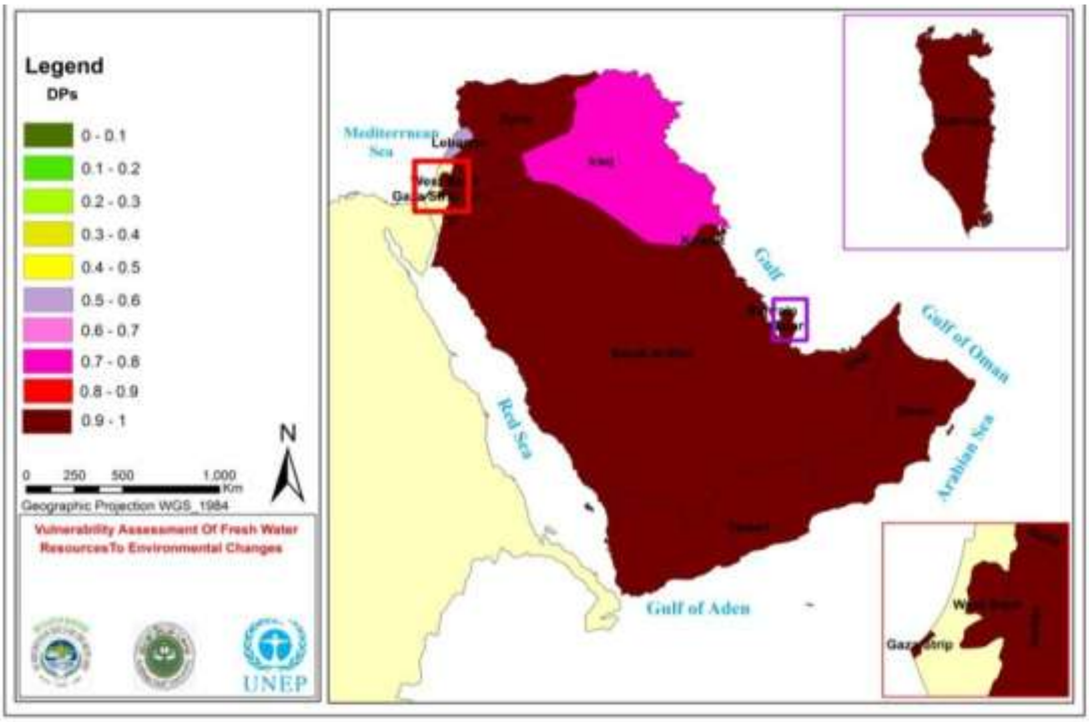


Figure 19: Aerial coverage of water exploitation pressure (DPs).

Safe drinking water inaccessibility (DPd):

This parameter represents the percentage of population without access to improved drinking water resources (Figure 20). In the last decade, most countries in WA have improved their services to supply clean potable water; 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. Palestine has showed 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. The aerial 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
Palastine		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

Source: UN-ESCWA (1993 and 2007)

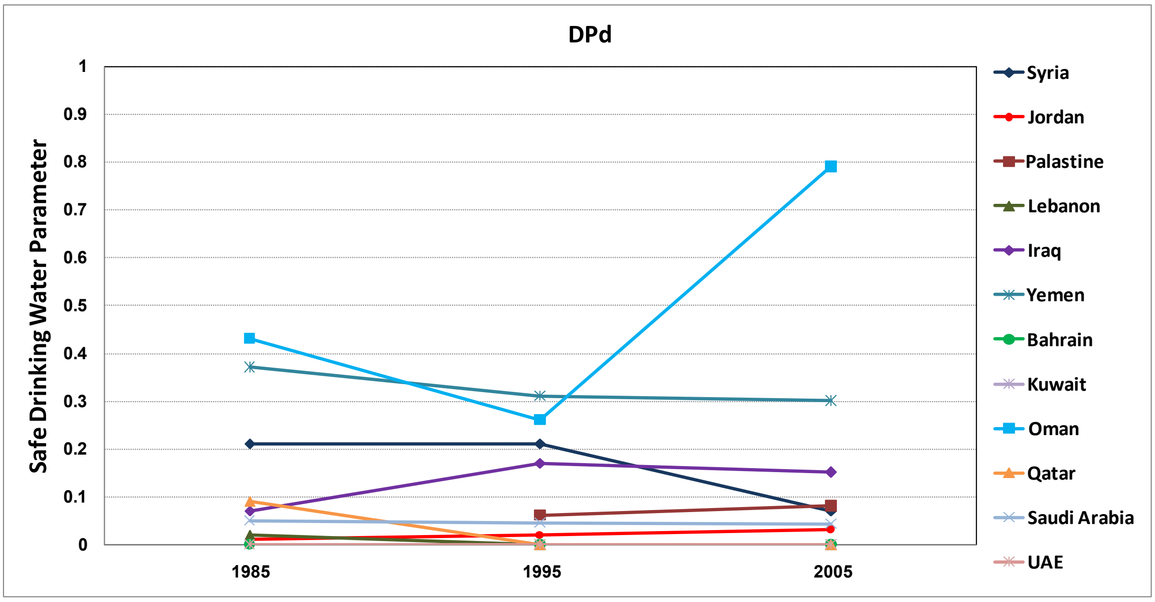


Figure 20: Variation trend of safe drinking water inaccessibility (DPd).

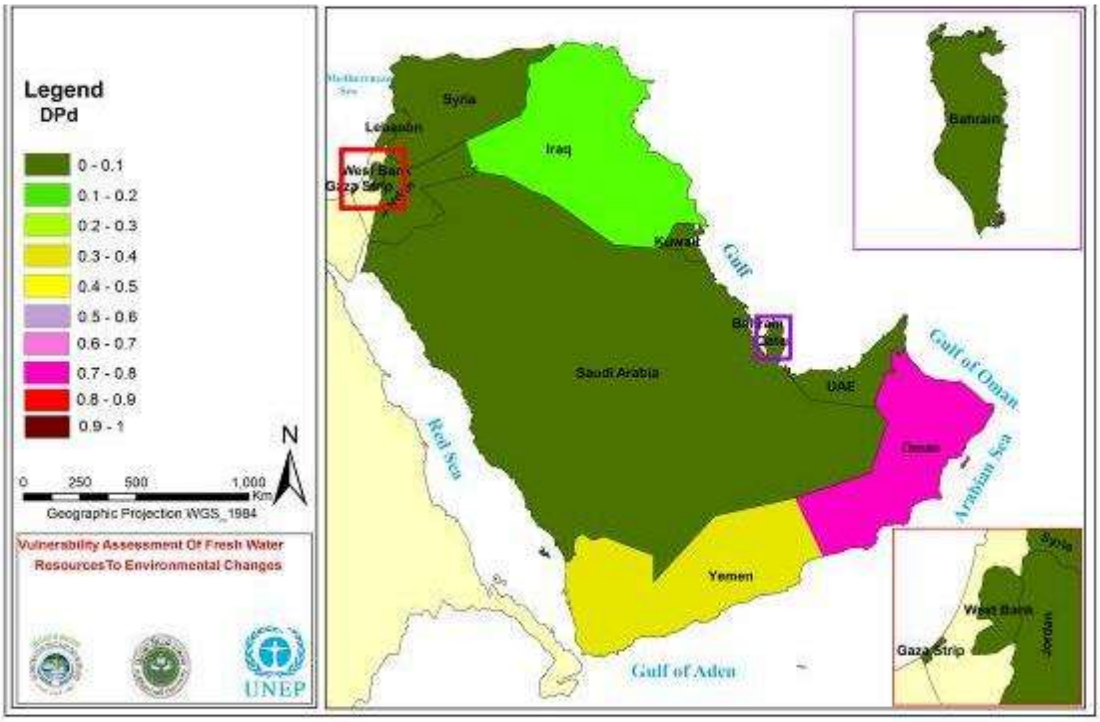


Figure 21: Safe drinking water inaccessibility parameter (DPd) for the year 2005.

4.2.3. Ecological health parameter (EH)

The ecological health of water resources can be impacted 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 will 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 the 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 2800 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 region; 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 pollution level was indicated in 1985 for, Qatar, Kuwait and UAE; however it was reduced in the year 2005 which could be attributed to investment in wastewater treatment facilities with advance tertiary treatment levels. Aerial variation is shown in Figure 23.

Table 5: Trend in water pollution (EHp) for WA. 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
Palastine			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
UAE	0.61	0.47	0.20

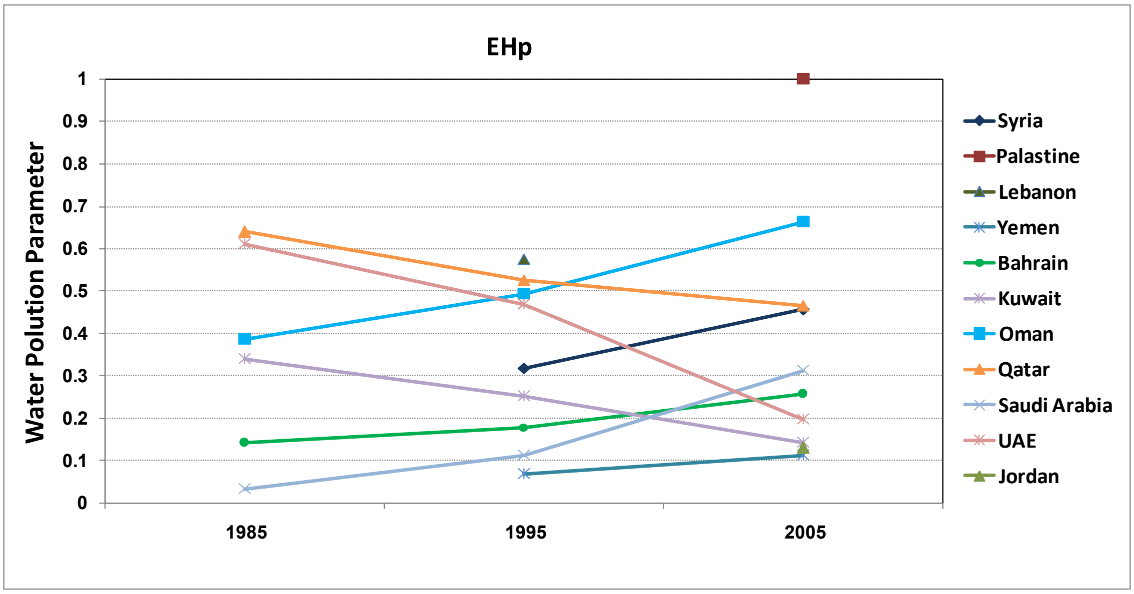


Figure 22: Trends in water pollution levels (EHp).

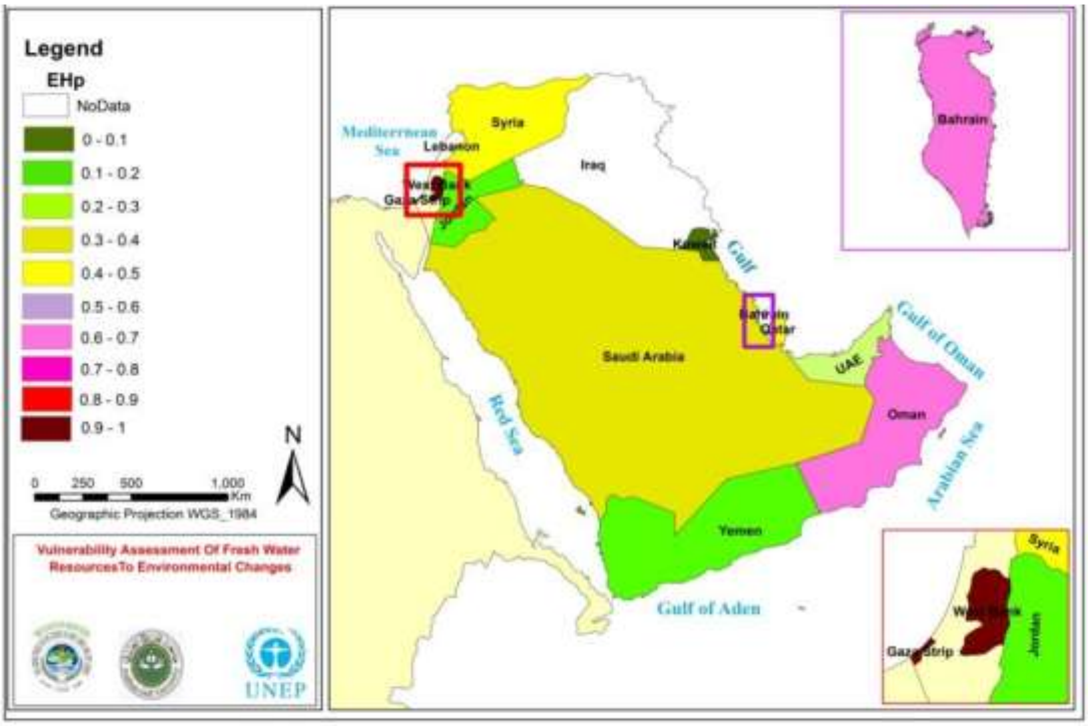


Figure 23: Aerial variation of water pollution (EHp) for the year 2005.

Ecosystem deterioration (EHe):

Ecosystem deterioration is defined in this study using the evaluation report of the state of land degradation and desertification in the Arab region (ACSAD/CAMRE/UNEP, 2004). In this report an estimation of the annual degradation rate comparing to total area of the country was calculated to estimate ecosystem parameter. A decrease in vegetation coverage due to natural and man-made actions 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, Jordan, Palestine and Yemen are experiencing moderate ecosystem deterioration that may have resulted from a decrease in vegetation cover due to a decrease in rainfall, over grazing and urban expansion into farm areas. Syria and Lebanon have relatively reasonable vegetation cover that can be attributed to higher rainfall. Severe deterioration is estimated for most countries of the AP GCC sub-region. The ecosystem deterioration values are higher than 0.86 for all countries except for Saudi Arabia which has values ranging between 0.1-0.44. The low values are because the fact that most of the land in Saudi Arabia is considered as range land (about 80% of the total area) (ACSAD/CAMRE/UNEP, 2004). The decreasing in the value from 0.44 to 0.1 indicates improvement of land management. For Bahrain, Kuwait, Oman, Qatar and United Arab Emirates, the overall conditions improved slightly over time. Aerial coverage 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
Palastine	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

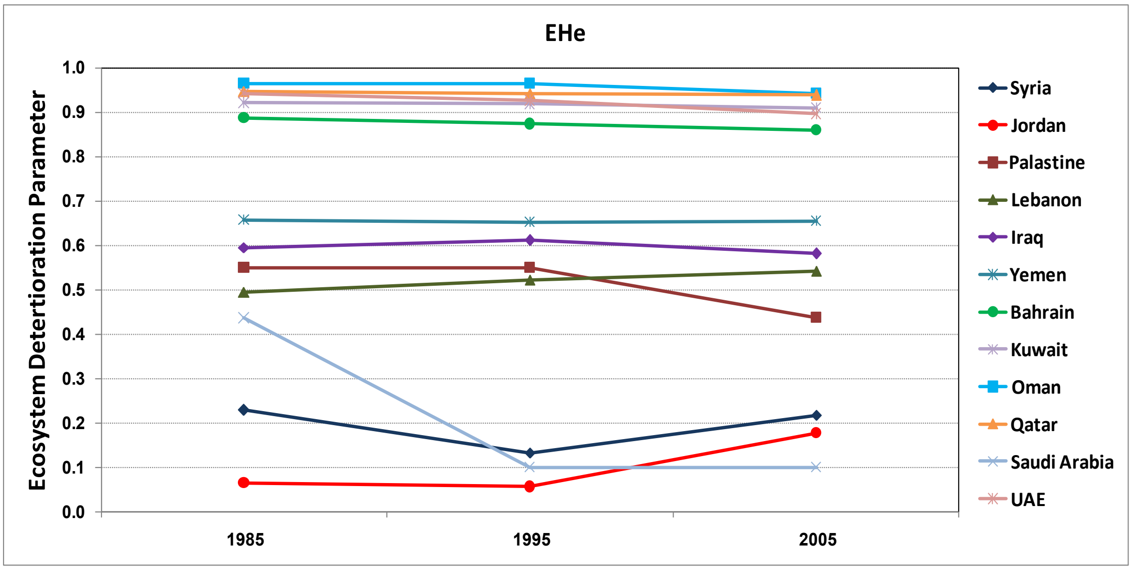


Figure 24: Trend of ecosystem deterioration (EHe)

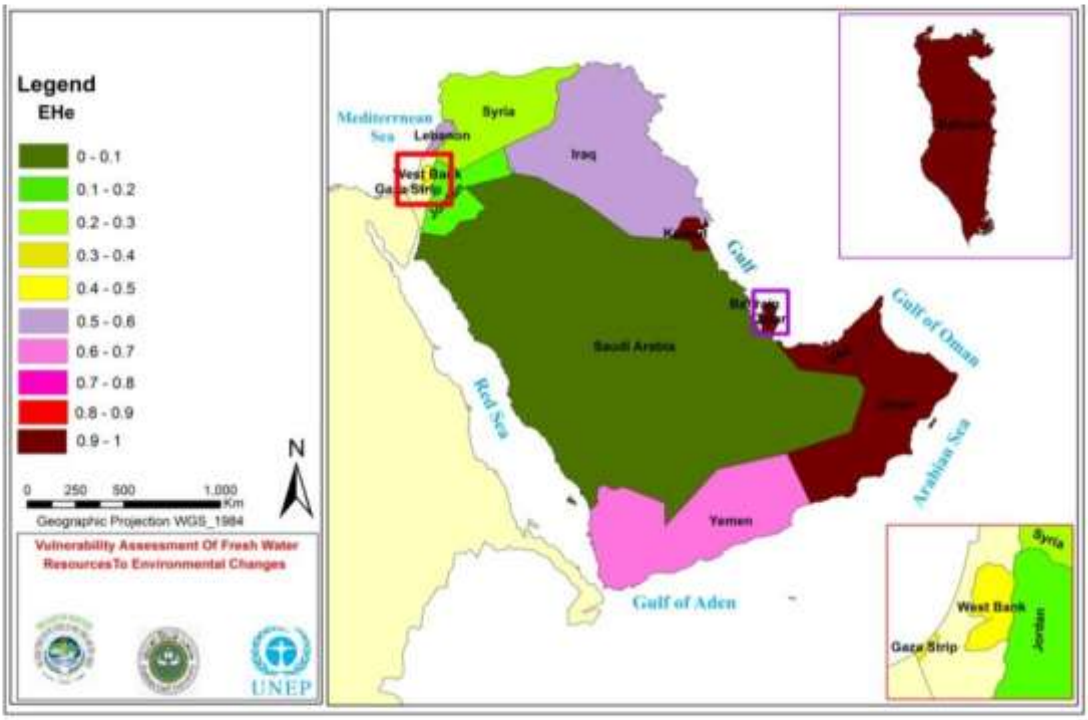


Figure 25: Ecosystem deterioration (EHe) coverage for the year 2005

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 over competition for shared surface water and groundwater resources. Water utilization inefficiency results in wastage of freshwater water 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 sources 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 relates 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 gross domestic product (GDP) of the country. Efficiency is estimated 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 major consumer of water (at more than 85%) 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 1m^3 of water for the countries of WA (personal communication with the Author of UNEP Guidelines 2009). The full equation is outlined in the Annex.

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 further, 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.

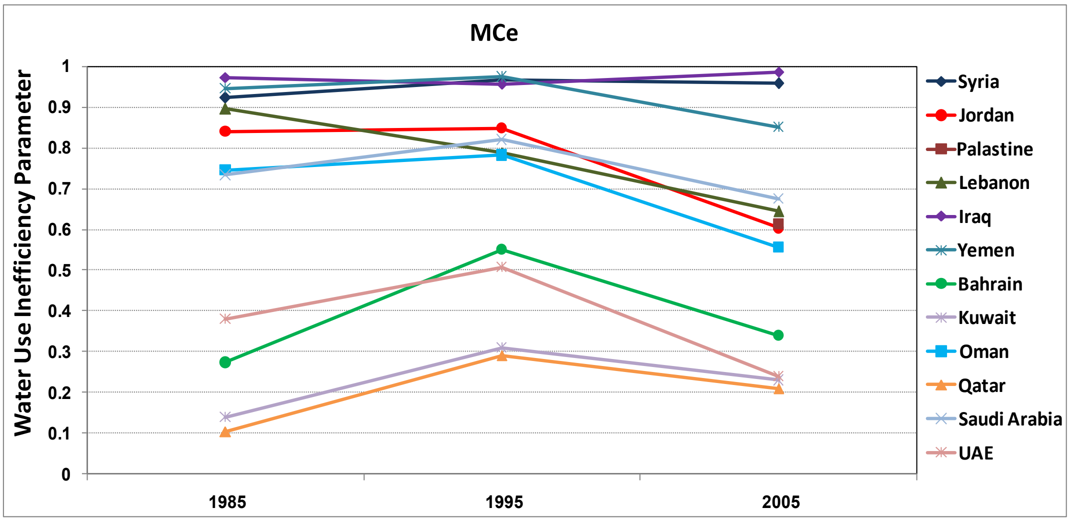


Figure 26: Trend of water use inefficiency (MCe).

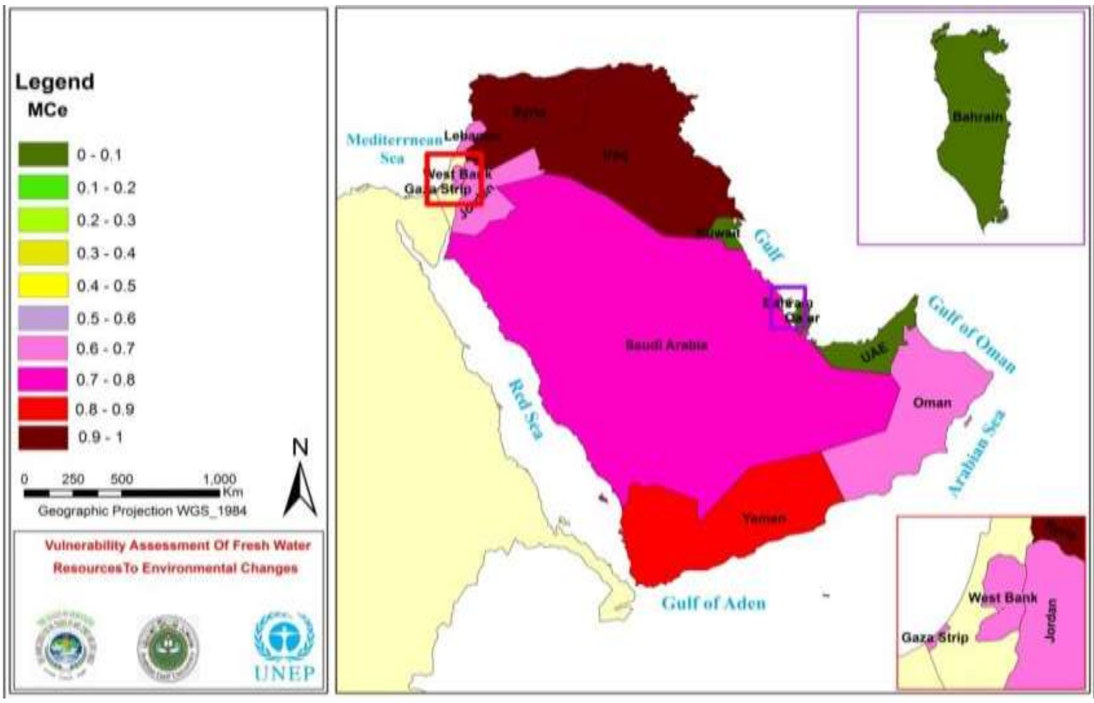


Figure 27: Water use inefficiency coverage for the year 2005.

Table 7: Trend in water use inefficiency parameter (MCe)

Mce			
Country	1985	1995	2005
Syria	0.922	0.966	0.958
Jordan	0.839	0.848	0.604
Palastine			0.614
Lebanon	0.895	0.788	0.644
Iraq	0.972	0.956	0.986
Yemen	0.945	0.974	0.852
Bahrain	0.273	0.551	0.340
Kuwait	0.140	0.310	0.230
Oman	0.745	0.782	0.556
Qatar	0.105	0.292	0.210
Saudi Arabia	0.733	0.820	0.676
UAE	0.380	0.507	0.240

Improved Sanitation inaccessibility (MCs):

This parameter is calculated as the proportion of population without accessibility to improved sanitation facilities (Figure 28 and Table 8). The analysis indicates that more than 95% of populations have access to improved sanitation facilities in Bahrain, Kuwait, Qatar and United Arab Emirates, whilst the lowest accessibility percentage to improved sanitation facilities is recorded for Yemen and Palestine. It can be concluded that there is a good management regarding livelihood matters for all countries as the inaccessibility percentage is decreasing with time and this may be due to investment in sanitation facilities by the majority of countries, except Yemen and Palestine. In Yemen most of the population is concentrated in rural areas with no adequate sewage networks. In Palestine, the situation is deteriorating as the result of the embargo on importing equipments due to border closure with the collapsing of sewage system in 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 fact sheet, 2009). The aerial variation of this data is shown in Figure 29.

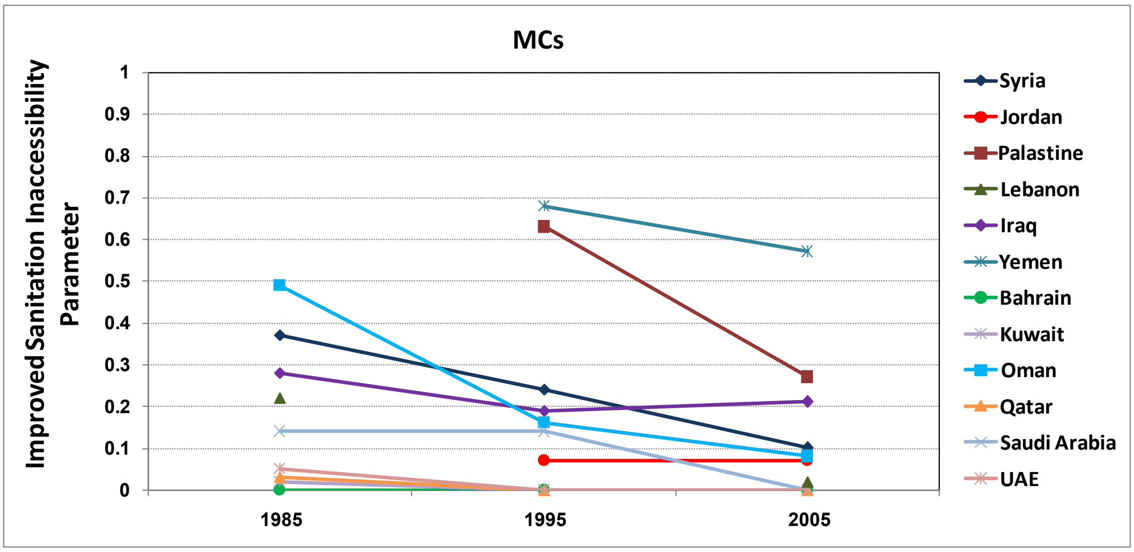


Figure 28: Trend variation of Improved Sanitation Inaccessibility Parameter (MCs). Values of 0 indicate least inaccessible and values of 1 indicate most inaccessible.

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

MCs			
Country	1985	1995	2005
Syria	0.37	0.24	0.10
Jordan		0.07	0.07
Palastine		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

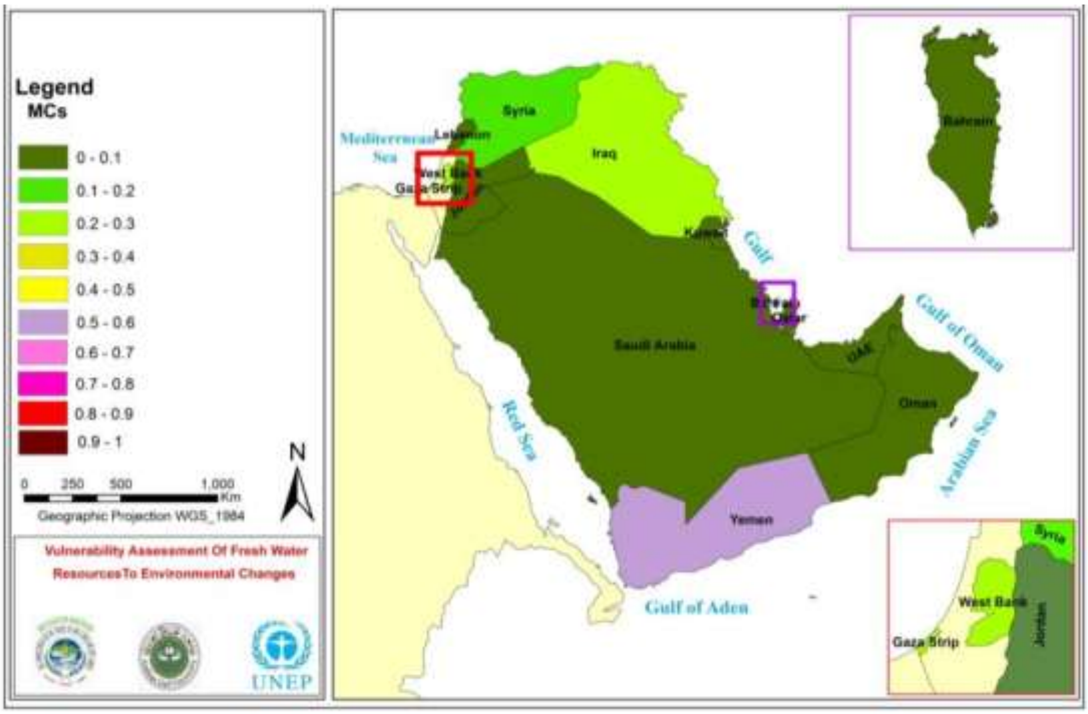


Figure 29: Improved sanitation inaccessibility parameter (MCs) for 2005.

Conflict Management Capacity Parameter (MCg);

This parameter defines the capacity of the country to manage competition over water utilization among different consuming sectors at the national and regional levels including neighbour countries that share surface and groundwater resources. This parameter was determined by expert consultation and using the conflict management capacity scoring criteria (see Annex). Palestine has the worst score since the Israeli occupation has the overall control on water resources. Other countries' scores vary according to the criteria mentioned in 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, excluding water desalination, of water supply. Up to now there is no coordination and cooperation between these countries for sharing the groundwater resources (Figure 30 and Table 9).

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
Palastine	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

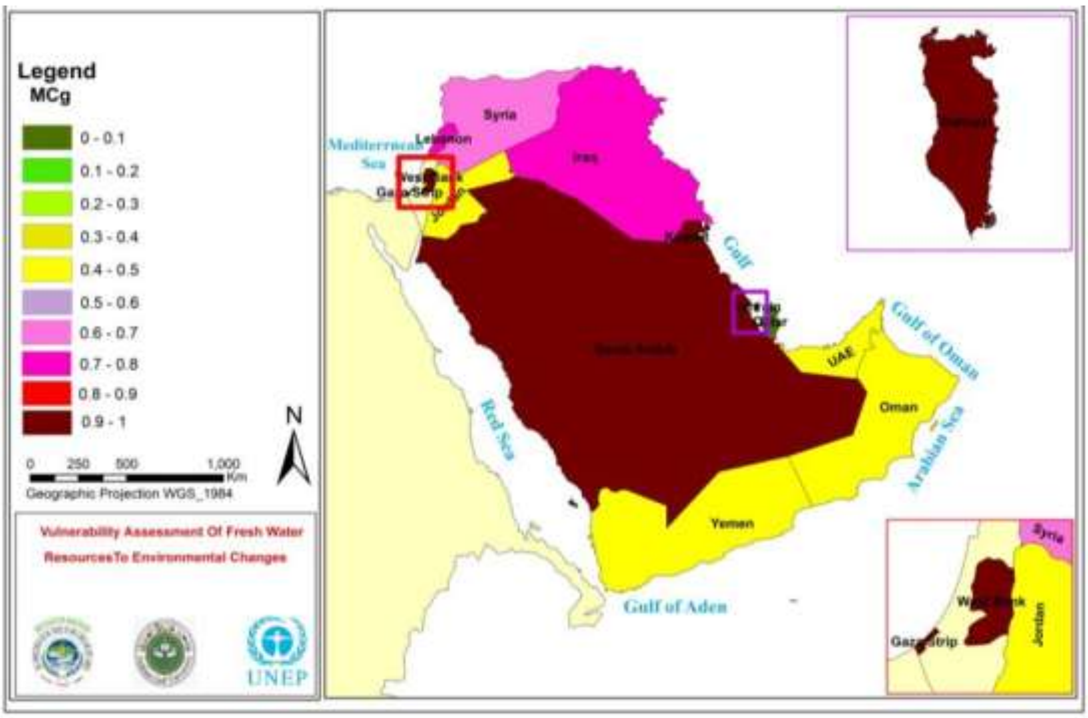


Figure 30: Conflict management capacity parameter (MCg), year 2005.

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 and presented in Tables 10 and 11.

To analyze 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 the countries to satisfy their water needs from the limited water resources.

The estimation provided in Table 10 show that the VI for all countries for the period 1985-2005 lies within the range between 0.4-0.7. This means that all the countries of West Asia region are characterized by high vulnerability. Values less than 0.4 indicate moderate to low vulnerability. As shown in Table 11, the vulnerability is increasing for Bahrain and Oman while for the remaining countries it is either decreasing or constant (Figure 32). The results indicate that the countries of WA are 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. Aerial 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 for improving water use efficiency in most of the Mashriq countries, since any variation in precipitation will affect the available water resources. The estimated vulnerability index showed that all the 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.

Table 10: Calculated vulnerability index with different 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
Palestine	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.

For GCC countries they all have also been experiencing a high degree of water stress and they have all high level of vulnerability with Oman on the top. Water resources variation due variation in precipitation is the dominant parameter with development pressure influencing the vulnerability of the region.

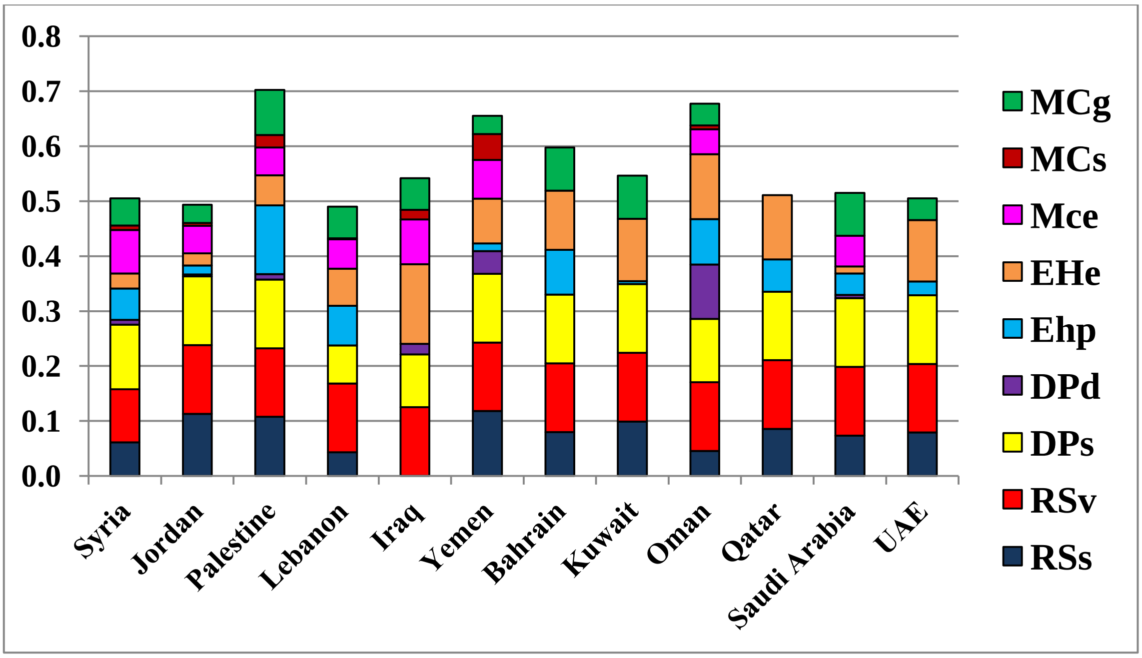


Figure 31: Calculated vulnerability index with different parameters, Values of 1 indicate most vulnerable and 0 indicate least vulnerable.

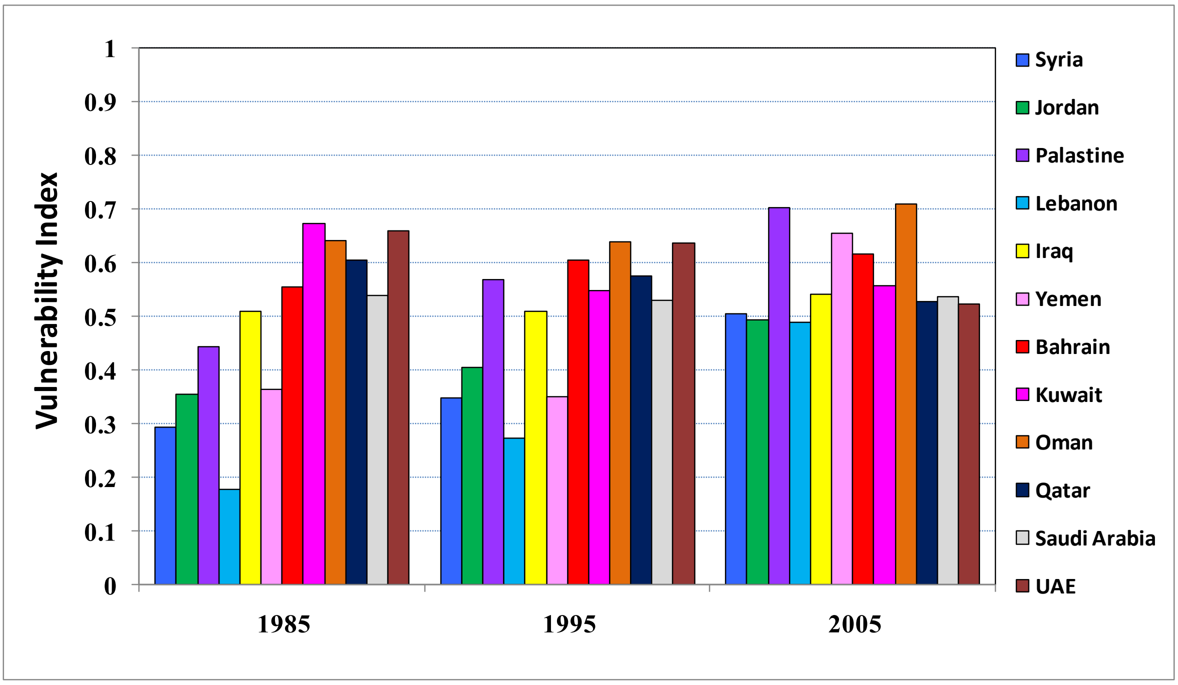


Figure 32: Calculated vulnerability index for each country according to the parameters (RS, DP, EH and MS). Values of 1 indicate most vulnerable, while values of 0 indicate least vulnerable.

Table 11: Vulnerability index values for the countries of WA.

Country	1985	1995	2005
Syria	0.294	0.348	0.505
Jordan	0.354	0.406	0.494
Palastine	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

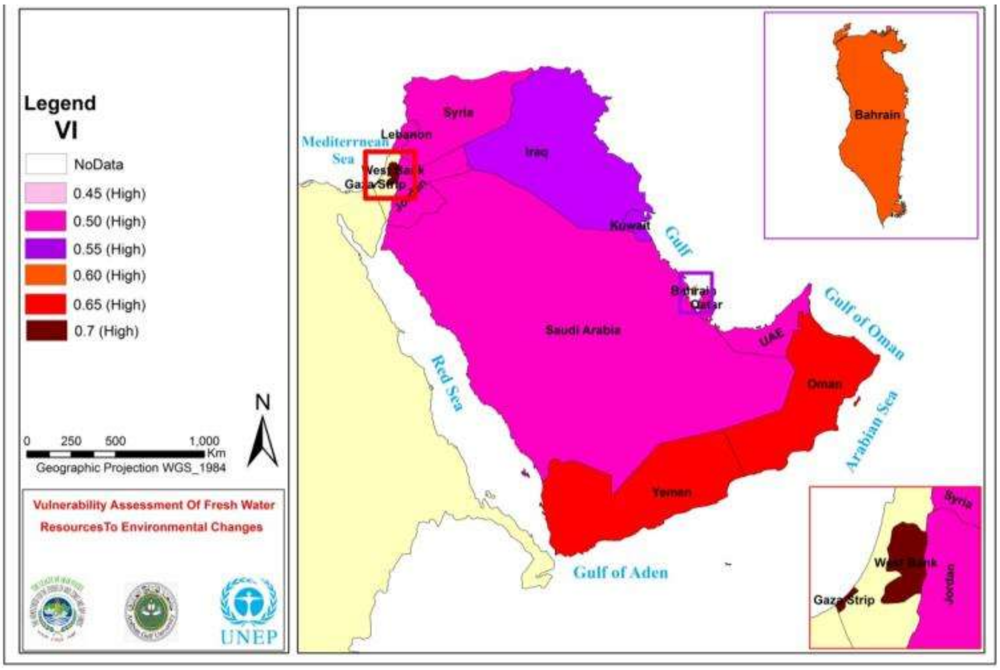


Figure 33: Vulnerability index (VI) map, 2005.

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 stresses, with Yemen and Occupied Palestinian Territories being the worst case.

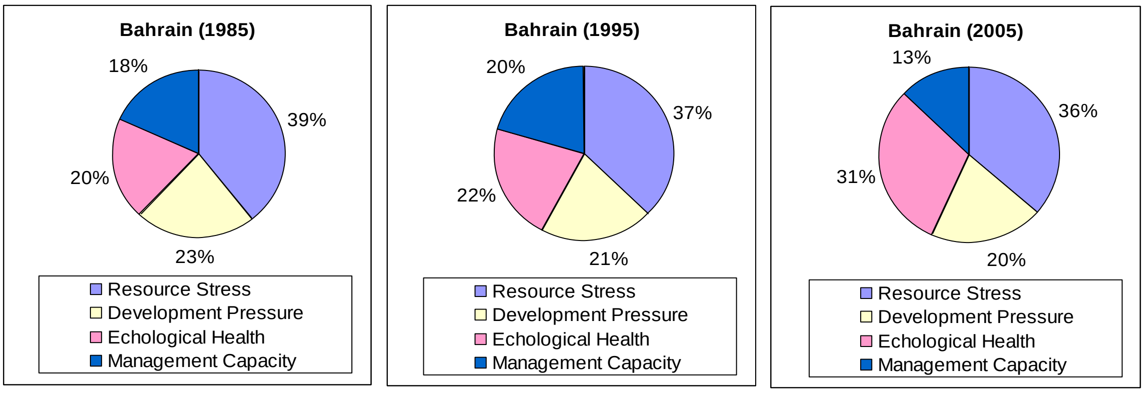


Figure 34: Share of the parameters group to the final VI for Bahrain.

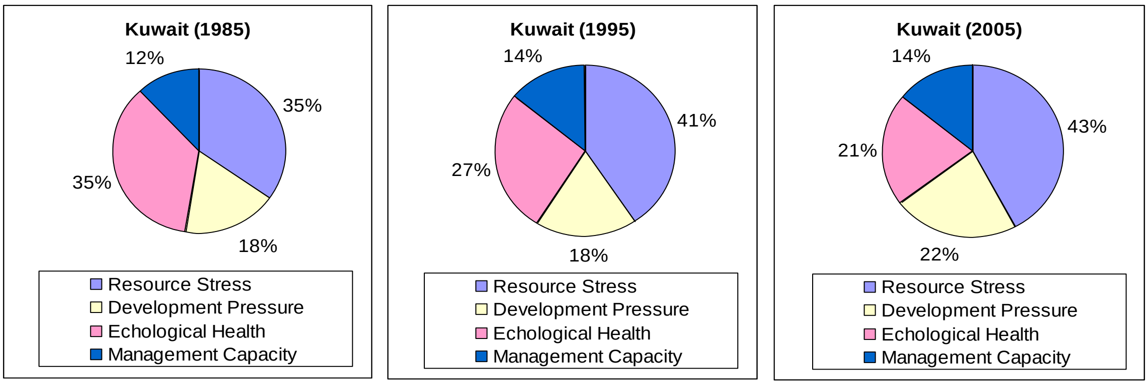


Figure 35: Share of the parameters group to the final VI for Kuwait.

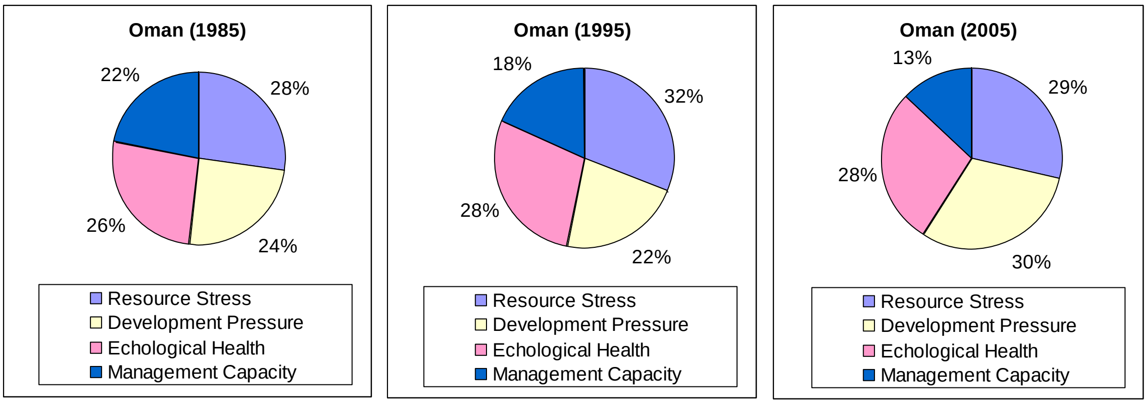


Figure 36: Share of the parameters group to the final VI for Oman.

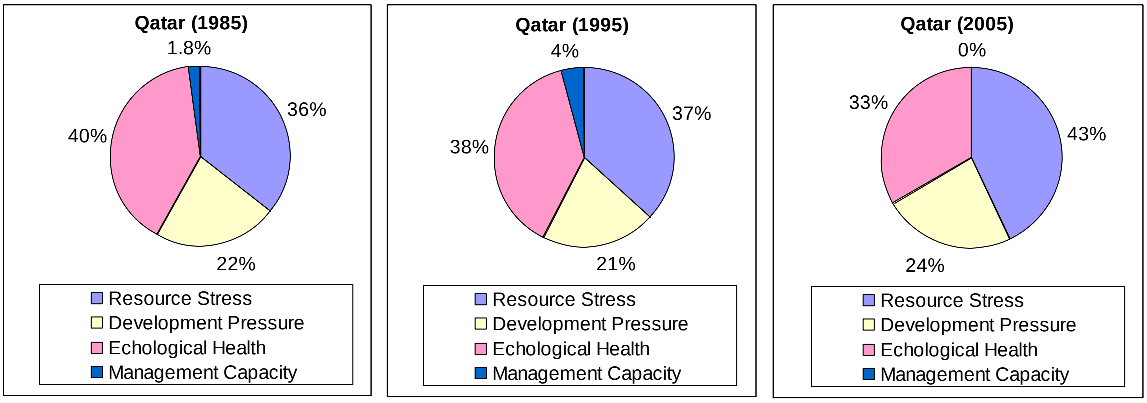


Figure 37: Share of the parameters group to the final VI for Qatar.

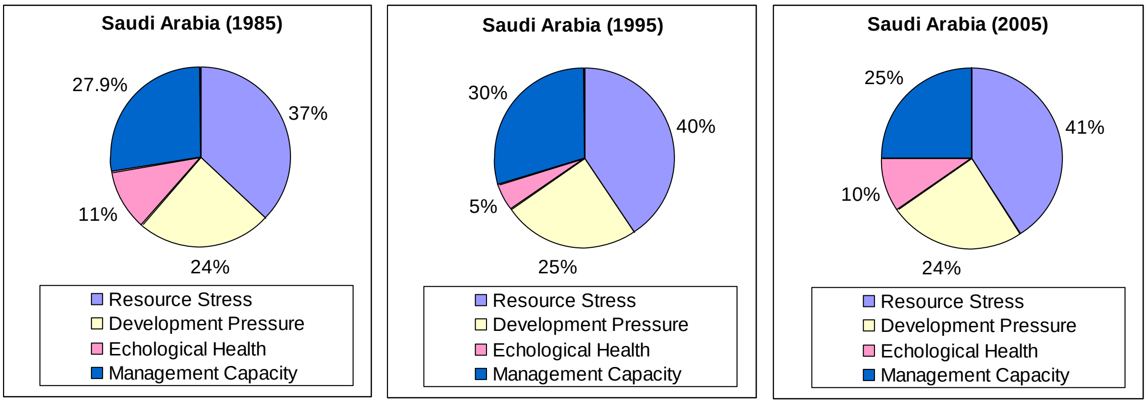


Figure 38: Share of the parameters group to the final VI for Saudi Arabia.

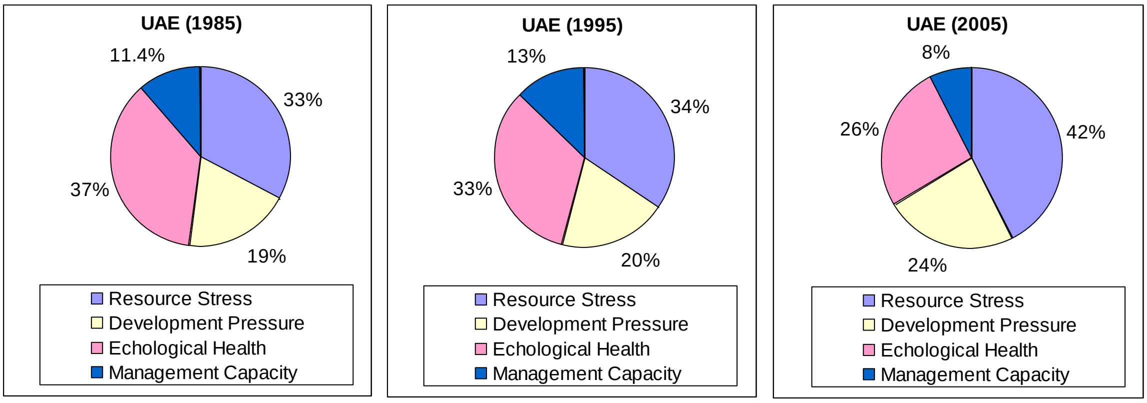


Figure 39: Share of the parameters group to the final VI for UAE.

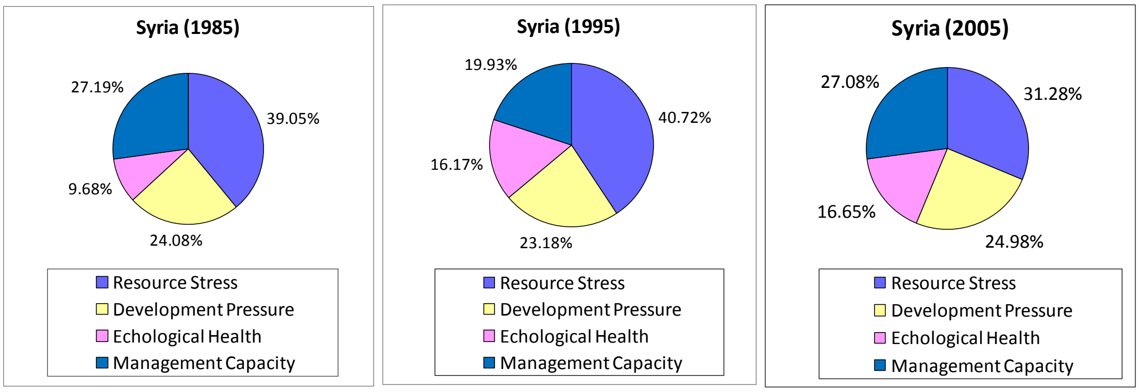


Figure 40: Share of the parameters group to the final VI for Syria.

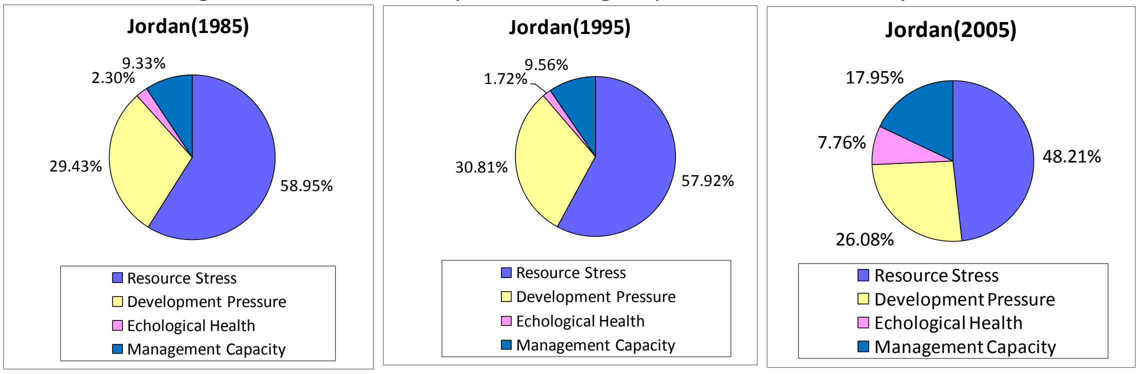


Figure 41: Share of the parameters group to the final VI for Jordan.

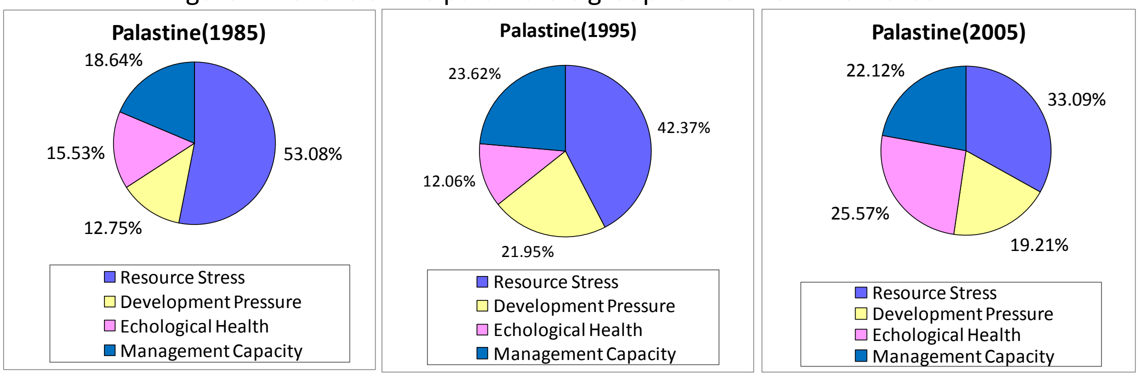


Figure 42: Share of the parameters group to the final VI for the Occupied Palestinian Territories

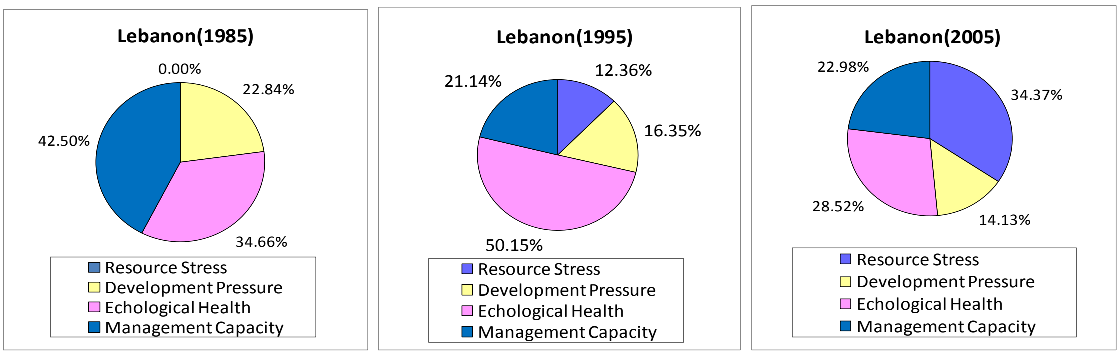


Figure 43: Parameters group to the final VI for Lebanon.

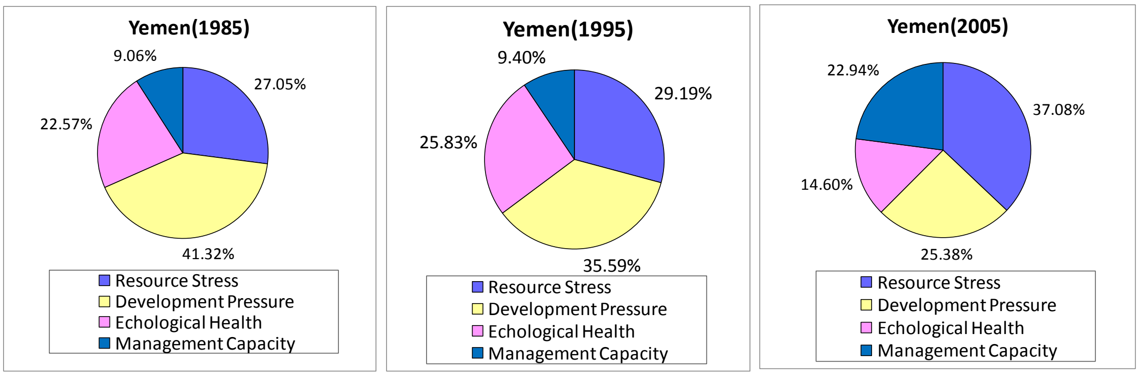


Figure 44: Share of the parameters group to the final VI for Yemen.

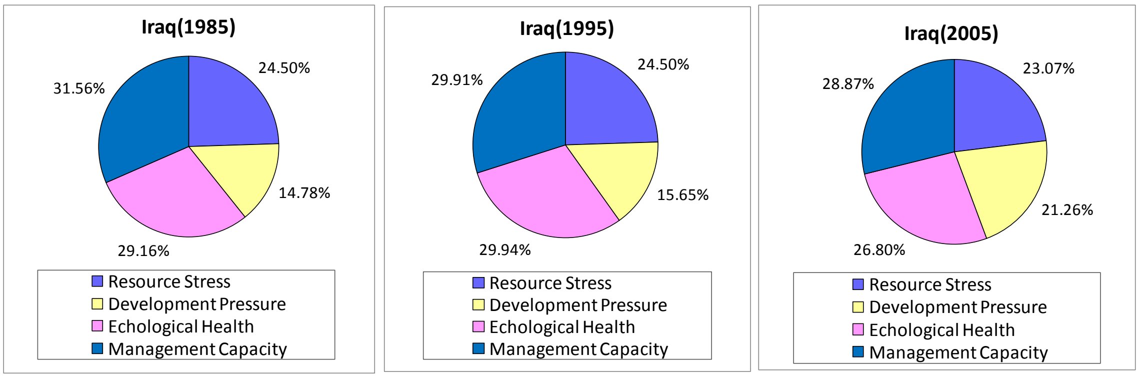


Figure 45: Share of the parameters group to the final VI for Iraq.

Chapter 5

Shared freshwater vulnerability to climate change

Chapter Key messages

- Countries within the Euphrates basin will have increasing freshwater vulnerability due to climate change. The future climate change scenarios predict that during the next decades a decrease in precipitation by 20 per cent and increase in temperature in Eastern Mediterranean area including the upstream of Euphrates River.
- Most countries of Dammam aquifer have enough financial resources to invest in desalination and wastewater treatment facilities for the domestic sector. The impact of climate changes is expected to be low in regard to its influence on the rainfall amount due to the limitation of surface water availability.
- The current development practice and the absence of coordinated management of the Dammam aquifer is expected to have political, technical, economic and social implications leading to future dispute among countries of the region.

Suspension bridge over Euphrates at Deir El Zore – Syria
(Source: UNEP, 2009)

Around 25 water basins (surface and groundwater) are shared between at least two riparian countries in West Asia region and 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 neighboring countries, and half of the total available water resources come from the Syrian water share of the Euphrates. For Iraq the dependency on outside resource varies between 51-75 per cent (UNEP, 2009).

The expected environmental impacts on shared water resources from water depletion, pollution and climate change are evaluated for two case studies in the Western Asia region, 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 vulnerability index (VI) was estimated for these two shared sources, taking into consideration the climate change impacts that may modify the rainfall regime in the West Asia region and impact on the 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 civilization 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 as a country sharing the basin, since many wadis in the Saudi territories are drained to Euphrates River (ACSAD-UNEP, 2001).

While 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-UNEP, 2001). Recent socio-economic development combined with population growth have placed increasing pressures on the water resources of Euphrates river basin, presenting 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 the 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 geologic transformations. The wet climate during past geological ages and later the extreme climatic condition that had 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.

Figure 46: The Euphrates and Tigris river basins and their drainage networks (ACSAD-UNEP, 2001)

Conflicting literature has been published with respect to the length of the shared Euphrates River, concerning its length 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 2940 km with a 40 per cent share in Turkey, 20.5 per cent in Syria, and 39.5 per cent in Iraq (ACSAD-UNEP, 2001). Estimates of the Drainage area of the basin according to most references are around 444000 km^2 while the recent DEM (Digital Elevation Model) data (90x90m) estimated the area at 450000 km^2 (this study). The aerial coverage in regards to the size of the basin in the four states is as follows: Turkey is covered by an area of 119042 km^2 (26.5 per cent), Syria at 93675 km^2 (20.8 per cent), Iraq at 195928 Km^2 (43.5 per cent) and Saudi Arabia at 41355 km^2 (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 Van Lake with an elevation of 4363m and the Black Sea at elevations ranging between 3000 and 4000 m above sea level. The catchment area in the hills of Keban is about 76000 km^2 where the elevation ranges between 1000 and 3500 m above sea level (ACSAD-UNEP, 2001). More than two thirds of the area of this reach lies at an elevation more than 1500 m above sea level; whereas it's eastern sections lie in relatively flat areas. The distribution of the basin area in relation to elevation is shown in Figure 47.

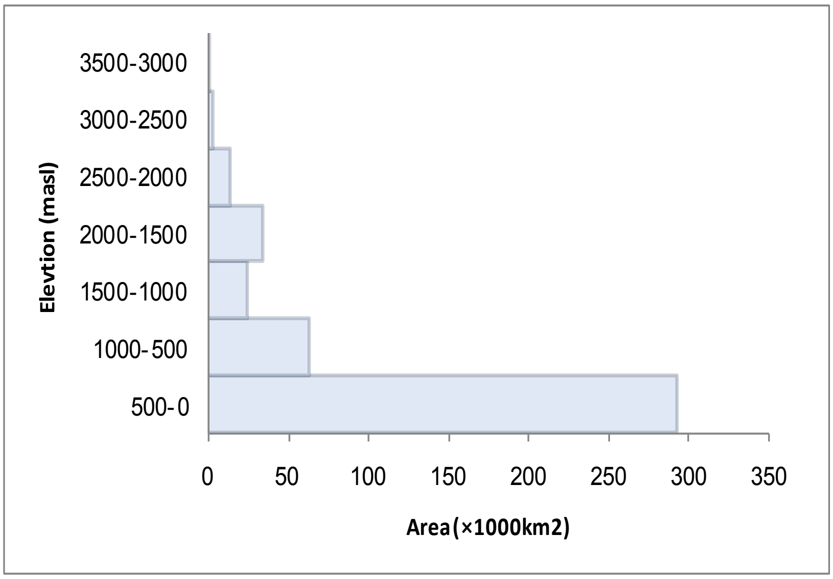
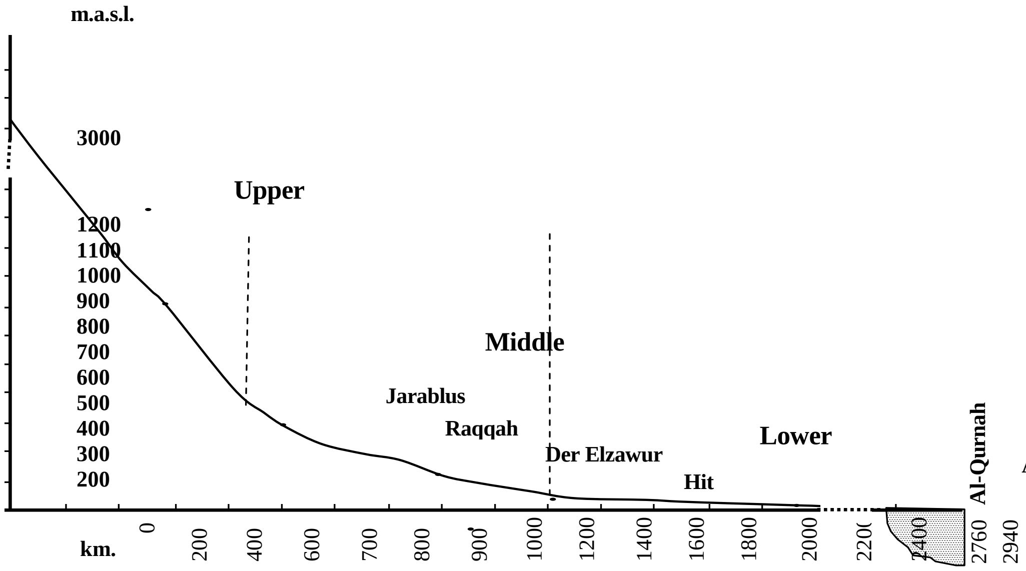


Figure 47: Area distribution according to the elevation of Euphrates basin (Using DEM data of 90m x 90 m resolution, this study).

The difference in elevations of the river course across the shared countries is shown in the longitudinal profile in Figure 48.



Source: Geography of the Arab World, Damascus University, 1971.

Figure 48: Longitudinal section along Euphrates river course.

Properties of the resource

Although more than the two thirds of the Euphrates drainage area lie outside of Turkey, 93 per cent of the main water resources originate 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 is estimated at about 32 000 mcm/year. A small amount of this water resource comes from Euphrates tributaries on the Syrian side and none from Iraqi territories, yet their river drainage area constitutes about half of the total drainage area of Euphrates basin. The flow regime of the river has changed due to the construction of many dams, of which the main one is the Keban dam in Turkey. The monthly average discharge of the river before the construction of this dam ranged from 309m^3/s in September and 2709 m^3/s in April. After construction of the dam, the monthly average discharge reached 1024 m^3/s in April. Of the annual average discharge of 32 000 mcm for the Euphrates, Syria and Iraq receive 15700 mcm.

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 Gulf. 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 attitudes 25° and 40° north of the Equator influences the regional variation of pressure and temperatures during summer and winter seasons and consequently on the quantities of the snow and rainfall.

The basin is characterized by four different climate zones - Mediterranean mountainous climate, Mediterranean interior climate, interior lowlands climate and desert climate. 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. The topographic elevation features especially at the upstream parts of the basin influence annual rainfall distribution with values ranging between 300 and 1000 mm 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 1000 mm per year falls on the upstream portion of the basin, while the snow covers the mountains peaks all around the year and it starts to melt in mid April.

The average annual rainfall in the three countries sharing the Euphrates River decreases from 700-1000 mm in Turkey to 150 mm in Syria, and 75 mm in Iraq (ACSAD-UNEP, 2001). The rainfall rates decrease south of Turkey and north of Syria (Al-Kabul river sub-catchments) to about 300-450 mm. The estimation of the average annual precipitation over the three major reaches of the river for a wet season having high rainfall years, indicates that the amounts of rainfall decrease from an annual average of about 1000 mm at the upper course at Anatolia, to 200-400 mm in the Syrian upper island (upper part of the middle course) and 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).

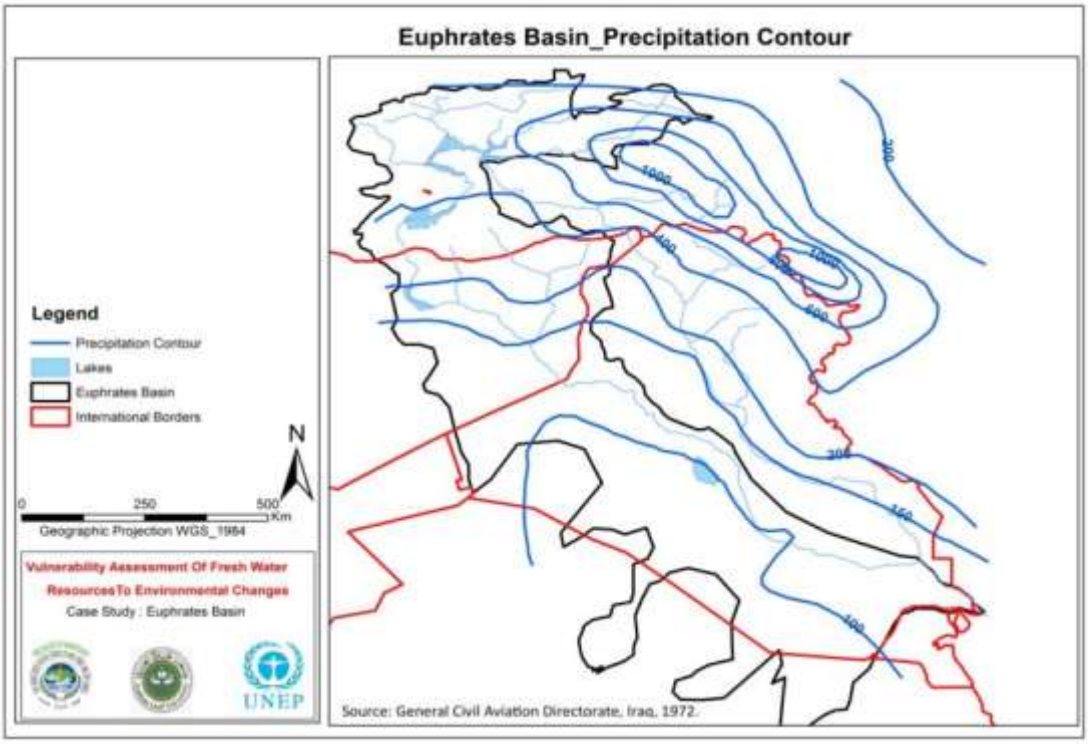


Figure 49: Isohyetal map for the Euphrates river basin

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

Water quality

The water quality of the water river and its tributaries is an important issue. The Euphrates River enters the Syrian territories with an average salinity of about 0.6 g/l rising to more than 1g/l at the Iraqi-Syrian borders. The increasing water salinity and pollution is a result of Syrian agricultural drainage and sewage water systems which are directed to 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). 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 that is, 180 000 mcm per year (UNEP, 2009). The Syrian share of the Euphrates water resources (approx. 6 600 mcm per year) constitutes two thirds of the total surface water resources in Syria and is used for domestic water supply for the major cities (Aleppo and Raqqa) and for irrigation purposes. 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 represent five times its average annual flow. It is estimated that a deficit of 2 000 to 12 000 mcm is expected if all the development plans are realized by the three countries. Water originating in the hills of Keban represents 72 per cent of the total resources of the Euphrates. The amounts of water received from the drainage area in Syria are limited to the flow from the three tributaries: Al-Sajur, Al-Balikh, and Al-Khabur rivers, and some seasonal flow tributaries depending on the intensity and amounts of rainfalls. Recently, Turkey has detained most of the flow of these seasonal tributaries. The contribution of wadis to the Euphrates flow reflects the wide range rainfall variability in the different reaches of the basin.

According to the provisional agreement between Turkey, Iraq and Syria (protocol signed with Turkey in 1987). Turkey releases minimum discharge of 500 m^3/second to the river (15700 mcm per year) at the Turkish-Syrian border. Of this amount about 42 per cent; equivalent to an average annual discharge of about 6600 mcm per year; is considered for use within Syria (after the agreement signed between Syria and Iraq in 1989). However, up to now, there has been no final official agreement between the three countries for sharing the river resources. At the level of the basin there is no regular cooperation between the three riparian countries sharing the basin. The first tripartite meeting was held in Bagdad in 1965 though no formal agreement was reached. The technical committee held about 16 meetings over a decade but did not fulfill any of its objectives.

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 the West Asia region (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 vulnerability index (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 vulnerability index for the year 2040 has been estimated considering that agriculture demand will remain as it is for the year 2000 and the domestic water demand will increase from the year 2000 following the population growth rate.

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 can be expressed as the per capita renewable national or regional water resources compared to an internationally agreed water poverty index of 1700 per capita water resources.

The renewable water stress for each country was estimated based on per capita water resources. The analysis indicates that the parts of basin within Syria and Iraq have comparable stress values ranging from 0.27 (Syria) to 0.20 (Iraq). The low values indicate more than adequate water sources 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 due to the very low water stress value shown in Figure 50.

Water Stress Parameter for year 2000, RSs			
Country	**R (m3/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

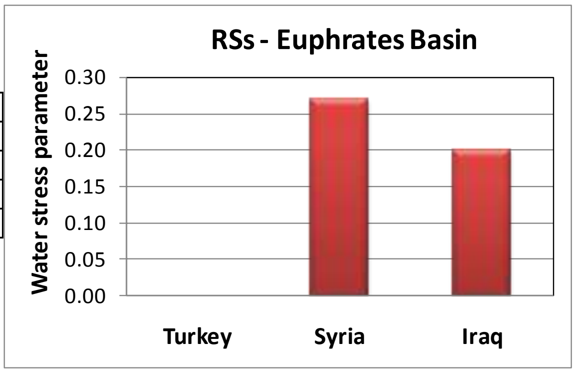


Figure 50: Water stress for the year 2000.

Water variation (RSv):

The water variation stress can be estimated by the coefficient of variation (CV) of the long-term average precipitation over a long period of observation preferably covering 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 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 available resources in these areas.

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

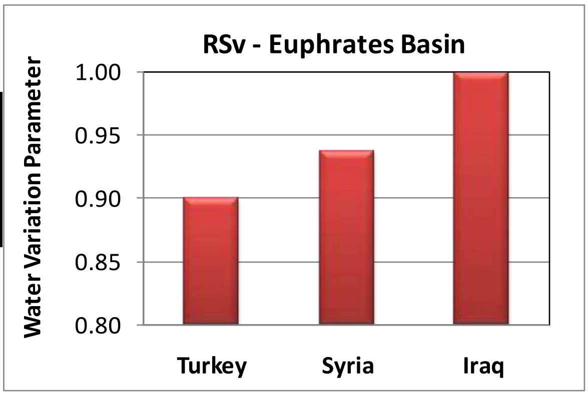


Figure 51: Water variation for the year 2000.

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 estimated by 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 types of socio-economical activities. The available data shows high water demand and a limited water supply for the basin. The exploitation values are high, indicating high development rates as shown in Figure 52.

Water Exloitation Pressures DPs2000					
Country	WRs		Date	WR	DPs
	Water supply			Total water resources	
Turkey	15700000	(1)	2000	15,848,000	0.99
Syria	7740000	(1)	2000	6,531,840	1.00
Iraq	20000000	(2)	2000	9,020,160	1.00

(1) ACSAD, 2001

(2) http://www.satiraq.com/

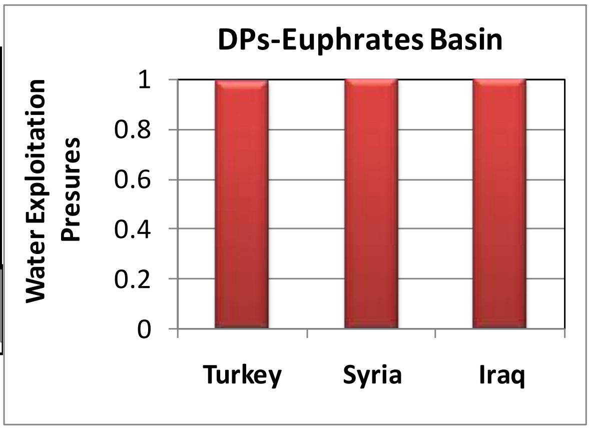


Figure 52: Water exploitation pressure for the year 2000.

Safe drinking water inaccessibility (DPd):

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

Safe Drinking Water Parameter (2000)

Country	DPd
Turkey	0.07
Syria	0.21
Iraq	0.19

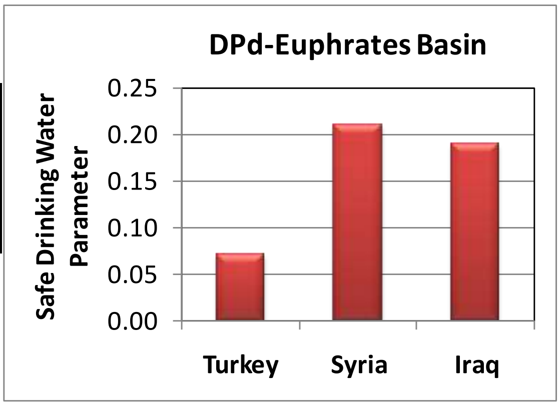


Figure 53: Safe drinking water inaccessibility for the year 2000.

Ecological health (EH) parameter

Estimation of this parameter requires the evaluation of the level of pollution and the deterioration that may be experienced by the ecosystem.

Water Pollution Parameter (EHp):

The pollution to water resources vulnerability 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 estimated.

Ecosystem Deterioration Parameter (EHe):

The population growth and the associated urbanization and other socio-economic development activities are impacting the surface and the groundwater systems by increasing the depletion rate and pollution. Due to lack of information regarding the land degradation at the basin level for the three countries and that we cannot take the available information at the country level and use it at the basin level, another alternative is used. The ecosystem deterioration is defined in this case study as the decrease in vegetation coverage due to natural and man-made actions, and EHe parameter has been estimated using Normalized Difference Vegetation Index (NDVI). This index is usually used to estimate the 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, therefore this index can be used as indicator for ecosystem deterioration. The value of NDVI was estimated using the 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 indicates high degree of deterioration in Iraq followed by Turkey and Syria as shown in Figure 55.

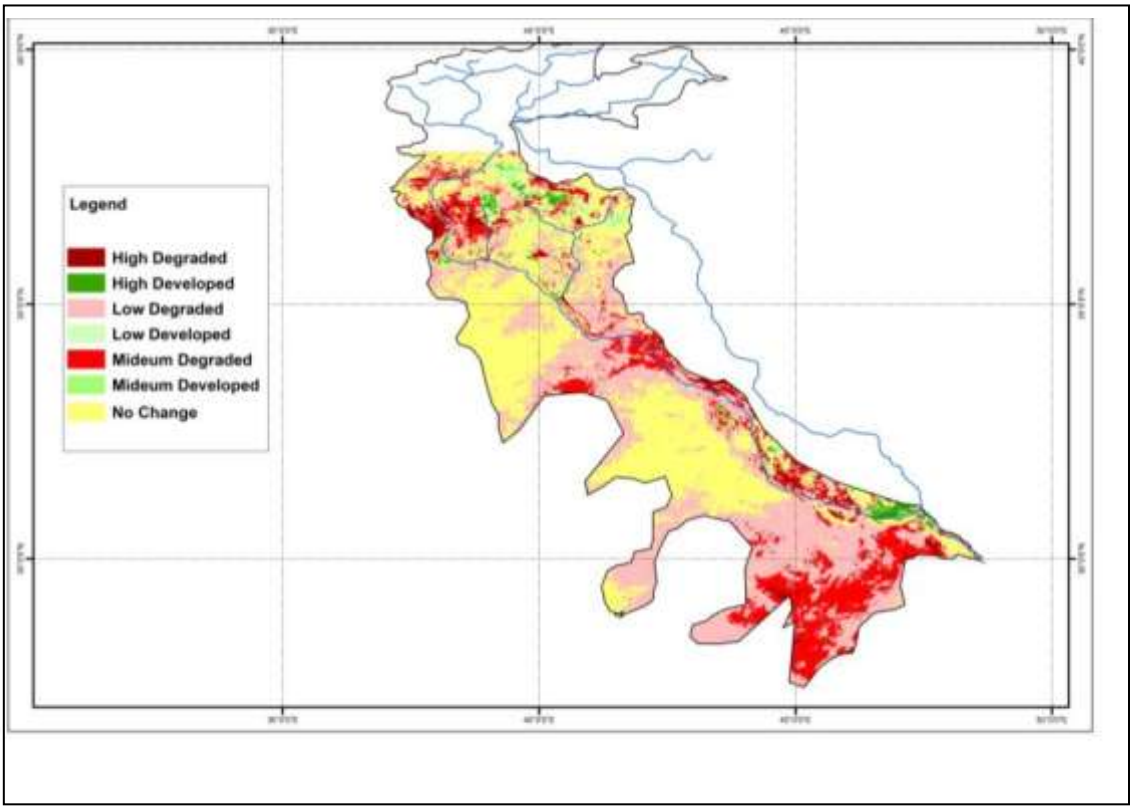


Figure 54: NDVI values for Euphrates River (1999-2007).

Ecosystem Deterioration Parameter EHe

Country	Ad(km2)(1) Area without vegetation	A(km2) Total Area	EHe
Turkey	19227	119042	0.1615
Syria	8879	93675	0.0948
Iraq	39566	195928	0.2019

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

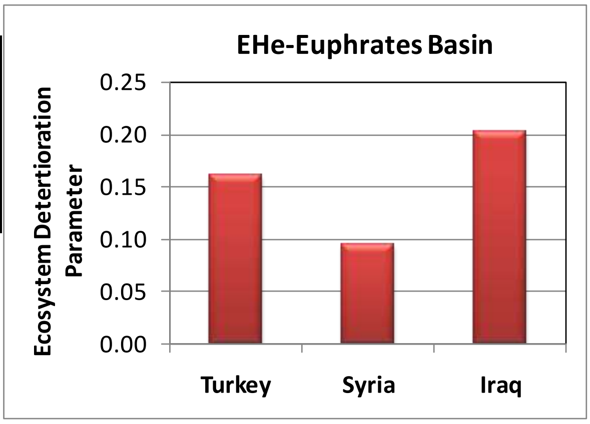


Figure 55: Ecosystem deterioration for the years 1999-2007.

Management capacity (MS) parameter

Evaluation of the management capacity provides a mean 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 sources (trans-boundary).

Water Use Inefficiency Parameter (MCe):

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 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. 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 of the parameter for all countries showing high water use inefficiencies as shown in Figure 56.

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

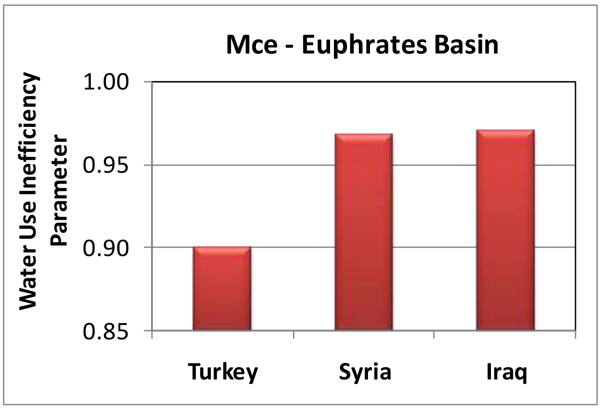


Figure 56: Water use inefficiency for the year 2000.

Improved Sanitation inaccessibility (MCs):

Availability of sanitation infrastructures reduces pollution levels and preserves water sources. 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. This parameter is calculated as the proportion of population without accessibility 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.

Improved Sanitation Inaccessibility Parameter MCs	
Country	**MCs**
Turkey	0.09
Syria	0.23
Iraq	0.20

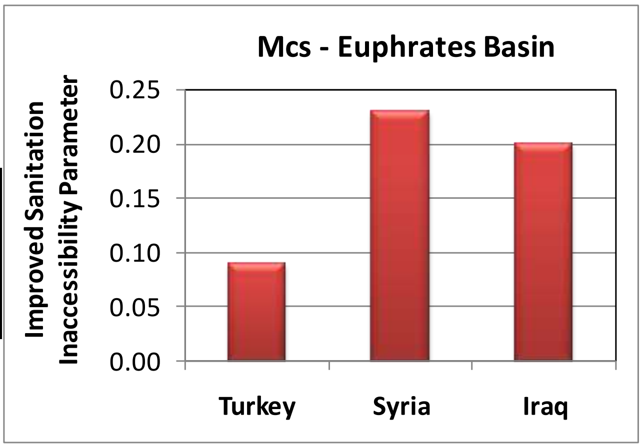


Figure 57: Improved sanitation inaccessibility for the year 2000.

Conflict Management Capacity (MCg)

This parameter was determined by expert consultation using the scoring criteria about conflict management capacity (see annex 1). The three countries have similar values for conflict management capacity 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.

Conflict Management Capacity Parameter MCg	
Country	**MCg**
Turkey	0.65
Syria	0.65
Iraq	0.65

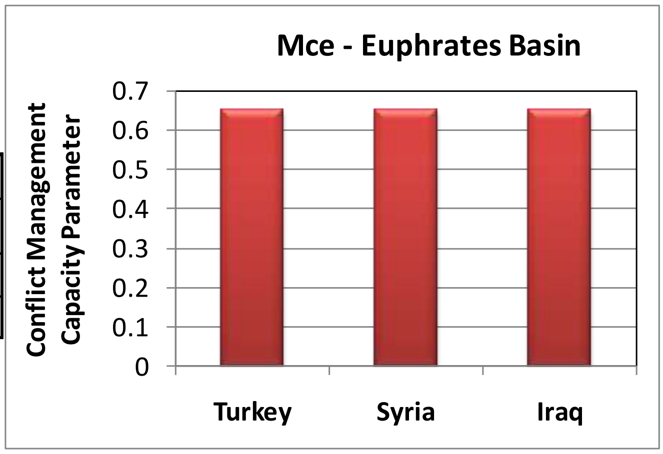


Figure 58: Conflict management capacity for the year 2000.

Fresh water vulnerability index estimation (VI)

The vulnerability index (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.

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.

Vulnerability Index

Country	VI
Turkey	0.42
Syria	0.48
Iraq	0.50

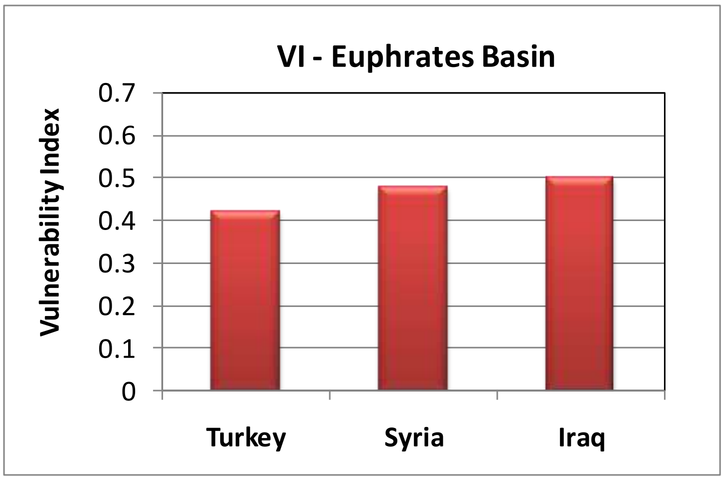
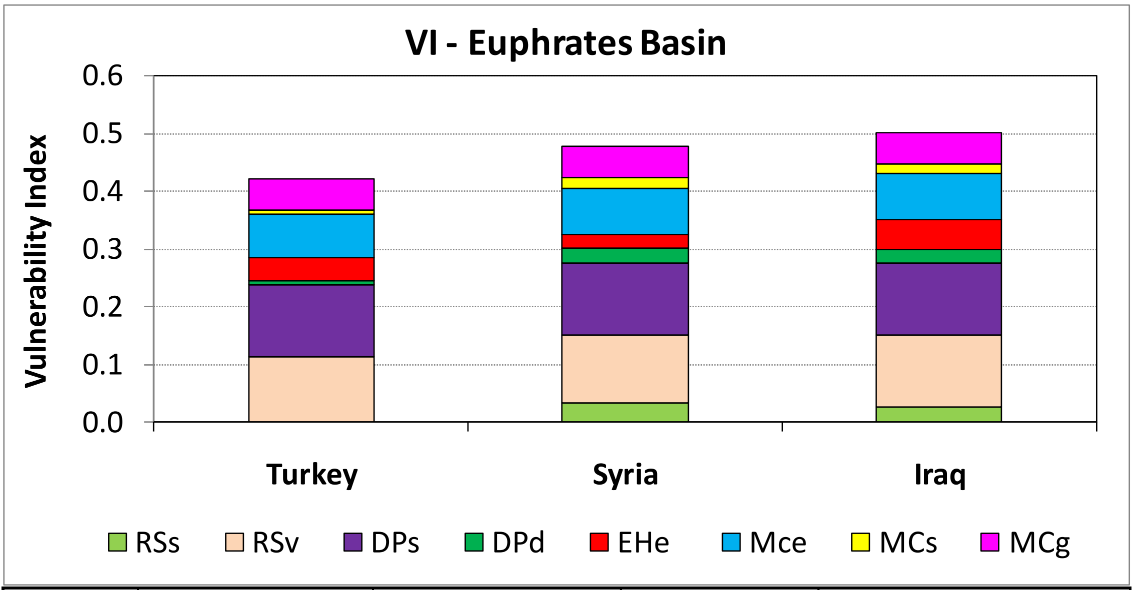


Figure 59: Vulnerability index parameter for Euphrates basin.

Further analysis of the data was undertaken and the values re-plotted as stacked bars showing the influence of the resources 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) as the rainfall and snow amount and frequency control freshwater availability. Further, climate change is expected to have a major impact on rainfall and snow variations. The second most influential factor is the water exploitation pressures (DPs) which reflect 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.



Category	Resource Stress		Development Pressure		Echological Health	Management Capacity		
Parameter	RSs	RSv	DPs	DPd	EHe	Mce	MCs	MCg
Turkey	0.000	0.113	0.124	0.009	0.040	0.074	0.007	0.054
Syria	0.033	0.117	0.125	0.026	0.024	0.080	0.019	0.054
Iraq	0.025	0.125	0.125	0.024	0.050	0.080	0.017	0.054

Figure 60: Vulnerability of Euphrates basin.

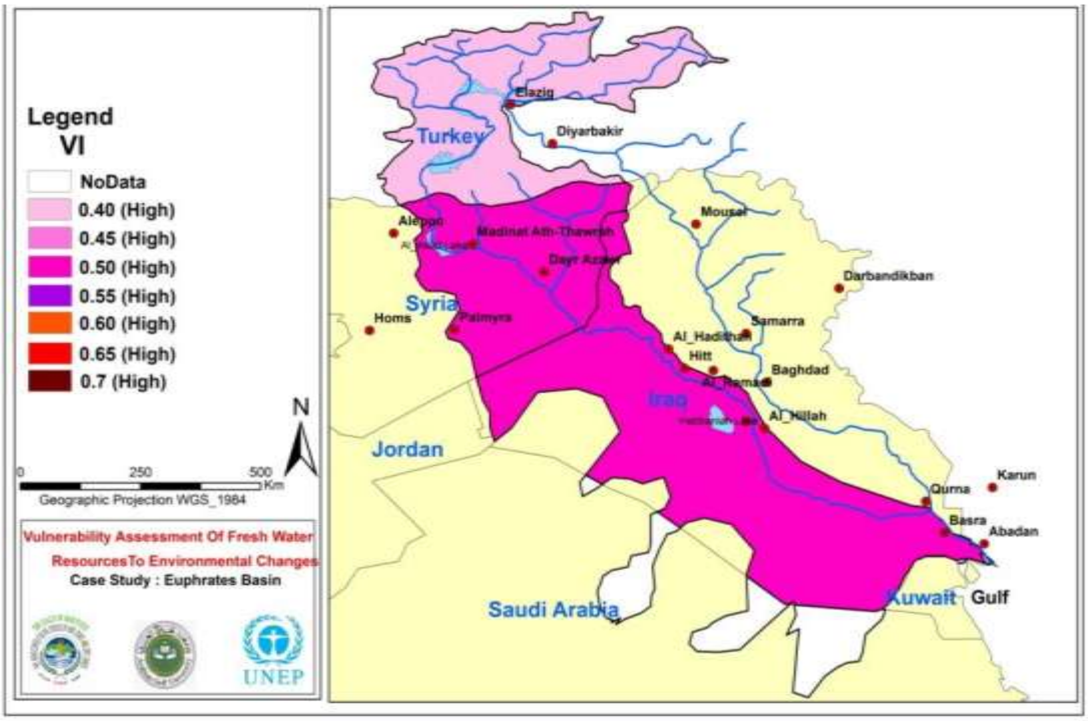


Figure 61: Euphrates basin vulnerability index map-2000.

5.1.5. Conclusion

The three countries sharing the Euphrates River basin are vulnerable in various degrees to environmental change (high vulnerability index). Even if the VI is less for Turkey due to the fact that the country is upstream and has additional water resources, situation could aggravate in the future due to climate change impacts. To decrease the vulnerability of the countries of the basin, it is necessary to have an integrated vision for the management of the basin and provide the basis for an optimum allocation of the available water. This requires the close cooperation with regards sharing and management of the water resource for all countries involved. It would be further beneficial for the countries involved to finalize an official agreement to prevent future conflict. As a first step for future cooperation and for overcoming the problem of contradicting data, it would be useful to agree on principals, norms, and standards of monitoring measurements. This will benefit future cooperation and protect the interests of future generations and environment of the region. Once such commonality has been established, it will be easier to determine practical measures of basin level cooperation.

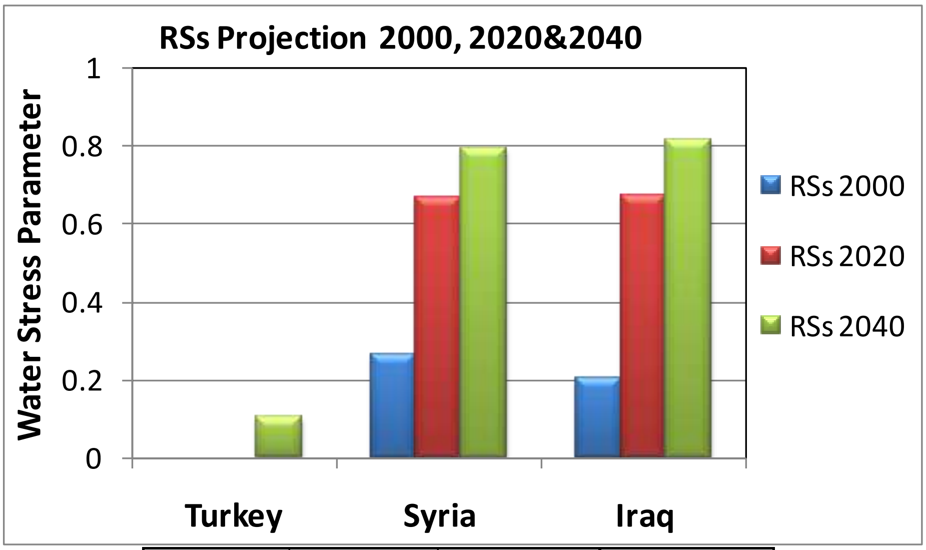
5.1.6. Future Scenarios for assessing freshwater vulnerability

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

Scenario 1: **Increased population growth**

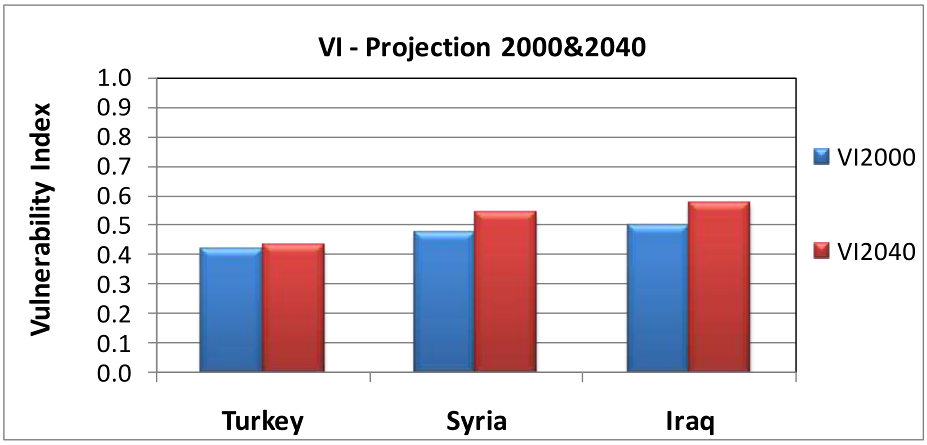
The population growth scenario suggests an increase of 2.5 per cent for Syria based on its present current population growth trend, 1 per cent for Turkey (WHO / UNICEF-Joint Monitoring Program for Water Supply and Sanitation 2008) and 3 per cent for Iraq (ACSAD-UNEP, 2001). For calculating the different parameters, it was assumed that the water requirement per person for the agriculture and domestic sectors will be maintained at the level of the year 2000.The water requirement for domestic sector was increased by the same rate of the population growth.

The water resources stress (RS) estimation indicates 0.27 for Syria and 0.20 for Iraq and 0 for Turkey in the year 2000 which imply 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 as show in Figure 62. This implies that competition for the shared water resource, 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 the water in Euphrates river agreements. The estimated vulnerability index for the years 2000 and 2040 is shown in Figure 63. The vulnerability index for the year 2000 ranged from 0.4 for Turkey to 0.45-0.5 for both Syria and Iraq. Higher values are predicted for the year 2040 for Syria and Iraq, estimated at 0.52 and 0.58 respectively. Higher population growth combined with a reduction of precipitation due to climate change is expected to lead to further increase in freshwater vulnerability. It is imperative that the concerned countries must focus on area where disagreements create obstacles in relationship and find areas of agreement and build on them. This will encourage dialogue and reduce future expected tension between the three concerned countries



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 62**:** Water stress parameter estimation for scenario 1.

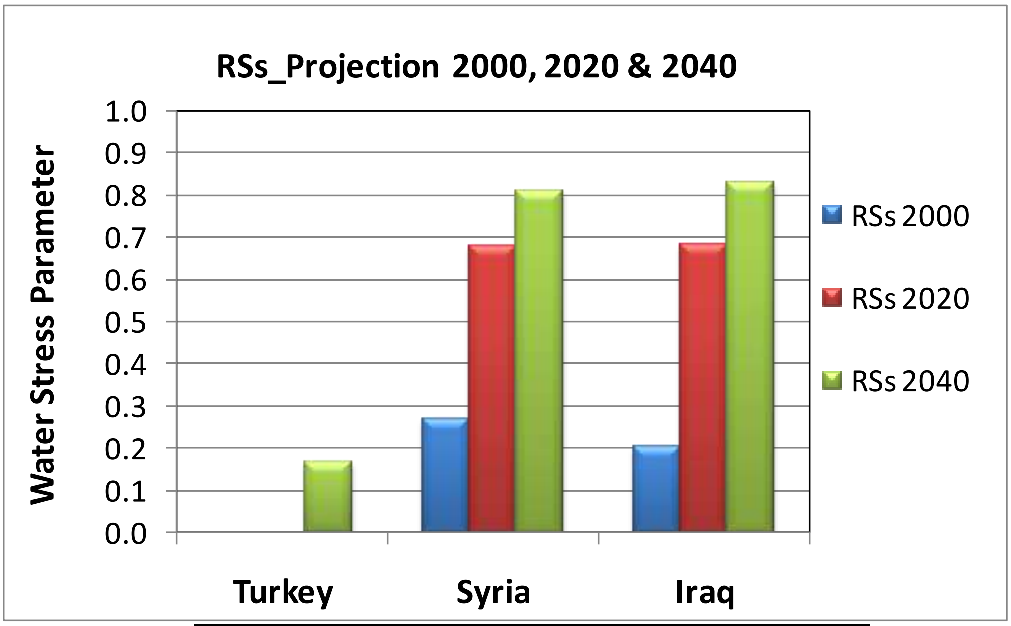


Country	VI - 2000	VI - 2040
Turkey	0.42	0.43
Syria	0.48	0.54
Iraq	0.50	0.58

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

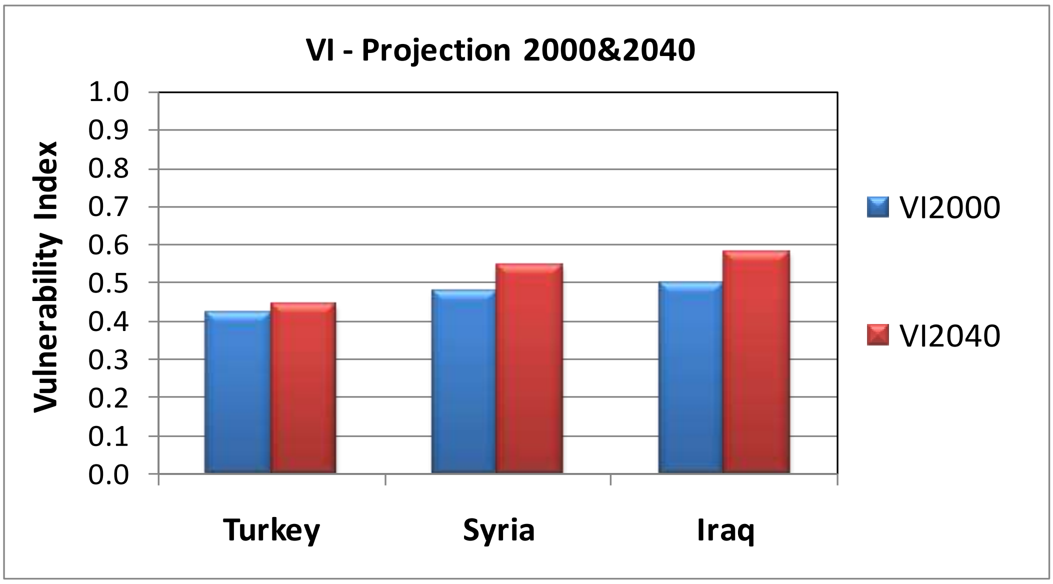
Scenario 2: **Decrease of 7 per cent in freshwater availability due to climate change**

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 basin area located in Syria while an increase from 0.20 to 0.83 for basin area in Iraq for the same periods. 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 vulnerability index shown in Figure 65 indicates that Turkey will have small increase in vulnerability estimated at 1 per cent while Syria and Iraq will be more because of higher population growth rate and lower water availability (expressed as per capita water resources) which is expected to decrease in the future due to population growth and climate change impact.



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 64: Water stress estimation for the scenario 2.



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

Figure 65: Vulnerability index estimation for the scenario 2.

The application of the vulnerability assessment indicates that all the countries within the Euphrates basin will have an increase of the freshwater vulnerability due to climate change, even Turkey. Future climate change scenarios predict a decrease in precipitation of 20 per cent and an increase in temperature in the Eastern Mediterranean area including the upstream parts of the Euphrates River. It is also expected that snow fall 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 agriculture and the 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 source of food production for the three countries. This issue makes 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. Actions are needed for defining a plan for adaptation and risk management. As the countries and populations living in the Euphrates basin heavily rely on agriculture activity; the focus of much of the adaptation strategy should be on agriculture sector and 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 experience and data exchange.

- Raising awareness and capacity building will help countries adaptation to climate change and reduce vulnerability.

5.2. Case study- Dammam shared groundwater aquifer

5.2.1. Introduction

Water scarcity in conjunction with increases in water demand in all sectors is contributing to full utilization of the available renewable water resources and the depletion of non-renewable water resources, particularly groundwater in all countries of the West Asia region. With few exceptions, the 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 the non-renewable shared aquifers is being mined at different rates in the GCC countries, mainly by the irrigation sectors. The significant spatial and temporal variation of rainfall has a major impact on aquifer replenishment. The present recharge to groundwater is very limited relative to the volume of groundwater stored in the aquifer during previous pluvial periods when most recharge occurred.

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

Table 12: Characteristics of non-renewable shared aquifers

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 Er Raduma	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

mcm= million cubic meters; ppm = parts per million

Source: (MAW, 1984; WB, 2005)

The current uncontrolled groundwater development practices, in the absence of joint agreements to manage the shared aquifers in a relatively sustainable manner, has resulted in detrimental effects including high depletion rates, increasing pumping costs and deterioration of water quality. These negative impacts resulting from groundwater development, combined with increasing demands for water which is expected to lead to further development, creates potential dispute among countries of the West Asia region. In addition, climate change impacts from the modification of the rainfall regime and sea level rise will 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 sources to the impacts of uncoordinated development and climate change. The aerial coverage of the Paleogene formations, which contain the Dammam aquifer in West Asia region (including the outcrop and discharge areas) is shown in Figure 66 (UN-ESCWA, 1999).

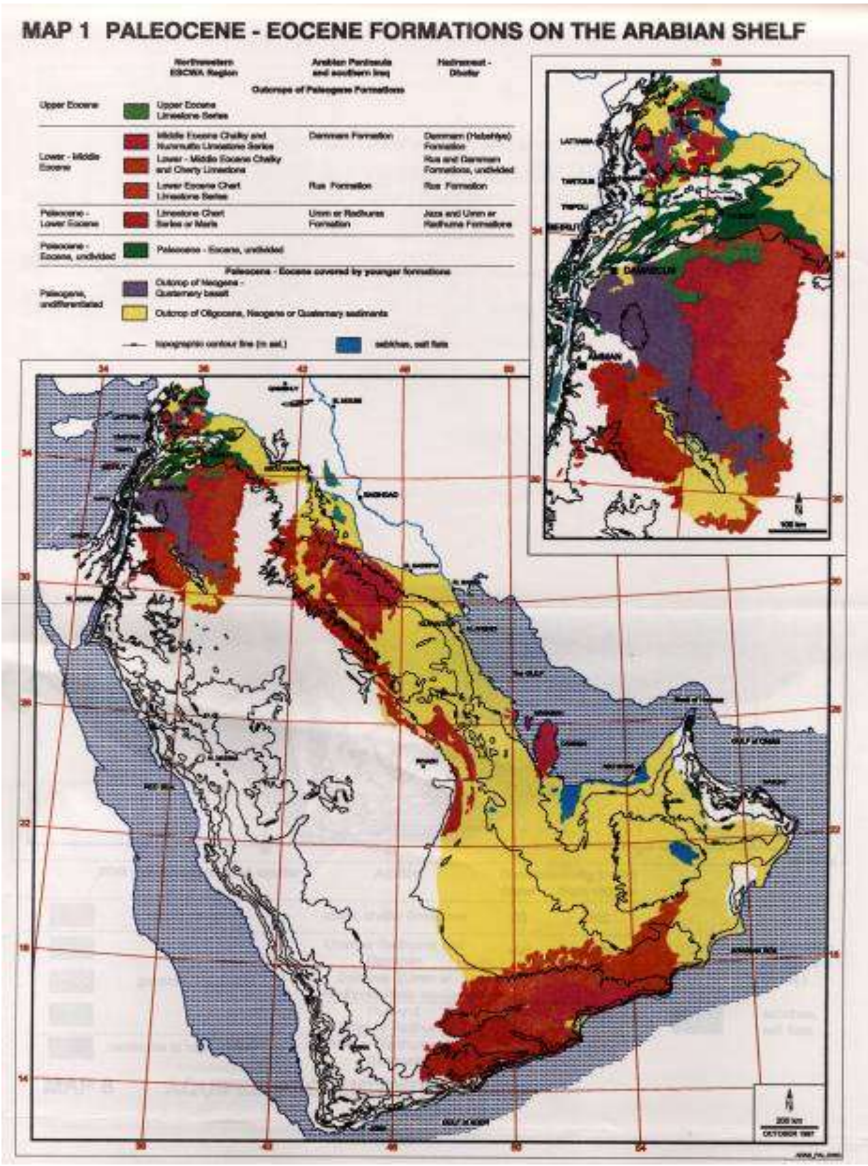


Figure 66: Paleogene formation aerial coverage include the Dammam aquifer (UN-ESCWA, 1999)

5.2.2. Characteristics of the shared Dammam groundwater aquifer

The Dammam formation is part of a complex Paleogene carbonate aquifer of the Eocene geological era. The shared Dammam aquifer covers a large area of West Asia region including parts of Syria, Jordan and 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 overlay 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 the GCC countries (UN-ESCWA, 1999). The aquifer is being mined at abstraction rates far exceeding the recharge rates. Figure 67 illustrates the range of aquifers' productivities in each country sharing the aquifer, while Table 13 shows the countries sharing the Dammam aquifer with the local names.

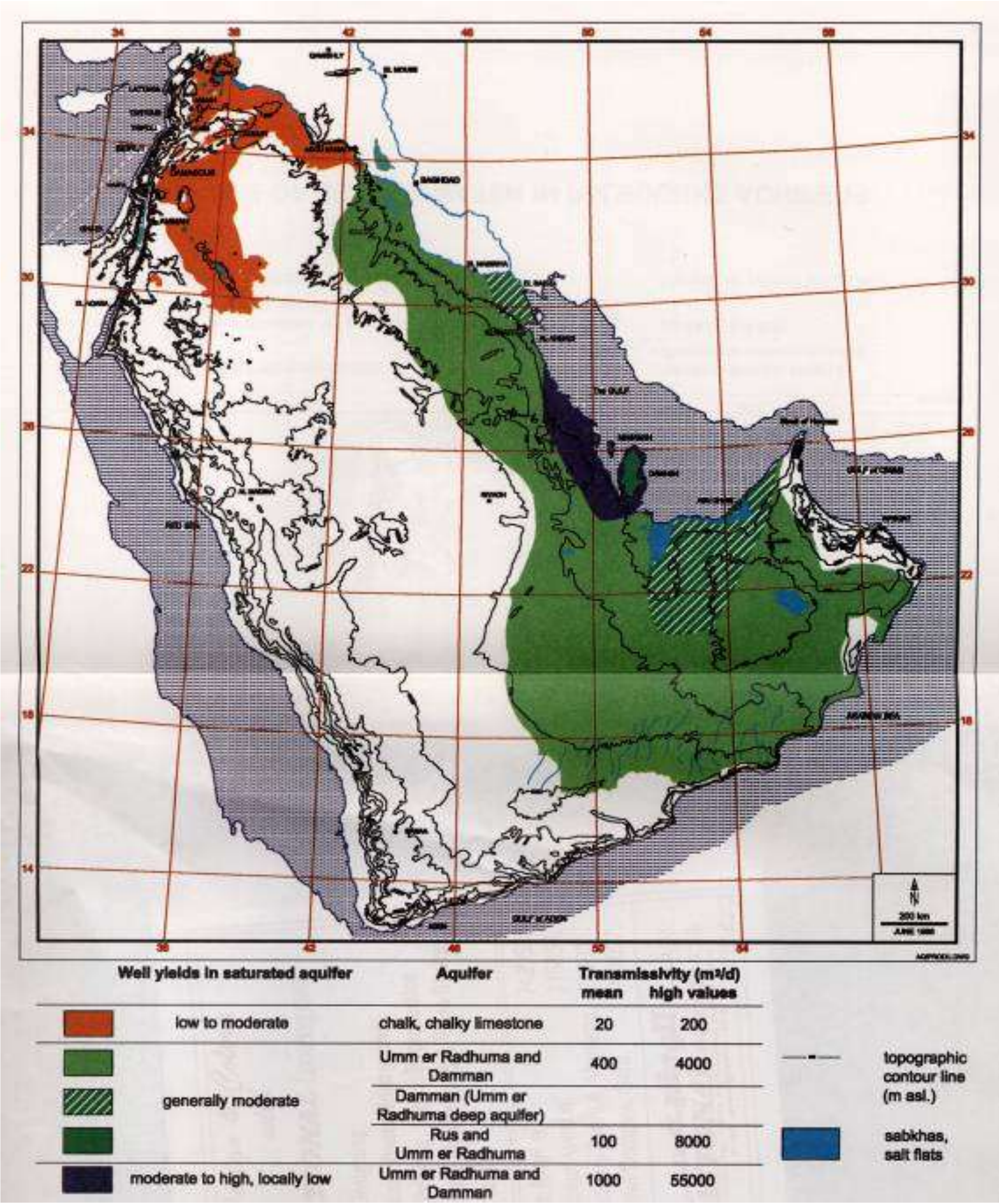


Figure 67: Aquifer Productivity classified as low, moderate and high in each country (GCC).

Table 13: Dammam aquifer characteristic in countries of the Mashriq sub-region (UN-ESCWA, 1999)

Country	Thickness (m)	Member name	Productivity (mcm)
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	

mcm = million cubic metres

The aquifers are under confined conditions for most of their areal extent due to their depth below the surface with 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 Dubai. The main hydrologic parameters of the aquifer exhibit large variations with depth and with area which can be attributed to the past tectonic structural activities and deposition environments. The magnitude of transmissivity (T), which is a measure of 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 the nature of fracturing and karstification (0.03-450 m^2/d), while in southern Iraq and the GCC countries the transmissivity ranges from 2 to 200 m^2/d. The storativity, which is a measure of 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 are limited, compared to the size of the aquifer. The average thickness of the aquifers ranges from 50 to 250m. Generally the depth increases in a south direction towards the coastal zone of the Gulf. The volume of groundwater reserve in the Dammam aquifer is estimated at 4 500 mcm.

Climate

The prevailing climatic conditions range from the sub humid zones in the Northwest to the arid climate in Arabian Peninsula. Average annual rainfall varies between 50 and 110mm. Random and localized storms are a common feature throughout the region. In the central areas summer temperatures can reach up to 50^{o}C. The predominant characteristic of rainfall pattern in the Arabian Peninsula is the temporal and spatial variability. The mean annual precipitation is about 110mm in Kuwait, 74 mm in Bahrain, and 75 mm in Qatar.

Exploitation

Prior to the advent of well abstraction, the aquifer main discharge was in the form of natural land and offshore springs discharge 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, *et al*. 1982) and about 300 mm^3/y for springs (GDC, 1980; Bakiewicz, *et al*. 1982). These Figures do not distinguish between the Umm Er Radhuma and the Dammam aquifer discharges and represent the pre-development conditions of the Paleogene 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 the 1930s and particularly the sudden increase in the riparian countries' oil revenues in the early 1970s, has resulted in a rapid population growth, urban development, industrial and agricultural expansion, and was accompanied by a dramatic increase in water demands and consumption. These demands have been met mainly by groundwater abstraction in place of the natural springs, which have experienced a significant reduction in their discharge as a result.

While the Dammam aquifer occurs 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 the 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 the extraction rates since 1940 and marked upward trend after 1965. The Dammam aquifer is used extensively in the coastal cities of the eastern province of Saudi Arabia for domestic, irrigation, and industrial purposes. Available records indicate that abstraction rate from the aquifer was about 171 mm^3/y in 1967 increased to about 430 mm^3/y in 1990 (Abderrahman, *et al*. 1995). In the northeastern region of the eastern province, characterised by significant agricultural activities the total Dammam aquifer abstraction was reported at about 540 mm^3/y in the early 1990s (Hasan, 1995). A large proportion (80%) of the water abstracted is used for agricultural purposes and the rest 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). After this time, abstraction dropped as a result of water quality deterioration and government intervention measures (introduction of TSE use in agriculture, wells metering, improving irrigation methods) to reach about 130

mm^3/y in 2009. Extracted water is used mainly for agricultural purposes, with small amounts used for blending with desalinated water for domestic supply, and industrial purposes.

In Kuwait, groundwater abstraction (government and private) 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. The total groundwater abstraction in Kuwait was about 35 mm^3 in the early 1970s, increasing to 71 mm^3 in the early 1990s (Al-Murad, 1994), reaching 460 mm^3 in 2005 (El-Awar, 2005). Groundwater extracted is used for both domestic non-drinking purposes and agricultural purposes.

Water quality

Water salinity (Total Dissolved Salts or TDS) ranges from 2000-6000 ppm; being affected by mixing with groundwater from other aquifer systems (with much higher salinity) in some locations or due to salt water intrusion along the coastal zones of the Gulf. The average salinity (in terms of TDS) for both Alat and Khobar aquifers ranges from 1000 ppm (west of the outcrop areas of the eastern part of Saudi Arabia) to more than 100000 ppm (at the Gulf). Both the Alat and Khobar aquifers show similar water quality characteristics with hydrochemical faces that are being 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 subsequent considerable increases in the salinity of the extracted groundwater in all the countries tapping the Dammam aquifer (Al-Zubari, 2001; Sayid and Al-Ruwaih, 1995; Al-Mahmood, 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, depth from the surface and aerial 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 peizometric head, increased level of salinity, mixing of water among aquifers and depletion of the aquifer reserves. These negative impacts are likely to be exacerbated by the anticipated impacts of climate change due to the 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 the Arabian Peninsula (AP) countries since it is not available at the aquifer level in 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 Arabian Peninsula, it was decided to omit these countries in the case study. The availability of detailed data on the recharge rates in each country and the rates of water being extracted from the Dammam aquifer to satisfy the 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 the amount of pumping volume, recharge, desalinated water, wastewater, population and the 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 vulnerability index (VI).

The resources stress (RSs) parameter

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

Water resources stress (RSs)

The availability of the 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 the past and future water demands of the level of the population size

The water stress (RSs) values for the year 1985 range from 0.68 in UAE to 0.82 in Kuwait. A small increase in water stress was observed in 1995. The values for year 2005 range from 0.56 in Oman to 0.66 in Kuwait (Table 14). The water stress is still high, however the increase in the desalinated water production which represents a significant amount of the available freshwater in most countries (with the exception of Saudi Arabia and Oman), reduced the water deficits as shown in Table 14 and Figure 68.

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

Water Variation (RSv)

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

Table 14: Water stress variation for period 1985-2005

RSs			
Country	**1985**	**1995**	**2000**
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

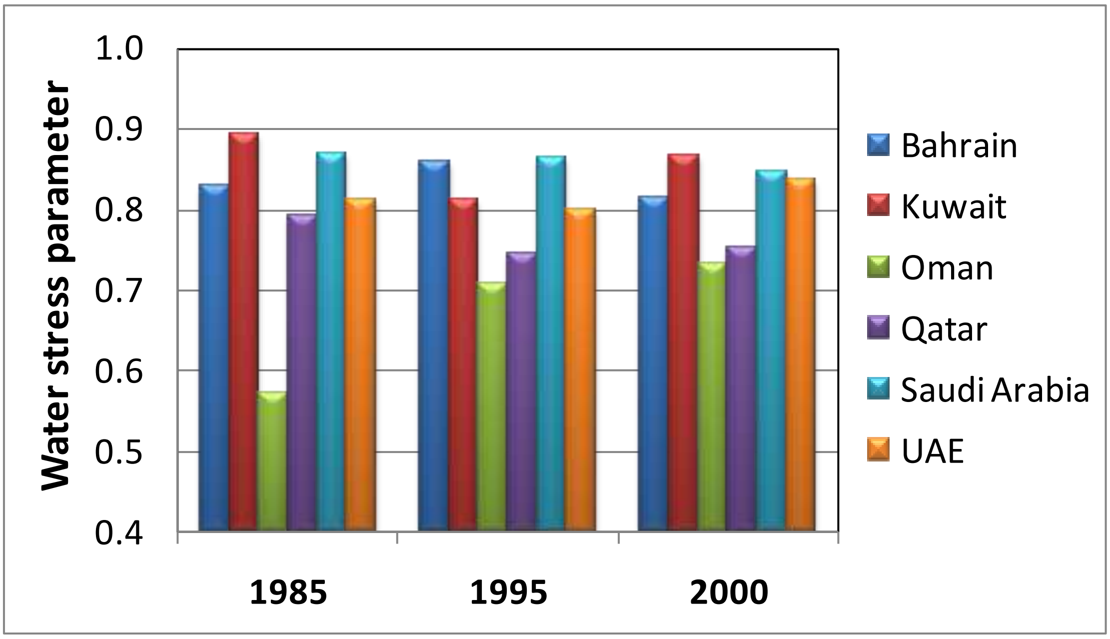


Figure 68: Degree of water stress for the AP sub-region

Table 15: Water availability variation (RSv) due to rainfall variability. CV is the coefficient of variation.

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 Development Pressures (DP) parameter

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

Water Exploitation (DPs)

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

Safe drinking water inaccessibility (DPd)

The supply coverage depends on the water resources development activities to provide the basic water need for different segment of the society. The drinking water supply coverage 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 the water supply 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 extent and population, need additional financial resources to improve the coverage especially in rural areas. The 1995 and 2005 trends indicates less coverage in Oman for the year 2005; while the situation in Saudi Arabia indicate improved coverage for the period 1995-2005.

Table 16: Water exploitation variation (DPs)

DPs			
Country	1990	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

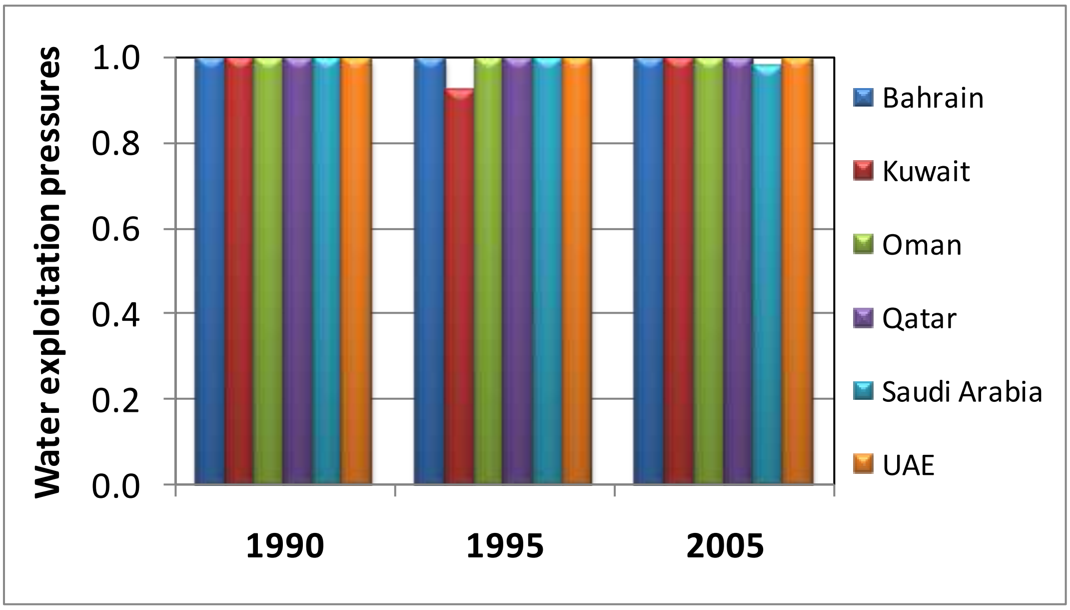


Figure 69: Water exploitation variation.

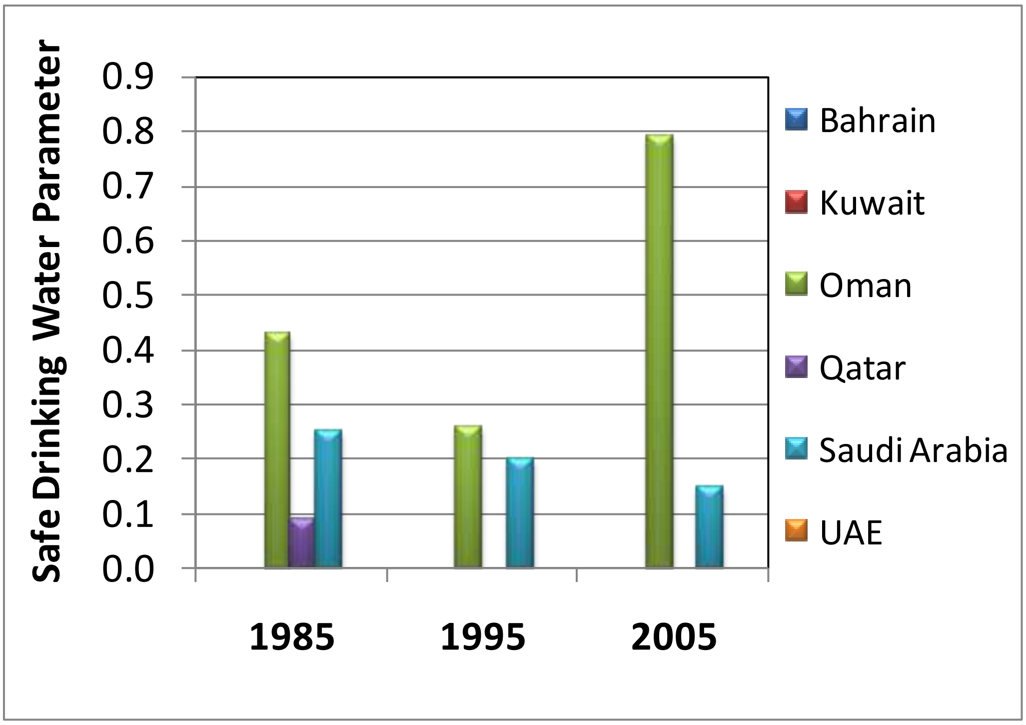


Figure 70: Drinking water supply inaccessibility.

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

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)

The pollution to water resources vulnerability is estimated by the ratio of the 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 for Kuwait, Qatar and UAE and relatively less pollution in Saudi Arabia and Oman. The pollution level has decreased in Saudi Arabia, Qatar and Oman for the period 1985-2005, but increased in Bahrain, Kuwait, and UAE. In 1995 the values ranged from 1 to 0.98 and from 0.26 and 0.29 in Bahrain and Kuwait, respectively, reaching 0.58 in Saudi Arabia. In the year 2005 the pollution from wastewater in all countries decreased with the exception of Oman and Bahrain as shown in Table 18 and Figure 71. The values in 2005 ranged from 0.05 in Kuwait, 0.29 in UAE to 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.

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

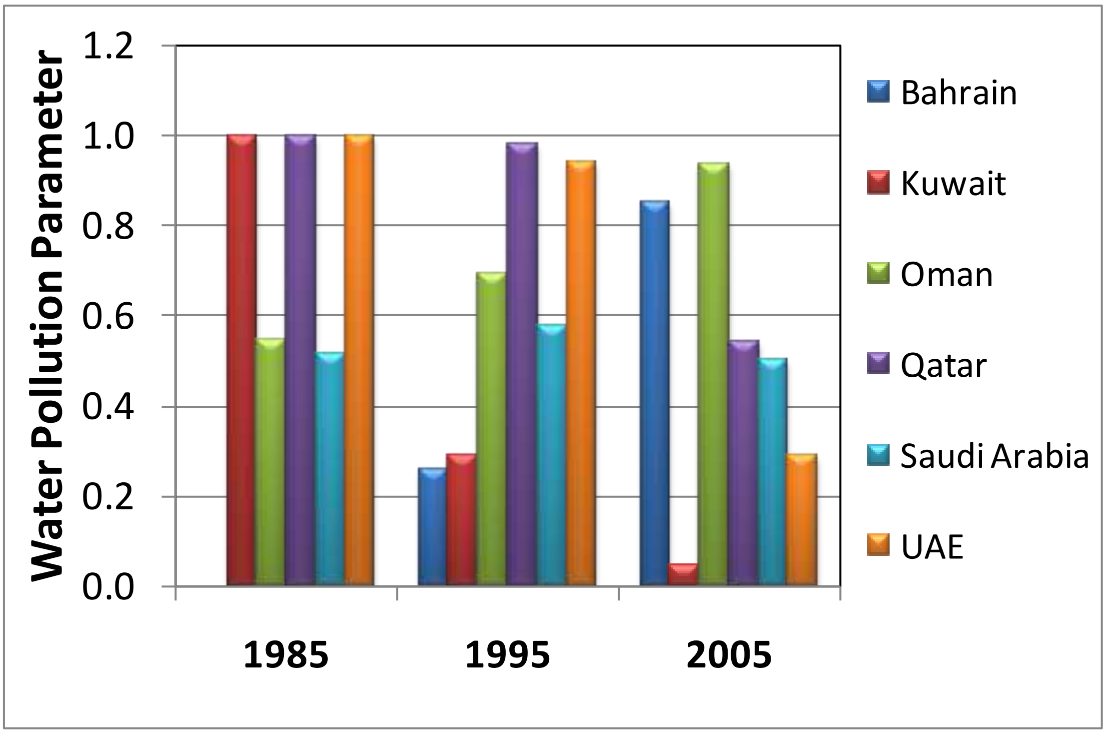


Figure 71: Water pollution variation.

Ecosystem deterioration (EHe)

The ecosystem deterioration is estimated as the ratio of land size without vegetation cover (Ad) to the total size of the country (A) assessed. Ecological deterioration values were high for all countries; being in the range of 0.92-0.95, 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 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 comparing to other countries sharing the aquifer in which the aquifer covers almost all the areas of these countries. Values for Oman for the period 1985-2005 may also be incorrect as most of its southern areas have adequate vegetation cover, due to agriculture activities and rains.

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

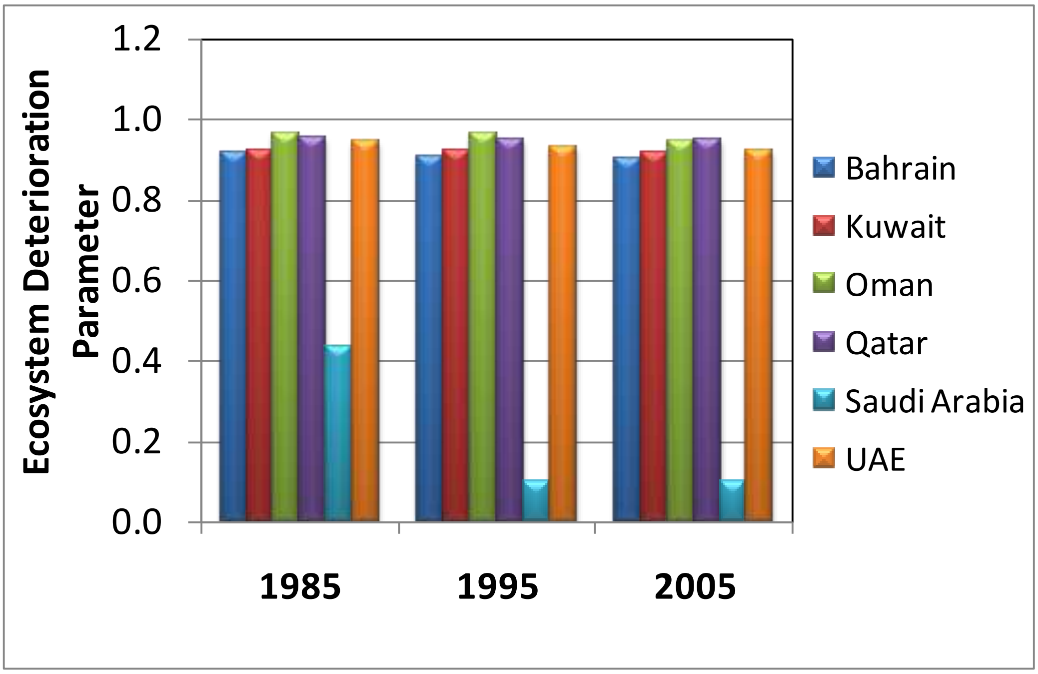


Figure 72: Ecosystem deterioration variation

Management capacity (MC)

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

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

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

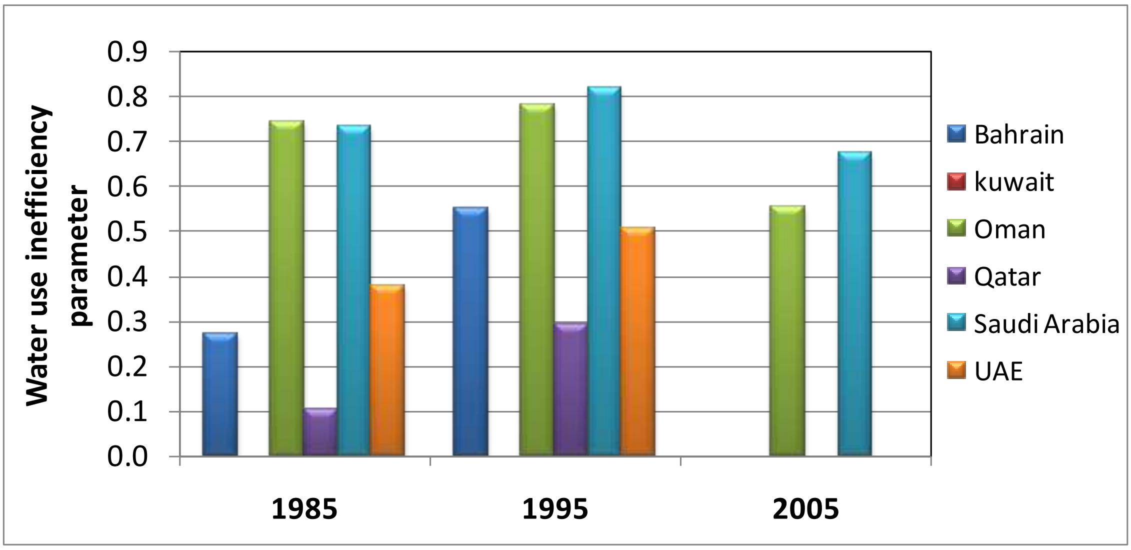


Figure 73: Water use inefficiency parameter.

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 (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 of the countries such as Bahrain, Kuwait and Qatar as most of their areas are considered urban where usually the service is better done than in rural areas. The sanitation coverage is adequate in most countries, with the exception of Saudi Arabia and Oman which has less coverage in the rural areas. Even though high sanitation coverage exits, waste water pollution is taking place as some of the wastewater treatment plants are operating in excess of their capacities. Large volumes are being disposed into the sea and wadi channels. The amount of reuse of treated wastewater is very small compared to the 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

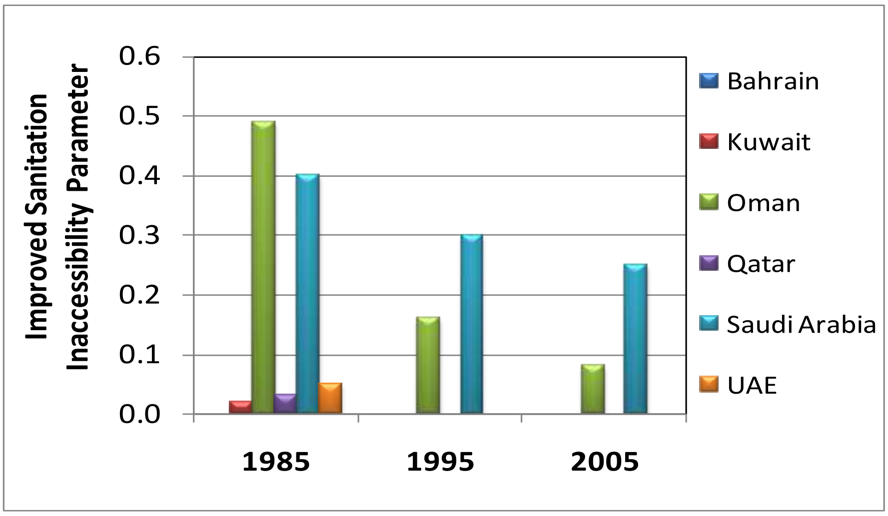


Figure 74: Sanitation Inaccessibility variation

The 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.

Results

The estimation 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 vulnerability index for each country.

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

Table 23: Calculation of four main parameters used for estimating vulnerability index for each country

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	0.5	0.5	0.5	0.5	0.5	0.5	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	0.5	0.5	0.5	0.5	0.5	0.5	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	0.5	0.5	0.5	0.5	0.5	0.5	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	0.5	0.5	0.5	0.5	0.5	0.5	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	0.5	0.5	0.5	0.5	0.5	0.5	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	0.25		0.25		0.25		0.25		
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	0.5	0.5	0.5	0.5	0.5	0.5	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	0.5	0.5	0.5	0.5	0.5	0.5	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	0.5	0.5	0.5	0.5	0.5	0.5	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	0.5	0.5	0.5	0.5	0.5	0.5	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	0.5	0.5	0.5	0.5	0.5	0.5	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	0.5	0.5	0.5	0.5	0.5	0.5	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	0.5	0.5	0.5	0.5	0.5	0.5	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	0.5	0.5	0.5	0.5	0.5	0.5	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	0.5	0.5	0.5	0.5	0.5	0.5	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	0.5	0.5	0.5	0.5	0.5	0.5	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	0.5	0.5	0.5	0.5	0.5	0.5	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	0.5	0.5	0.5	0.5	0.5	0.5	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	0.5	0.5	0.5	0.5	0.5	0.5	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, the vulnerability index values for the period of the analysis proved relatively high (in the range of 0.55 to 0.77). Bahrain values increased from 0.57 to 0.65 while Kuwait and Qatar showed a decrease from 0.62 -0.68 to 0.53 as shown in Table 24 and Figure 75. The same decreasing trend was observed for Saudi Arabia and UAE. The case of Oman indicates increasing vulnerably with time. All countries are not expected to face severe freshwater vulnerability due to the role of desalination in providing drinking water supply without the influence of any natural impact and the availability of financial resources. The high water supply and sanitation coverage provided represent dominant factors in the vulnerability index. Most countries have the needed financial resources to invest in desalination and wastewater treatment facilities for the domestic sector.

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

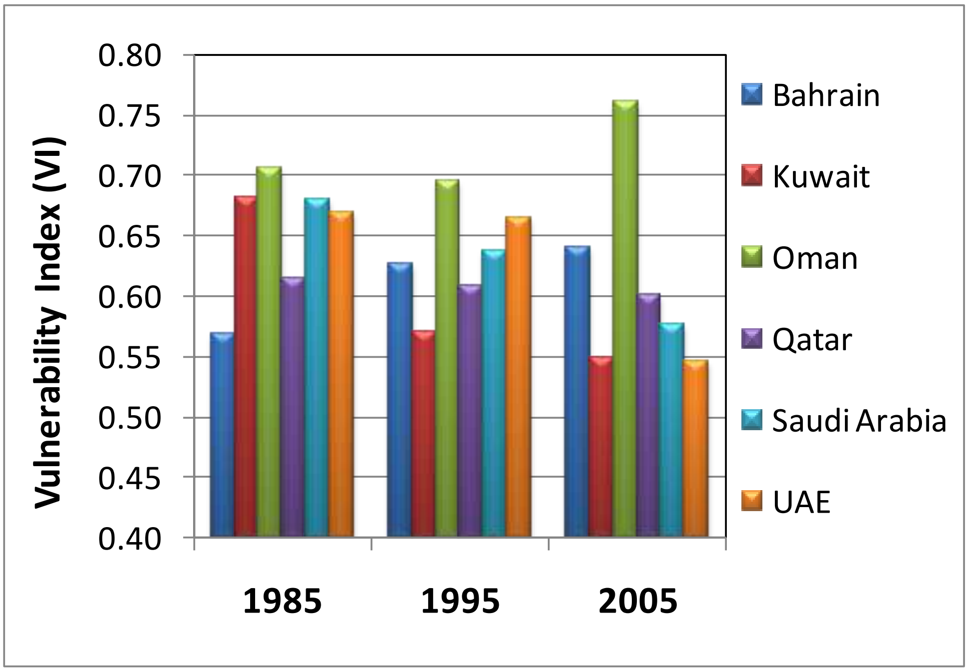


Figure 75: Variation of VI of Dammam aquifer for all countries.

Analysis

The current development practice and the absence of coordinated management of the Dammam aquifer is expected to have political, technical, economic and social implications leading to future dispute among countries of the region.

Political aspects

The current unplanned development of the shared Dammam aquifer, where abstraction is taking place in excess of the amount of natural recharge and without any coordination between the concerned countries. This is leading to a decline in the water level and increased salinity levels consequences and the reduction of interflow from Saudi Arabia to Bahrain, Kuwait, UAE and Qatar. This may lead to the migration of saline lenses, mixing of water amount among layers, reduction of spring discharges in lowland areas and coastal zones and increasing water deficit because the available ground water became highly saline and not convenient to be used for drinking supply needs.

Decision makers need to be aware that the current practices may result in potential sources of dispute in the near future and at the same time they do not have the political will to coordinate the 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 sustainability, they have not raised their concern about the future development. 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 the 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 dispute among countries of the region.

Availability of legal and enforcement agreements can achieve equitable allocation of the water and management of the aquifer under a limited mining condition. Existing legal frameworks on shared groundwater resources should form the base for dialogue, debate, cooperation, coordination and development and management of water projects for shared resources. The many articles of existing legal frameworks are very suitable for the management of the Dammam aquifer within the framework of the GCC secretariat. The issue of shared Dammam groundwater resources needs immediate attention in order to avoid potential disputes among countries given the impact of the current development on the Dammam aquifer in all the countries.

Technical aspects

The current development practices are contributing to the deterioration of water quantity and quality of the Dammam aquifer. In addition, climate change, in terms of reduced recharge and salt water intrusion, will further result in problems related to the water balance of the aquifer especially for downstream countries of eastern Saudi Arabia, Kuwait, Bahrain and Qatar. The 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, even if it is very limited in quantity it is expected to decrease as a result of large variations of rainfall over the outcropping areas due to climate change. The lack of monitoring and enforcement of drilling licensing 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 of water of low quality. Such practice is diminishing the availability of the resources and has disturbed the dynamic balance with a reversal of flow. The lack of information dissemination and exchange among countries has hindered further the joint development and management of the aquifer as assessment were made and scenarios were developed at the national level of each sharing countries without taking into consideration their impact on the situation of the neighboring countries. This issue should be highlighted at the level of decision makers in each country proving that any miss management of the groundwater resources of the aquifer will have negative impact on the aquifer in neighboring countries. A coordination mechanism should be settled among the riparian countries to avoid this impact and drawing a sustainable exploitation policy for the resource 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 the high mining rates has social Implications on the 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. Depletion of the resource and deterioration of groundwater quality will deprive the human being of their MDG rights. Also, governments may not have the adequate financial resources to provide needed 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 deficit 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 with increased investment. Deterioration of aquifer water quality has also increased dependency on the costly desalinated water. Saudi Arabia, Bahrain, Kuwait and Qatar are increasingly relying on desalinated water from 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 for providing more desalinated water to compensate the change of mixing ratio. Evidence in the region indicates that international lending institutions have been reluctant to provide needed funds for water supply development that depend on shared resource due to the absence of shared agreements.

Chapter 6

Future of freshwater vulnerability in West Asia region

Chapter Key messages

- The vulnerability of freshwater resources in West Asia is expected to continue to increase in the future if the current trends of population growth and agricultural policies continued, and the issue of shared water resources is not resolved.
- It is expected that the vulnerability of freshwater in the region would be exacerbated by the impact of climate change, manifested by increasing water scarcity and variability, increasing water deficits by widening the gap between available water resources and demands, and might lead to additional conflicts between the 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.
- The issue of shared water resources among countries outside the region, as well as between 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.

6.1. Introduction

Inadequate levels of water management, population pressure, unsustainable agricultural policies, and the expected negative impacts of climate change constitute major challenges to the management of the water sector in the region of West Asia. 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 the current trends will have significant implications on the water availability in the near future and for future generations, in addition to possible deterioration of the fragile desert ecosystem.

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 the process of water resources management. In the Mashriq, shared surface water resources, which contribute more than half of the national water balance for some countries, may experience large degrees of uncertainty due to either the lack of effective implementation of some of the existing agreements (between some countries), and/or the 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, since 60% of the 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., seawater intrusion), thus increasing water scarcity and decreasing food production. These impacts need to be addressed properly in water resource planning at the national and regional levels to ensure inclusion of mitigation and adaptation measures in water resource management strategies and programs.

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 West Asia are: population growth, financial capabilities, 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 WA region as a whole, are rare, which makes it impossible to estimate the vulnerability index 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 [1], estimation of water availability from major rivers originating outside the region is subject to a number of uncertainties and estimating its impact on the future availability of freshwater resources and thus the vulnerability index would not be possible; these uncertainties include population growth and socio-economic activities of the upstream riparian countries, the volatile hydro-politics of the region, as well as the expected impacts of climate change. However, while there is a difficulty in fully quantifying the component parameters of the freshwater vulnerability as an index, the trend and impact of many of the drivers can be qualitatively predicted, and a narrative storyline, supported by some VI parameters that can be calculated with a degree of certainty, can be made on the future vulnerability in the region.

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

6.2.1. Scenario I: Business as Usual

In this scenario, the population size and growth rate is based on the United Nation's population projection trends reported in its publication for the countries of the region. The per capita domestic water consumption in the region is assumed to reach 150 l/day by the year 2020 and are maintained to the year 2040 based on the demand management and conservation efforts made by the countries of the region in the domestic sector. In addition, it is assumed that the water demands of 2005 in the agricultural sector, the main water consumer and where most of the saving can be made, are maintained assuming that the countries' on-going efforts in increasing the water use efficiency in this sector are successful in achieving an increase in production while still using the same amounts of water.

The impact of the future size of the population in the countries of WA would have direct and indirect impacts on freshwater vulnerability components in these countries. The direct impacts would be in the general lowering of the 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)), potential increase in percentage of population without safe drinking water (Safe Drinking Water Inaccessibility Parameter (DPd) and without sanitation (Improved Sanitation inaccessibility (MCs)), and the volumes of untreated wastewater (Pollution Parameter (EHp)). However, while the first and

[1]using the world population prospects by the UN (i.e., *World Population Prospects (The 2008 Revision, http://esa.un.org/unpp, prepared by Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat*).

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 size of the population impacts on the three latter parameters would be significant in the GCC countries due to their energy and financial capabilities 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 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 the WA countries, while OPT (Occupied Palestinian Territories), Jordan and Yemen will have extreme water stresses due to the limited water availability in view of the accelerated population growth. In most of the GCC countries, it is expected that expansion in desalination will alleviate the 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 the upstream riparian countries could cause significant increase in water scarcity in these two countries in the future, since large amount of their available water resources originates from outside.

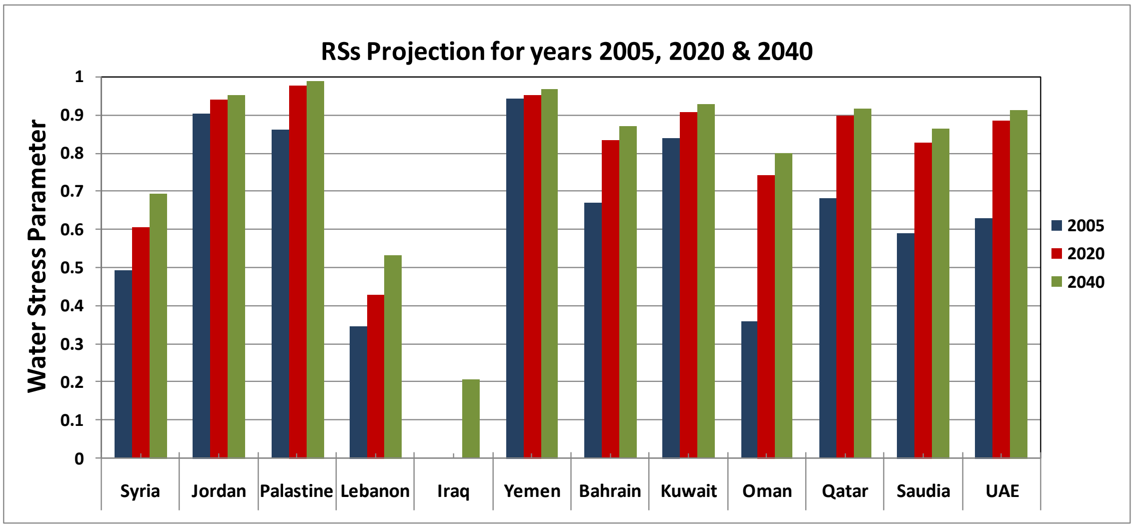


Figure 76: Water stress (RSs) estimation for scenario (1).

The increase in the population will exert increasing 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 over-drafting and mining of freshwater resources.

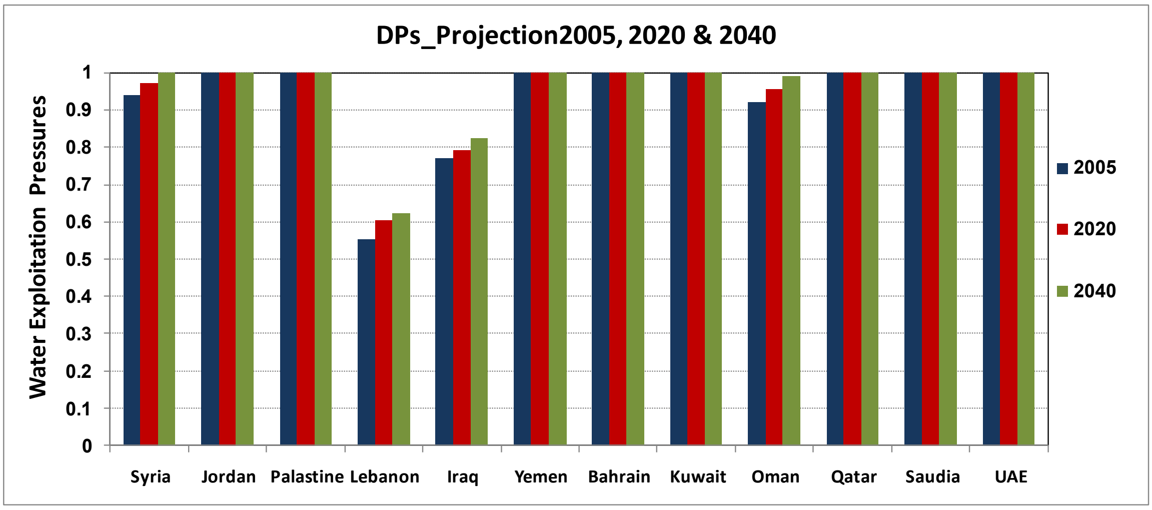


Figure 77: Water exploitation pressure, DPs (Scenario 1).

An important aspect to be considered is that over-drafting 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 and depletion of the resources or their 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 of the countries in WA (except for OPT and Yemen), and is expected to improve with time, over-drafting of water resources might lead to the deterioration of the quality of these supplies in the future. The deterioration of the quality (salinization) of the 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 the current trends of population growth and agricultural policies continued, and the issue of shared water resources is not resolved. Table 20 is an attempt to qualitatively estimate the trends of freshwater vulnerability in WA region and the expected impacts of its main drivers. The Table differentiates between the GCC countries and the Mashriq countries and Yemen based on the importance of the agricultural sector to the economy of the countries, 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 the population growth and agricultural policies (increase in 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 the GCC countries due to their financial capabilities in providing water supply (desalination) and 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 in modifying the GDP produced per cubic meter (i.e., MCe).

Table 25: Estimated trends of freshwater vulnerability in WA region.

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).

6.2.2. Scenario 2: Impacts of Climate Change

The IPCC latest available report (Bates *et al,.* 2008) provides an overview of projected impacts on the water resources of different regions of the globe, which are solely based on Global Circulation Models (GCMs). The ensemble of the GCMs projects 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 exercises are not appropriate for down-scaling to a country or watershed level, for their results and implications can vary significantly between watersheds, and local data and information will be needed to estimate the changes on the country or watershed level (Cap-Net, 2010).

In WA, detailed studies on the impacts of climate change on water resources are generally limited and are available only for 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 countries level. For the purpose of this work, 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, thus it will be 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% for all the countries, except for Yemen which is expected to have an increase of 3%, by the year 2040 (ACSAD Expert Group). The result is that the decrease in available water under normal population growth in the region is expected to lead to further increase in water stress and a general decrease in the amount of exploitable resources.

Figure 78 illustrates the estimated water stress for the countries of WA region. Climate change will increase threats to freshwater resources in the region (compared to the business as usual scenario; Figure76) 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.

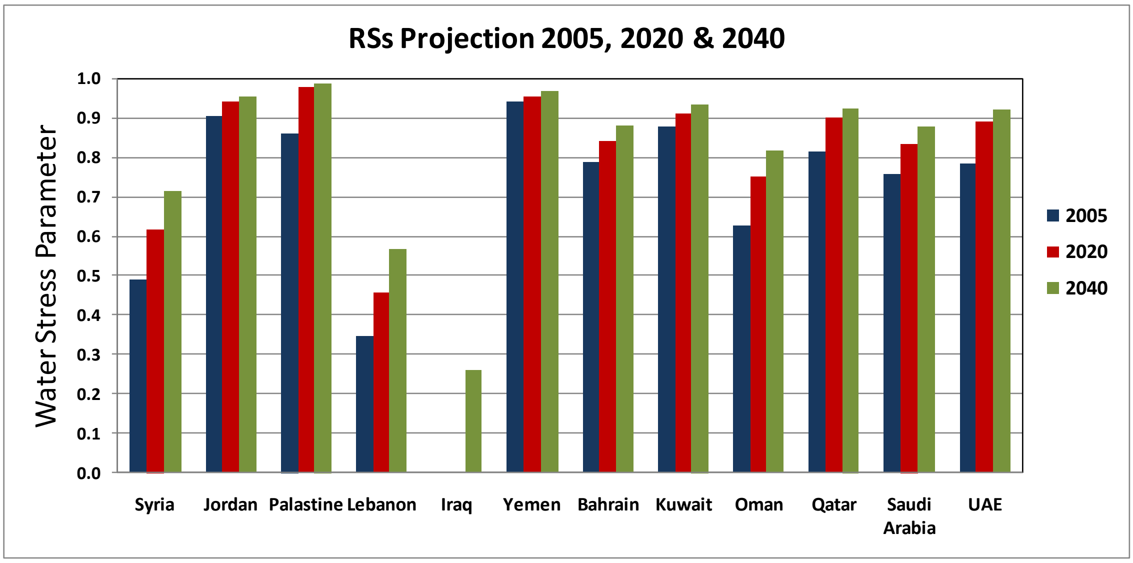


Figure 78: Water stress projection 2040 (scenario 2).

Similarly as in scenario I, but with more intensification to compensate for the shortage of water resources due to climate change, 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 over-drafting of water resources, as discussed above in the Business as Usual scenario. Furthermore, the unresolved issue of shared water resources might lead to additional conflicts between the riparian countries under the expected impacts of climate change in reducing available water resources and increasing demands, thus increasing the overall vulnerability.

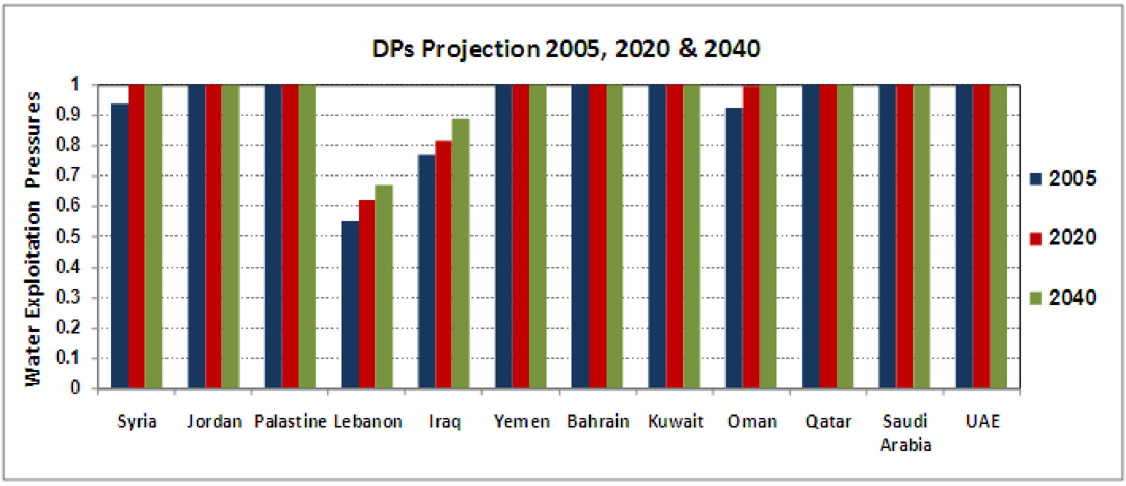


Figure 79: Water exploitation pressure parameter (scenario 2).

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 continued, 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 capabilities in providing water supply and sanitation and due to the absence of, or very limited dependence on shared water resources. It is expected that the vulnerability of freshwater in the region would be exacerbated by the impact of climate change, manifested by increasing water scarcity and variability, increasing water deficits by widening the gap between available water resources and demands, and might lead to additional conflicts between the riparian countries.

Therefore, it is imperative that the countries of the region consider the potential impacts of climate change in their water resources planning by integrating the appropriate adaptation measures in their water programs. Furthermore, the issue of shared water resources among countries outside the region, as well as between 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 7

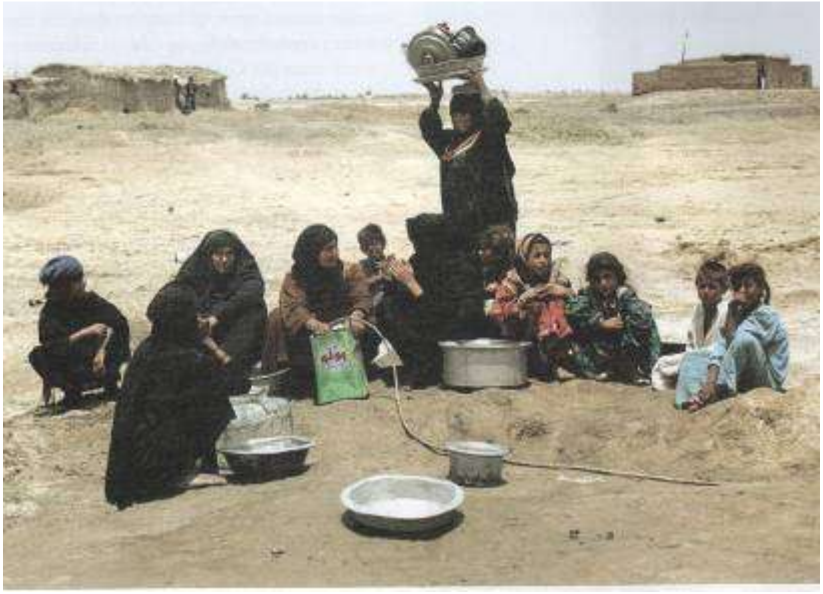
Challenges and Opportunities

Chapter Key messages

- The main water management challenge facing the countries of West Asia region is the continuous increase in water scarcity and the increasing stresses and deterioration placed on the region's limited natural water resources due to increasing water demands, which pose major threats and implications not only on the future development of the countries of the region, but also for the sustainability of their past socio-economic achievements.
- The lack of water management enabling environment of integrated water management policies with adequate legislative framework, 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, and improvement of the legal and institutional provisions are key to efficient development and management of water resources and must be given the utmost attention to lower freshwater vulnerability in the region.
- It is expected that climate change will impose further stresses on the limited freshwater resources in the countries of West Asia and intensify their vulnerability, especially for those countries relying on shared water resources, which in the absence of sharing agreements will increase tension between riparian countries. The issue of shared water resources should be given high priority by the countries of West Asia to finalize water resources sharing agreements according to the international water law.
- Large water saving opportunities exists in the agricultural sector, which uses more than 80% of the total water consumption in the region and where most of water wastage occurs. Savings are possible through increasing irrigation efficiency by the introduction of irrigation and agricultural techniques, reuse of treated wastewater, augmentation by agricultural drainage water, and the implementation of incentive/disincentive system.
- Municipal wastewater has become an increasing source of water with considerable potential in alleviating water scarcity in the region, as their volumes increase proportionally with increasing urban consumptions. With proper treatment they can be used to supplement water demands in the agricultural and industrial sectors, as well as in managed aquifer recharge schemes.
- While the increase in the reliance on desalinated water in the region is inevitable in the future and contributes in lessening water scarcity, especially for the GCC countries, desalination technology are capital and energy intensive, largely imported, provide limited added value to the countries' economies, and have many negative environmental impacts. There is an urgent need for cooperation among the West Asia countries as well as with the Arab Countries to investment in R&D for these technology, with the aim of acquiring and localizing these technologies in the region, reducing their cost, increasing the reliability of

the water source they produce, increasing their value for their economies, and reducing their environmental impacts.

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



Arab environment climate change (2009)

The main water management challenge facing the countries of West Asia region is the continuous increase in water scarcity and the increasing stresses and deterioration placed on the region's limited natural water resources due to increasing water demands. These conditions pose major threats and implications not only on the future development of the countries of the region, but also for the sustainability of their past socio-economic achievements. The 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.

The previous chapters have indicated that the main key drivers that impact the water the water sector and its vulnerability in West Asia are population growth, financial capabilities, agricultural policies, uncertainty in the issue of shared water resources, and the incremental impacts of climate change. While in the short-term, relatively high financial capabilities can lower freshwater vulnerability in some of the countries, such as the GCC, its success in reducing this vulnerability is questionable in the long-term; despite the strenuous efforts made by these financially capable countries in modifying the water scarcity situation through augmenting their water resources by the expansion in desalination plants – a process associated with high economic and environmental costs - they still face serious water deficits due to the continuously increasing water demands by rates that exceed water development rates.

In fact, water resources management approach and lack of clear comprehensive policies in West Asia countries has lead to the increase of freshwater depletion and quality deterioration, and thus has contributed to their vulnerability in these countries; in the past three decades, the countries efforts were concentrated principally on supply management and augmentation to meet the spiraling water requirements, without giving adequate attention to demand management, efficient allocation, conservation, and protection. This has led to the emergence of many unsustainable water uses, for example: low water use efficiency; growing demands and per capita water use; increasing cost of water production and distribution; and 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, economical, 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, out-dated water legislation and enforcement of existing laws, in addition to low scientific and technological competencies particularly in the field of water management and planning.

Cooperation among the water-related ministries at all stages, including planning and investment is critical. The backbone for appropriate water resources management for each country relies on 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 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, NGOs and local associations.

Fortunately, most of the countries in the region have realized that efficient development and management of water resources require policy reforms, with more emphasis on demand management measures and improvement of the 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 will be critical if the countries want to overcome inefficient use of water resources and make their use sustainable, and thus lower their society's vulnerability to freshwater shortage.

The water situation will become further complicated in the future as large percentages of the water resources in the region are shared between either the countries of the region or with neighboring countries. Unfortunately, shared water resources often lack sharing agreements or lack their implementation when these agreements exist, which could constitute a potential conflict in the future with the increasing water demands in the riparian countries. Furthermore, the expected impacts of climate change are likely to exacerbate this deterioration and thus inducing more pressure on natural water resources and increase freshwater vulnerability; based on the findings of the international studies, the region will experience less and more erratic precipitation, increased drought frequency and an increase in average temperature; 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 tension between riparian countries sharing these rivers.

The issue of shared water resources, both surface water and groundwater, should be given high priority by the countries of West Asia in order to finalize agreements and form treaties regarding water allocation, including quality considerations, according to international water law. The achievement of such agreements is considered an urgent matter, particularly in view of the expected climate change impacts on the region's water resources. This would alleviate tension between competing riparian countries (tension means also increasing costs of conflict) and will help the concerned countries in defining their water policies based on real Figures about the water share and not on estimated ones. This could also assist in achieving integrated basin management, which is the best way to ensure the integrity of the ecosystem and enable better management of the watershed, providing benefits to the water body itself. It also encourages exchange of knowledge and experience which is very costly to gain by 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 it significantly contributes to reducing available fresh water 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 have protection strategies for these limited freshwater resources to enhance their availability and sustainability.

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

With escalating water consumption in the ever-expanding urban areas in WA countries, municipal wastewater has become an increasing 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 the 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 groundwater artificial recharge under Managed Aquifer Recharge 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), both (ASTR) schemes).

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 capabilities. 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; the GCC countries have an annual desalination capacity of about 9500 mcm (AFED, 2010). While desalination is contributing to the alleviation of water scarcity in the region and lower its freshwater vulnerability and its future expansion is inevitable for some countries to meet their domestic water demands (i.e., GCC), desalination technologies are capital and energy intensive and have many negative environmental impacts. Furthermore, these technologies are still largely imported and desalination industry and projects provide limited added value to the countries' economies. There is an urgent need for cooperation among the West Asia countries as well as with the Arab Countries to investment in R&D for these technologies, with the aim of acquiring and localizing these technologies in the region, reducing their cost, increasing the reliability of the water source they produce, increasing their value for their economies, and reducing their environmental impacts.

Finally, in view of the immense freshwater challenges facing the countries of West Asia region and the available opportunities to modify the situation, the issue of water resources management (and not water supply) should be placed high on the national priorities list of these countries. In this regard, political will is needed to take actions for the sustainable management of water resources and a necessary pre-requisite to lower the freshwater vulnerability in the countries of 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. This should be strengthened to help increase recognition of water resource problems and develop support for effective actions among stakeholders.

Chapter 8

Policy solutions: The way towards sustainable water management

Key Chapter Messages

- There is an urgent need to put integrated water resource management (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 addressing this issue. An enabling environment (policies, legislations, organizational structures, institutional capacities, and financing) need to be established for effective water resources management.
- Water policy reforms are urgently required in most of the countries of West Asia, which should address the integrated management aspect, water governance, impact of climate change, food security, and taking into consideration the specific requirements and the prevailing social, economic, and cultural conditions in the region.
- In order to cope with the water scarcity and lower freshwater vulnerability in the region, a major shift to demand management, water use efficiency, and conservation need to be made, and should focus on the agriculture sector where most of the 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 framework.
- 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.

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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 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 understanding of the problem and its solution are still emerging. It is clear from the above analysis that the vulnerability of freshwater resources in West Asia countries is a result of inadequate management levels and will be increased by the impacts of climate change. The following are the main policy options in both.

8.1. Water Resources Management

- There is an urgent need to put integrated water resource management (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 addressing this issue. An enabling environment (policies, legislations, organizational structures, institutional capacities, and financing) needs to be established for effective water resources management.

- Water policy reform should address the integrated management aspect, water governance, impact of climate change, food security taking into consideration the specific requirements and the prevailing social, economic, and cultural conditions.

- Demand management measures should focus on the agriculture sector with emphasis on improving irrigation water use efficiency in this sector which consumes more than 85 per cent of the available fresh water in some countries. Increased efficiency would increase agriculture productivity and reduce water depletion from non-renewable sources and water saved can meet more than the domestic water demand.

- 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 framework. 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 is needed.

- The decision making process should be changed from the currently practiced top-down approach to more of a 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 form treaties regarding water allocation for the shared groundwater resources according to international water laws. The existing agreement between Syria, Iraq and Turkey, Lebanon and Syria and Syria and Jordan on the shared surface water sources need to be implemented fairly and allow a high flexibility to regulate and monitor flows in term of quantity and quality and also undertake periodic review to insure effectiveness.

- Improved financial performance of the water sector calls for the design of a cost recovery approach taking into consideration the poor segment of the society. Subsidies and loans to the water consuming sectors should be used as leverages 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.

- Realizing 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 valuable for the achievement of agreements on shared water resources at present than waiting for the future.

- Update exiting policies to include structural and non-structure adaptation measures to reduce the vulnerability to climate change and put in place effective programs to minimize the expected impacts and risks. Cooperation and exchange of data and information at the national and regional level regarding the vulnerability of the region to climate change and measures for mitigation and adaptation could help in alleviating negative impacts on the countries of the region.

- There is a need to formulate emergency plans for disasters and extreme climate change events such as flood and drought in order to increase the resilience of the communities and water consuming sectors. Water resource planning processes need to account for management under uncertainty of water variability and disaster risk management.

- Undertaking socio-economic impact assessments of climate change on human being and design of appropriate monitoring mechanism suitable or arid environment and develop adaptive measures including assessing their effectiveness.

- Support research, monitoring, and information networking regarding climate change issues at national and regional level and assess impacts at regional level.

References

Abdel Hamid, M. (2009). Climate Change in the Arab World: Threats and Responses. The Henry L. Stimson Center, Washington, USA: 45-60.

Abderrahman, WA., Rasheeduddin, N., Al-Harazim, IM., Esuflebbe, JMEqnaibi, BS. (1995). Impacts of management practices on groundwater conditions in the eastern province, Saudi Arabia. *Hydrogeology Journal*, 3,4: 32-41.

ACSAD (2009). Water Economy in the Arab region.

ACSAD/CAMRE/UNEP (2004). State of Desertification in the Arab World (Updated Study), Dec. 2004, 634p (In Arabic).

ACSAD-UNEP (2001). Surface water resources in the Euphrates and Tigris river basins , 181pp.

AFED (2009). Arab environment: climate change. Arab forum for environment and development. Beirut, Lebanon.

AFED (2010). Water: sustainable management of a scarce resource. Arab forum for environement and development. Beirut, Lebanon.

AFESD and KFAED (2010). An overview of agricultural development and food security in Arab countries. Presented at the Joint Technical Meeting of the Arab Coordination Group Institutions and The OECD Development Assistance Committee, Vienna, Austria, 29-30 April 2010. Arab Fund for Economic and Social Development and Kuwait Fund for Arab Economic Development Available at:
http://www.arabfund.org/Data/site1/pdf/An%20Overview%20of%20Agricultural.pdf.

AGFUND/WB (2005). A Water Sector Assessment Report on the Countries of the Cooperation Council of the Arab States of the Gulf. World Bank Report No. : 32539-MNA.

Al-Mahmoud, M.J. (1987). Hydrogeology of Al-Hassa Oasis. MSc Thesis, King Fahd University of Petroleum and Minerals, Dhahran

Al-Murad, MA. (1994). Evaluation of Kuwait aquifer system and assessment of future well fields abstraction using a numerical 3D flow model. MSc Thesis, Arabian Gulf University, Bahrain.

Al-Zubari, W. K. (2001). Towards the Establishment of a Total Water Cycle Management and Reuse Programme in the GCC Countries. In: Water in the Arabian Peninsula, Problems and Policies, Section IV: Urban Conservation and Recycling, ed., Kamil A Mahdi, pp. 255-273, Ithaca Press.

Al-Zubari, W.K. (2008). Integrated Groundwater Resources Management in the GCC Countries - A Review. Proceedings of the Eighth Gulf Water Conference: Water in the GCC…Towards an Optimal Planning and Economic Perspective, Manama, Bahrain, 2-6 March. Water Science and Technology Association, Bahrain.

Al-Zubari, WK. and Lori, EJ. (2006). Management and Sustainability of Groundwater Resources in Bahrain. *I. J. Water Policy Journal*, 8: 127-145.

Bakiewicz, W., Milne, DM., and Noori, M. (1982). Hydrogeology of the Umm er Radhumma aquifer, Saudi Arabia, with reference to fossil gradients. *Q. J. Eng. Geol*. 15: 105-126.

Bates, B.C., Z.W. Kundzewicz, S. Wu and J.P. Palutikof, Eds. (2008). Climate Change and Water. Technical Paper of the Intergovernmental Panel on Climate Change, IPCC Secretariat, Geneva, 210 pp. Available at: http://www.ipcc.ch/pdf/technical-papers/frontmatter.pdf.

Cap-Net (2010). Groundwater Management in IWRM: Module 10: Groundwater and Climate Change (Training Manual). UNDP Cap-Net. Available at: http://cap-net.org/.

CEDARE and AWC (2005). Status of Water MDGs Achievement in the Arab Region. The Centre for Environment and Development for the Arab Region and Europe and the Arab Water Council. CEDARE, Cairo.

CEDARE and AWC (2006). State of the water Report in the Arab region.102pp.

Dabour, N. (2006). Water Resources and their Use in Agriculture in Arab Countries. *Journal of Economic Cooperation*, 27 (1), 1-38. http://www.sesrtcic.org/files/article/25.pdf.

El-Awar, FA. (2005). Formulation of a Medium-Term Programme for Sustainable Development of Agriculture and Fisheries, Component: Irrigation and Water Resources Management. FAO Project: TCP/KUW/3001.

GDC (Groundwater Development Consultants), (1980). Umm Er Radhumma Study, Bahrain Assignement, Vol. III: Groundwater Resources. Ministry of Agriculture and Water, Kingdom of Saudi Arabia.

Gruen, George E., (2000). Turkish Waters: Source of Regional Conflict or Catalyst for Peace? Water, Air, & Soil Pollution. 123:565-579.

Guner, Serdar, (1997). The Turkish-Syrian War of Attrition. Studies in Conflict & Terrorism 20(1):105-116. Available online at: http://web.macam.ac.il/~arnon/Int-ME/water/ TURKISH-SYRIAN%20WAR2.htm [Accessed 1 May 2009].

Hamad, I, Abdelgawad, G. and Fares, F. (1996). Barada River Water Quality and its Use in Irrigated Agriculture (Case Study). Proceedings of a UNEP-ROWA/AGU Regional Workshop on the Technologies of Wastewater Treatment and Reuse, Manama, Bahrain, 2-4 June.

Hanson, C.E., Palutikof, J.P., Livermore, M.T.J., Barring, L., Bindi, M., Coret-Real, J., Durao, R., Giannakopoulos, C., Good, P., Holt, T., Kundzewicz, Z., Leckebusch, G.C., Moriondo, M., Radziejewski, M., Santos, J., Schlyter, P., Schwarb, M., Stjernquist, I. and Ulbrich, U. (2007). Modeling the impacts of climate extremes: an overview of the MICE project. *Climatic change*, 81, Supp. 1, 163-77.

Hasan, A. (1995). Modeling of groundwater flow system in Wadi Al-Miyah area, Eastern Saudi Arabia. MSc Thesis, KFUPM, Saudi Arabia.

IPCC (2007). *Climate Change 2007: Impacts, Adaptation and Vulnerability - Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. (Eds. Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M. and Miller, H.L.). Cambridge University Press, Cambridge and New York. http://www.ipcc.ch/ipccreports/ar4-wg2.htm.

Khordagui, H. (2007). Climate change in ESCWA region: Reasons for concern. Proceedings of an Expert Group Meeting on Trade & Environment Priorities in the Arab Region. Cairo, Egypt, 11-13 November.

Kitoh, A., Yatagai, A., and Alpert, Pinhas (2008). First super-high-resolution model projection that the ancient “Fertile Crescent” will disappear in this century. Hydrological Research Letters 2: 1-4. Published online in J-STAGE (www.jstage.jst.go.jp/browse/HRL).

LAS-UNEP, EOAR (2010). Environment Outlook of the Arab Region, 465pp.

MAW (Ministry of Agriculture and Water) (1984). *Water Atlas of Saudi Arabia.* Riyadh, Kingdom of Saudi Arabia.

Meslemani, Y. (2008). تأثيراتتغيرالمناخوالتكيففيمنطقةشرقالمتوسط / سوريا. Draft UNFCCC initial national communication for Syria. (in Arabic), Unpublished.

Sayid, S.A.S. and Al-Ruwaih, F. (1995). Relationship among hydraulic characteristics of the Dammam Aquifer and wells in Kuwait. *Hydrogeology Journal*, 3(1), 57-70.

Shindell, D. (2007). Testimony at House Oversight and Government Reform Committee hearing on Political Influence on Government Climate Change Scientists, January 30. Accessed June 9, 2009.

UN-ESCWA and Arab Planning Institute (API) (2002). Economic Diversification in the Arab Region: Proceedings of the Expert Group Meeting, Beirut, 25-27 September 2001, United Nations, 2002.

UN-ESCWA/ BGR and GTZ (2004). Enhancing Negotiation Skills on International Water Issues in the ESCWA Region. Beirut: ESCWA.

UNDP (2005).2005 نحو نهوض المرأة في الوطن العربي ,تقرير التنمية الإنسانية العربية للعام

UNDP (2006). Human Development Report 2006. Beyond scarcity: power, poverty and the global water crisis. Palgrave Macmillan, New York.

UNDP (2009). Arab human development report 2009: Challenges to human security in the Arab countries. United Nations Development Programme, Regional Bureau for Arab States (RBAS), New York.
UNEP/GEO 2 (2000). Global Environment Outlook 2000, UNEP's Millennium Report on the Environment. United Nations Environment Programme, Nairobi, Kenya, 398pp.
UNEP/GEO 3 (2002). Global Environment Outlook 3, GEO-3: Past, Present and Future Perspectives. United Nations Environment Programme, Nairobi, Kenya, 446pp.
UNEP/GEO 4 (2007). Global Environment Outlook 4, GEO-4: Environment for development. United Nations Environment Programme, Nairobi, Kenya, 540pp.
UN-ESCWA (1993). المياه والسلام في الشرق الأوسط. E/ESCWA/ENR/1993/3. United Nations, New York (in Arabic).
UN-ESCWA (1999). Groundwater Quality Control and Conservation in the ESCWA Region. E/ESCWA/ENR/1999/1. United Nations Economic and Social Commission for West Asia, Beirut.
UN-ESCWA (2003). Sectoral water allocation policies in selected UNESCWA member countries; An evaluation of the economic, social and drought related impact. Report No.E/UNESCWA/SDPD/2003/13,68pp.
UN-ESCWA (2005). Regional cooperation between countries in the management of shared water resources: case studies of some countries in the ESCWA region. E/ESCWA/SDPD/2005/15, Incorporated.
UN-ESCWA (2007). ESCWA Water Development Report 2: State of Water Resources in the ESCWA Region. E/ESCWA/SDPD/2007/6. United Nations Economic and Social Commission for Western Asia, New York.
UN-ESCWA (2009). Knowledge Management and Analysis of ESCWA Member Countries Capacities in Managing Shared Water Resources. ESCWA, document E/ESCWA/SDPD/2009/7.
UN-HABITAT (2003). The Challenge of Slums - Global Report on Human Settlements 2003. Millenium Development Goals (MDG), 1-84407-037-9, 310pp.
UNU (2002). INWEH leads project to reduce blue baby syndrome in Syria. *UNU Update*, 14. United Nations University. http://update.unu.edu/archive/issue14_6.htm.
WEC (2001). Satellite data analysis of cropping and irrigation water use in the Sana'a basin. Water and Environment Center, Sana'a University, Sana'a.
WHO/UNICEF (2008). World Health Organization and United Nations Children's Fund Joint Monitoring Programme for Water Supply and Sanitation (JMP) 2008. Progress on Drinking Water and Sanitation: Special Focus on Sanitation. UNICEF, New York and WHO, Geneva.
World Bank (2005). A Water Sector Assessment Report on the Countries of the Cooperation Council of the Arab States of the Gulf. Report No.: 32539-MNA. http://www-wds.worldbank.org/external/default/WDSContentServer/WDSP/IB/2008/05/19/000020953_20080519112639/Rendered/PDF/325390ENGLISH01eport0Clean006125105.pdf
World Bank Fact Sheet (2009). Gaza Strip Water and Sanitation Situation. http://go.worldbank.org/XDNONKWR50
WWC (2004). E-Conference Synthesis: Virtual Water Trade – Conscious Choices, March 2004. WWC Publication No. 2. World Water Council. http://www.worldwatercouncil.org/fileadmin/wwc/Programs/Virtual_Water/virtual_water_final_synthesis.pdf.

Annex

A. Vulnerability Index (VI) estimation

According to the UNEP methodology, vulnerability is a function of four main water availability, use and management parameters. The vulnerability index can be assessed from the application of a number of governing equations to estimate the four parameters of; water resource availability stress (RS), development (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 the renewable water resources availability and consumption pattern of the growing population (RSs) and water variation parameter resulting from long term rainfall variability (RSv). These two parameters are assessed to determinate the water resources availability to meet the pressure of water demands for the growing population taking into consideration the 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 the available water sources.

A.1.1. Water resources stress (RSs)

The water availability of the 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 the past and future water demands of the level of the population size. Thus, the water resources stress parameter can be expressed as the per capita renewable national or regional water resources compared to an internationally agreed water poverty index of 1700 per capita water resources. However for the Western Asia region characterized by scarce water sources, it would have been more appropriate to use a realistic value of 1000 (m^3/person) instead of the standard per capita of 1700. 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 sources to the size of the population for a given year. Thus, the water resources stress RSs can be expressed as follows:

Water renewability stress (RSs)

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

$$RS_s = 0 \qquad \text{(R≥1000)}$$

Where:

RS_s : water 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 the Western Asia region rainfall amount and variability determine how much surface water will be availability and its contribution to the groundwater recharge .Also surface water inflow from neighboring countries is another component must also be considered. Thus the water resources variability is estimated by the coefficient of variation (CV) of a long rainfall record for a period (20-50 years). The guideline methodology (UNEP) designate a set rainfall variation values for the coefficient of variation 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 CV less than 0.3 it reflect low variability. The coefficient of variation CV is estimates by the ratio of the standard deviation of the long rainfall record to the average rainfall as follow:

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

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

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

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

$$RS_v = 1 \qquad \text{(CV≥0.3)} \qquad (4)$$

Where:

RSv_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 depend on the rainfall and recharge distributions. The higher frequency of occurrence and the amounts contribute to an enhanced the 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 supply potential. Thus the degree of the water sector development can place stress on the available water sources. 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 sources capacity in meeting the water demand in the domestic, industrial and irrigation sectors, while the water supply coverage is the percentage of the provision of drinking water and level of services. The water development parameter (Dp) is estimated as follow:

A.2.1. Water Exploitation (DPs)

The 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 the total water demand (domestic, industrial and irrigation)(WRs) for a given year to the available amount of renewable water sources (WR) that consist of ; surface water and groundwater save yield (river flow or run off and recharge). Desalination being a dependable water supply sources is considered as an essential component of the renewable sources for the sub-region (GCC countries). The degree of water exploitation is estimated by the following equation;

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

Where:

DPs : water resources exploitation

WRs : total water supply (water demands)

WR : total renewable water resources

A.2.2. Safe drinking water inaccessibility (DPd)

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

$$DP_d = \frac{P_d}{P} \tag{6}$$

Where:

DP_d: safe drinking water

P_d: population without access to improved drinking water sources

P: total population

A.3. Ecological Health (EH) Parameter

The water ecological health parameter is a measure of the pollution impact from different sources on the ecosystem equilibrium and protection. The arid ecosystem with low resiliency takes long time to regenerate or adjust to a reasonable stage of sustainability. Water pollution in the Western Asia region represents major threats to future water availability as well as poses a major health impact. These impacts can be assessed by two variables; namely, the water pollution (EHp) and the 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 degree of impacts on the environment. The ecosystem also can experienced deterioration in term of desertification from unsustainable land use management practices (lose of arable land to low rainfall, lose of productivity from rain fed areas, over grazing and urban expansion) and the impact of the different hydrological processes specially rainfall and run off with erosion and sedimentation impacts .

A.3.1. Water pollution (EHp)

The pollution to water resources vulnerability is estimated by the ratio of the total untreated wastewater (WW) discharge in water receiving systems to the total available renewable water resources (WR). The amount of the 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 causes of pollution in the region as sewage with certain concentrations can make about 10 times the quantity of clear water totally unusable and lose of already limited water sources.

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

$$EH_p = 1 \quad \text{(WW≥0.1*WR)} \qquad (8)$$

Where:

EHp: water pollution

WW: total wastewater

WR: total renewable water resources

A.3.2. Ecosystem deterioration (EHe)

The population growth and the associated urbanization and other socio-economic development activities are impacting the surface and the groundwater systems by increasing the depletion and pollution stresses. Expansions of land uses through sustained urbanization rates, and the irrigated areas and over grazing have contributed directly or indirectly to the vulnerability of the region water resources. The natural landscape is being modified by the removal of the vegetation cover and thus is contributing to the modification of the hydrological properties of the land surface with impact on the functioning of ecosystems. Land use has impact on water resources conservation and protection leading to higher vulnerability on the region water resources. The ecosystem deterioration is estimates as the ration of land size without vegetation cover (Ad) to the total size of the country (A) assessed as follow:

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

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 mean to evaluate how effective the water sector is being managed. The lacks of implementing good management practices in line with the integrated water resources management approach has been contributing to 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 (trans-boundary).

The efficiency of a water resources management system 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 term of the 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 river or aquifer to reduce trans-boundary disputes. A good dispute management framework can be assessed by its effectiveness in enhancing the institutional arrangements, policy formulation and implantation, effective communication mechanisms, and implementation efficiency. The final score of the conflict management capacity parameter (MCg) is determined by a matrix represented in the UN guideline methodology but the selected values call for a judgment to be provided by a water expert familiar with the water situation in the region especially on the shared water sources. 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 follow;

A.4.1. Water use inefficiency parameter (MCe)

Un sustained water resources management practices in absence of 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:

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

$$MC_e = 0 \qquad (WE \geq WE_{wm}) \qquad (11)$$

Where:

MCe : water use inefficiency

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

WE_{wm} : mean WE of selected countries

A.4.2. Improved Sanitation Inaccessibility (MCs)

Availability of sanitation infrastructures reduces the pollution levels and preserves the water sources. 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 proportion of the population without accessibility to improved sanitation facilities to the total population as follows:

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

Where:

MCs: improved sanitation inaccessibility

Pd: population without access to improved sanitation

P: total population

A.4.3. Conflict Management Capacity (MCg)

Water sources are being used to meet the domestic water demand and socio-economic and ecosystem requirements**.** Competition over water utilization among different consuming sectors at the national and regional levels including neighbor countries that are sharing surface and groundwater resources can lead to social and political tension. The assessment of the management of disputes depends on the evaluation of the levels of; the institutional arrangement, communication and implementation of a viable water sharing agreement. According the assessment guideline, the conflict management capacity can be assessed utilizing the matrix of Table A.1 by selecting different capacities values (institution, agreement, communication and implementation) with a designated scoring criteria ranging from 0.0 to 0.25.

Table A.1: Conflict management capacity parameter matrix

Category of capacity	Description	Scoring criteria 0.0 ◄──►		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

The assessment of a conflict management coefficient must take into consideration the inter relation of all variable 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 the consolidation of the values of the four main parameters estimated by the above mentioned 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 i^{th} category

x_{ij}: value of j^{th} parameter in i^{th} category

w_{ij}: weight given to j^{th} parameter in i^{th} category (the four parameters)

w_i: weight given to i^{th} category

The vulnerability index (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.

Because the process of determining relative weights can be biased which can make the final results difficult to be compared with each other, 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.

Table A.2: Weight given to each parameter in the calculation of the vulnerability index (VI)

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*(0.33*G+0.33*H+0.33*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)								

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 VI

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 (0.4-0.7)	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.