CHAPTER 18

Intensive groundwater use in the Middle East and North Africa

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ABSTRACT: Middle East and North Africa (MENA) is home to 6% of the world's population and have some 1.4% of the world's water resources. The freshwater availability *per capita* in 50% of MENA countries is below 500 m^3/yr. Water shortages in the region are also compounded by water quality degradation. Groundwater is the main source of water in 54% of MENA countries. High water stresses are met with groundwater over-abstraction, which is likely to exacerbate with time. This is clearly manifested by the presented examples of intensive groundwater use. Analysis of the water situation suggests that the fragmented supply oriented approach to water development must give way to integrated water resources management. Challenges and opportunities for integrated water resources management in MENA are also discussed in this chapter.

1 REGIONAL PERSPECTIVE

1.1 *Geographic extent*

The Middle East and North Africa (MENA) is a regional grouping of countries defined primarily by its history and culture, comprising that expanse of territory in which Asia, Africa and Europe converge and which is deeply penetrated by the Mediterranean Sea, the Red Sea, and the Persian Gulf. To the south, the Sahara Desert divides it from tropical Africa; to the north its outer limits lie in the latitude of the Black and Caspian seas. On the east and the west it extends as far as the Indian and Atlantic Oceans, respectively. The MENA region defined in this context comprises 26 countries (Algeria, Bahrain, Comoros, Cyprus, Djibouti, Egypt, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Libya, Mauritania, Morocco, Oman, Palestine, Qatar, Saudi Arabia, Somalia, Sudan, Syria, Tunisia, Turkey, United Arab Emirates, and Yemen), which cover a total surface area of over 16,000,000 km^2 (Fig. 1).

Much of the southern portion of the region consists of a series of ancient unfolded plateau formations, while the north is an area of pronounced crustal disturbance, characterized by fold mountains and basins and fractures but recently formed. The southern plateaus continue without much break into Central and Southern Africa; this is for the most part a region of vast, open plateaus sand-covered deserts. Some disturbance has, however, taken place, producing abrupt lowland rifts or troughs (the largest being the Red Sea and Gulf of Aden). The northern mountainous portion of the region exhibits high jagged peaks and abrupt alternation of formidable mountains, deep valleys, and sheer drops to narrow coastal lowlands. A further characteristic is the repeated rise and fall of the land surface, producing extensive terraces, flats and former shorelines both on the seacoast and along major river valleys.

1.2 *Climate*

Geographical location in close proximity both to extensive seas and to continental areas has very considerable effects upon the climate. Furthermore, topographical variation together with disposition in relation to coastlines and prevailing winds may produce climatic differences on a considerable scale.

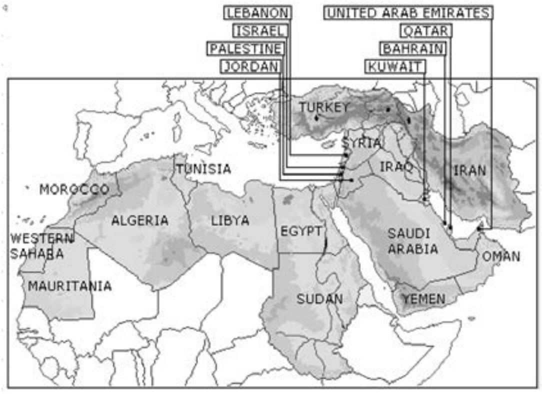

Figure 1. Map of the MENA region.

In consequences, the region experiences some of the highest summer temperatures of any part of the globe (over 40°C). In winter, although coastal areas remain generally mild, the interiors become very cold, especially in parts of Eastern Turkey, Northern Iraq, and Iran (–30°C). The region is to a large extent a transitional area between the equatorial and mid-latitude climate. A characteristic feature of all subtropical latitudes, of which the MENA region occupies substantial parts, is the prevalence of aridity (Shahin 1996). In arid and semi-arid lands, water deficiency is by far the most important controlling factor for plant production.

1.3 *Population*

The countries of the MENA region are home to about 400 million people, about 6% of the world's population. The three smallest countries (Bahrain, Djibouti, and Qatar) each have a population of about half a million inhabitants. The two largest countries (Egypt and Iran) comprise about 60 million inhabitants each. Together with Algeria, Morocco, and Sudan, these five most populated countries account for about 70% of the region's population. Most MENA countries are experiencing rapid population growth and have high dependency ratios. Demographic indicators for selected countries in the region are given in Table 1.

Because of the extreme aridity of much of the region, the population is distributed very unevenly among countries and within them. It is the relative availability of water that determines population distribution and density.

Table 1. Demographic indicators for selected MENA countries (World Resources Institute 2000).

Country	Population (10^3)			Average annual change (%)	
	1950	2000	2025	1975–1980	1995–2000
Algeria	8,753	31,471	46,611	3.1	2.3
Egypt	21,834	68,470	95,615	2.4	1.9
Iran	16,913	67,702	94,436	3.3	1.7
Iraq	5,158	23,115	41,014	3.3	2.8
Israel	1,258	6,217	8,277	2.3	2.2
Jordan	1,237	6,669	12,063	2.3	3.0
Kuwait	152	1,972	2,974	6.2	3.1
Lebanon	1,443	3,282	4,400	–0.7	1.7
Libya	1,029	5,605	8,647	4.4	2.4
Morocco	8,953	28,351	38,670	2.3	1.8
Oman	456	2,542	5,352	5.0	3.3
Saudi Arabia	3,201	21,607	39,965	5.6	3.4
Syria	3,495	16,125	26,292	3.1	2.5
Tunisia	3,530	9,586	12,843	2.6	1.4
Turkey	20,809	66,591	87,869	2.1	1.7
UAE	70	2,441	3,284	14.0	2.0
Yemen	4,316	18,112	38,985	3.2	3.7

1.4 *Economic overview*

MENA's size and population alone make the region economically significant, and its vast human, financial, and natural resources endowments enhance this significance. However, countries vary substantially in resources, economic and geographical size, population, and standard of living. Despite the harsh climate, limited water resources, and scarce arable land, the region enjoys abundant natural resources. About two thirds of the world's known crud-oil reserves lie under the MENA region, with one quarter located in Saudi Arabia. Iran has 15% of the world's reserves of natural gas. Morocco alone has more than 30% of the world's phosphate rock. The region also possesses numerous non-fuel mineral and non-mineral resources.

According to the World Bank, the gross domestic product (GDP) of the region is equivalent to 12% of that of the developing countries. Although the average *per capita* GDP in the region is twice that of developing countries, individual countries in the region differ greatly (El-Erian *et al*. 1996). During the 1990s, regulatory reform measures helped improve economic performance in most economies of the region (Table 2). Despite these improvements, important challenges remain.

Of paramount importance to the region's sustainable development is preservation of its natural resource base. Agriculture and rural economy is still a significant activity in the region in terms of the number of people it employs, and in some countries it still provides a substantial part of the GDP. Water and agriculture projects are underway in the region with growing emphasis on water management.

Table 2. General economic indicators for selected MENA countries.

Country	GDP At market prices (US$ billions)		Agriculture value added (% of GDP)	GDP growth (%)
	1996	2000	1999	1999
Algeria	46.85	53.82	11.4	3.2
Egypt	67.65	98.33	17.4	6.0
Iran	104.74	98.99	20.9	2.5
Israel	97.26	110.33	—	2.2
Jordan	7.03	8.34	2.4	3.1
Kuwait	31.07	—	—	—
Lebanon	12.99	16.58	11.8	0.8
Morocco	36.64	33.36	14.8	–0.7
Saudi Arabia	141.34	—	—	0.4
Syria	15.88	16.49	—	–1.5
Tunisia	19.59	19.46	12.8	6.2
Turkey	181.47	199.90	15.8	–5.1
UAE	47.88	—	—	—
Yemen	5.48	8.67	20.4	3.8

Source: World Development Indicators database, World Bank.

2 THE WATER SITUATION IN MENA

2.1 *Water availability*

Annual renewable water resources in MENA average about 590,000 Mm^3. This is equivalent to some 1.4% of the world's annual renewable water resources. Of this, about 220,000 Mm^3 (about 37%) are provided by river flows from outside the region. Besides renewable surface water and groundwater, there are substantial non-renewable groundwater resources, and countries in the region have varying access to brackish water and unlimited seawater. Table 3 compares renewable water resources in MENA countries. In 2000, over 60% of MENA countries had a *per capita* supply of less than 1,000 m^3/yr. For MENA, *per capita* supply in 2025 is projected at 682 m^3/yr, equivalent to only 12% of that for the world. The most striking aspect of these figures is the rapidity with which scarcity has arisen. Over a life span of 75 years, supply *per capita* will have fallen by almost 85%, from 4,462 m^3 in 1950 to 682 m^3 in 2025 because of population growth. Many countries in the region (Algeria, Gulf States, Jordan, Israel, Yemen) mine their groundwater resources. Obviously, use of non-renewable resources cannot continue indefinitely.

Table 3. Water availability in MENA region.

Country	Annual renewable water resources (km^3)	Availability (m^3/yr *per capita*)		
		1950	2000	2025
Algeria	13.90	1,588	442	298
Bahrain	0.10	—	163	127
Comoros	1.00	—	1,837	1,102
Cyprus	0.80	—	1,044	889
Djibouti	0.30	—	454	308
Egypt	68.50	3,137	1,000	716
Iran	72.40	4,281	1,069	767
Iraq	111.10	—	4,806	2,709
Israel	2.80	2,226	450	338
Jordan	0.70	566	105	58
Kuwait	0.16	1,052	81	54
Lebanon	3.10	2,148	945	705
Libya	0.80	777	143	93
Mauritania	11.40	—	4,270	2,391
Morocco	29.80	3,328	1,051	771
Oman	1.00	2,193	393	187
Qatar	0.09	—	147	79
Saudi Arabia	2.40	749	111	60
Somalia	15.70	6,935	1,555	740
Sudan	87.30	9,499	2,960	1,887
Syria	12.70	3,634	788	483
Tunisia	3.90	1,105	407	304
Turkey	143.20	6,882	2,150	1,816
UAE	0.20	2,857	82	61
Yemen	4.10	950	226	105
MENA	587.45	4,462	1,067	682
World	42,655.00	16,917	7,045	5,452

Source: World Resources Institute (2000), World Development Indicators database, World Bank, and ESCWA (1999).

Mining of accessible groundwater resources is also often risky since interactions with river flows may affect surface supplies, and declining watertables can result in saline intrusion from brackish water or the sea. Mining of the non-renewable supplies of the large, so-called fossil aquifers, is potentially longer term given the enormous volumes of water in storage (the Nubian aquifer alone is estimated to contain more than 150,000 km^3 or 250 times the average annual renewable supply for the region). Constraints on exploitation of such aquifers will ultimately be economic rather than physical.

Non-conventional sources will become increasingly important. The region already accounts for over 50% of total world desalination capacity. Given its high capital and running costs (US$ 1–1.50 per m^3) desalination is almost wholly confined to supplying industrial and domestic users in rich oil countries, with larger plants invariably associated with available cheap energy. Similar high cost considerations apply to water imports. Meanwhile, this is likely to be constrained by political issues associated with water transfers across national boundaries. Within the region, reuse of treated wastewater will play an increasing role.

Inter-annual variations are more significant in arid than in humid areas of the world. Therefore, a major factor affecting water availability problem in MENA is its high seasonal and inter-annual variability. Annual precipitation varies from negligible amounts in desert areas to more than 1,500 mm in some mountainous regions with most rain falling in the winter months. Areas of moderate rainfall (500–750 mm) include Lebanon and Northern Israel, most of Northern and Western Iran, and the northwestern countries of Africa as far inland as the southern slopes of the Atlas Mountains. Streamflow varies markedly during the year in response to rainfall/run off patterns. Discharges in the low flow summer season typically average from one-fifth to one-tenth of the high flow winter season. Water availability therefore fluctuates markedly during the year. Variability has three important implications for water management. First, it introduces an element of uncertainty, which makes estimation of water's value in the next best economic use quite difficult. Second, expensive storage capacity is required to utilize seasonal and inter-annual flows. Third, systematic contingency planning is required to minimize adverse effects of extreme hydrologic events. Systematic responses are also required to distribute risk among water use sectors in a planned and equitable manner.

2.2 *Water withdrawal*

Annual withdrawals by sector in MENA countries are summarized in Table 4. These estimates are based on the figures published in World Resources Institute (2000) and ESCWA (1999). Other sources give substantially different estimates and the figures quoted must therefore be regarded as approximate. Although in developed countries the *per capita* domestic water use can exceed 150 m^3/yr, a reasonable supply to maintain human health may be 40–80 m^3/yr *per capita*. By 2025, if renewable resources are to be fully mobilized, five MENA countries will barely cover basic human needs. Elsewhere, renewable supply would still exceed basic human requirements by varying amounts. However, not all

Table 4. Water withdrawal in MENA region.

Country	Annual withdrawal			
	Total (km^3)	Sectoral withdrawal (%)		
		Domestic	Industry	Agriculture
Algeria	4.50	25	15	60
Bahrain	0.29	30	3	67
Comoros	1.00	—	—	—
Cyprus	0.80	—	—	—
Djibouti	0.12	16	2	82
Egypt	63.10	6	8	86
Iran	70.03	6	2	92
Iraq	42.80	3	5	92
Israel	1.71	29	7	64
Jordan	0.98	22	3	75
Kuwait	0.54	37	3	60
Lebanon	1.29	28	4	68
Libya	3.89	9	4	87
Mauritania	1.63	6	2	92
Morocco	11.05	5	3	92
Oman	1.22	5	2	93
Qatar	0.28	19	4	77
Saudi Arabia	17.00	9	1	90
Somalia	0.81	3	0	97
Sudan	17.80	5	1	94
Syria	14.41	2	4	94
Tunisia	2.68	14	3	83
Turkey	35.50	16	11	73
UAE	2.11	24	9	67
Yemen	2.93	7	1	92
MENA	298.47	14	4	82
World	3,760.00	9	24	67

Source: World Resources Institute (2000), World Development Indicators database, World Bank, and ESCWA (1999).

renewable supplies in the region can be mobilized at acceptable cost given their location and variability. The volume of economically available water is thus could be much lower than the quoted estimates. Irrigation is by far the largest user, accounting for perhaps 85% of the total use region wide. Though water is predominantly used for irrigation, demand for water is expanding most rapidly in urban areas. The region is already highly urbanized and the share of domestic and industrial demand is significantly higher than in other parts of the developing world.

Most countries in the region are classified as middle income and the percentage of the urban population that has access to safe drinking water is almost approaching 100%. Urban sanitation coverage is also relatively high. In contrast; rural areas are much less well served, with only about 66% of the population having safe access. Despite efforts to slow population growth rates in the region, expected future growth rates are still high by world standards. The proportion living in urban areas is projected to increase from 60% to about 75%. The share of renewable water supplies absorbed in urban areas will thus need to rise from less than 10% to more than 20% simply to maintain present overall use rates. Increased efficiency in irrigation and reallocation from irrigation to other uses could in most countries provide sufficient renewable water to meet demands elsewhere. But reallocation from irrigation raises very difficult questions and, despite the costs involved, most countries continue investing in expensive new supplies while maintaining allocations to relatively low-return agriculture.

Withdrawals in several countries already exceed renewable supplies: the Gulf States, Libya, and Yemen. Others appear to be essentially at the limit or soon will be: Egypt, Israel, and Jordan. Other countries face severe regional deficits even if overall they are in surplus. Mobilizing local surpluses for use elsewhere is usually very expensive because of the transfer costs, and full mobilization is almost always impracticable due to social and physical constraints.

2.3 *Water scarcity*

Scarcity of water is a major constraint in arid and semi-arid countries of the region. In many countries, all available water resources, which can be used for economic purposes, have already been developed or are in the process of development. The overall prospective analysis focusing on estimated water withdrawals as compared to available resources (commonly termed the water stress index) indicates that over 70% of MENA countries are classified under high water stress. The more critical issue is that the current *per capita* availability has fallen below the line of absolute water scarcity of 500 m^3/yr in 50% of MENA countries. Furthermore, by the year 2025, over 80% of the countries would have crossed the water poverty threshold. It is evident that water scarcity will remain the dominant state in the MENA region.

2.4 *Water quality*

Due to the scarcity of water in the region, a direct and critical link exists between water quantity and water quality. Comprehensive data on water quality in MENA are not available, but recent World Bank studies suggest that deteriorating water quality is becoming a serious issue in many countries. Although reliable comparative information is not available, numerous examples of emerging water quality problems are quoted. Contamination by fertilizers and pesticides, dumping of municipal and industrial wastewater into rivers and lakes, solid waste deposits along riverbanks, and uncontrolled seepage from unsanitary landfills are degrading freshwater resources and impose health risks. The principal sources of pollution include the following:

- Untreated municipal wastewater, leaching from poorly maintained and functioning cesspools, and washing of fecal matter and other waste from the surface of the ground into water bodies.
- Untreated industrial waste, discharging into municipal sewer systems or directly into water bodies.
- Seepage from unsanitary landfills where the majority of the region's solid waste is dumped.
- Seepage and runoff of agrochemical such as fertilizers and non-biodegradable pesticides.

Declining water quality caused by contamination from these sources is affecting public health, the productivity of resources, and the quality of life. Once contaminated, groundwater seldom regenerates and, although rivers are to some extent self-cleansing, declining quality increases treatment costs to downstream users and may preclude reuse for particular purposes. Seawater intrusion into coastal aquifers is a critical issue in several countries and waterlogging and associated secondary salinity are widespread problems in many major irrigated areas. Accordingly, water shortages in the MENA region are compounded by water quality degradation and pollution.

3 GROUNDWATER RESOURCES IN MENA

3.1 *Occurrence and magnitude*

Groundwater in the MENA region is found in numerous aquifer systems with storage and yield characteristics that depend on each aquifer's areal extent and its hydrologic and hydrogeologic properties. The major aquifer systems are either of sandy and/or calcareous facies. Also, unconsolidated and alluvium deposits as well as volcanic deposits prevail in the region. From the hydrologic point of view, the water bearing formations are either naturally recharged or of fossil or non-renewable nature. Most of the naturally recharged aquifers are moderately replenished due mainly to the limited precipitation rates prevailing in the region.

The geological history of the region dates back to the Pre-Cambrian (more than 500 million years BP). The basement rock is exposed in large surfaces in the region, principally in Mauritania, South and West of Algeria, the southern part of Libya, Southwest and East of Sudan, and East of Egypt, forming the so-called African Shield. It is also exposed along the coast of the Red Sea forming the Arabian Shield. Thick layers of sand and sandstone suitable for groundwater storage were deposited on the basement rock during the Paleozoic some 300 million years ago. During the Mesozoic period additional layers of sand and Nubian sandstone covered a large surface extending from North Sudan to the Western Desert in Egypt and Libya. In the latter part of that period, estimated at 120 million years BP, thick layers of low permeable limestone were deposited in the Arabian Peninsula. In the Tertiary (Eocene up to the beginning of the Pleistocene) and Quaternary (Pleistocene and Recent), alternating series of calcareous rocks and sand were deposited in many areas forming Al-Hamada in Algeria and Morocco, and together with limestone in Egypt, Syria, Iraq, and the southern part of the Arabian Peninsula. The Atlas region belongs in fact to the Mediterranean region and is characterized by formations where clays and other rocks, such as calcareous rocks and dolomites belonging to the lower Jurassic, are dominant. These formations can be found in the Upper Atlas in Tunisia, and the high plateaus in Morocco and Algeria.

Because of the similarity in the geologic history of the region, the same rock unit would often form a producing aquifer in two or more countries of the region. That is why many of the major aquifers in the region are shared between two or more countries (e.g. the Paleogene aquifer in the Arabian Peninsula or the basalt aquifer between Syria and Jordan, the Nubian Sandstone between Egypt and other North African countries, and the Grand Erjs shared by Algeria, Morocco, and Tunisia). Some hydrogeological units in the region are also vertically interconnected.

3.2 *Shared aquifer systems*

Our objective in this section is not to provide a detailed description of the hydrogeology of the shared aquifers systems in the region but rather to point out their occurrence and potentials for sharing. Ten major shared aquifer systems are identified in the region. In the following paragraphs, a brief description of each aquifer is given (Al-Eryani 2001).

3.2.1 *Eastern Mediterranean carbonate aquifer system*

This aquifer system is part of the Eastern Mediterranean basin which covers an area of about 48,000 km^2 extending through four MENA countries: Jordan, Lebanon, Syria, and Israel. The Lebanese rivers (Orontes, Litani, and others) and the Jordan River form the major drainage network of this basin. This regional aquifer system is best observed in the Alouite mountains (Syria), the Palmyrian mountains (Syria), the Anti-Lebanon range (Syria and Lebanon), Mount Hermon (Syria and Lebanon), the Lebanon mountains, and the eastern and western highlands (Jordan). Hydrogeologically, the aquifer is a regional complex of carbonate rocks consisting of two major units: a lower Jurassic unit and an upper Cenomanian-Turonian unit, both composed mainly of limestones and dolomites.

3.2.2 *Jebel el-Arab basaltic aquifer system*

This aquifer system is part of the Horan and Arab Mountain basin which cover an area of 15,000 km^2 extending through three MENA countries: Jordan, Saudi Arabia, and Syria. The Golan plateau constitutes the main occurrence of water resources for this basin, which is considered a main source of the Yarmouk and Azraq basins through the springs of Mazreeb, El-Hamma and El-Azraq. Hydrogeologicaly, the main aquifer is made of a complex layering of basalt flows of different ages. The thickness of the basalt layers changes markedly from the vast volcanic plateau of Southwest Syria to Eastern Jordan and Northern Saudi Arabia. The total thickness ranges from 20 m in the Hamad basin up to 300 m near Jebel el-Arab. Also, the saturated thickness and degree of saturation vary from one place to another.

3.2.3 *Jezira Tertiary limestone aquifer system*

This limestone and dolomite aquifer is of Middle Eocene to Oligocene age. It forms one hydrogeological unit in the Jezira area of Syria and is up to 300 m thick in Turkey. The thickness of the Paleogenic limestones increases in an eastwardly direction to about 560 m in the Jezira (Syria), and to 1,034 m in Qaratchik. In spite of its great thickness in the eastern area, the aquifer is hydrogeologically more important in the northwestern part of a Jezira. The water-bearing limestone formation outcrops in Turkey to the north of the border zone, extending from the Belikh area to the Khabour River in Syria. The aquifer extends along the Syrian border with Turkey, from Ain Al-Arab east of the Euphrates to Ras Al-Ain and beyond. The Khabour River channel between Ras Al-Ain and Hassakeh forms the southern border of the aquifer system, which also extends southward as far as Jebel Abdel Aziz area in Syria. The annual recharge to the aquifer system is estimated at 1,600 Mm^3, and discharge occurs via two large springs in Syria: Ras Al-Ain (40 m^3/s) and Ain Al-Arus (6 m^3/s).

3.2.4 *Jezira Lower Fars-Upper Fars aquifer system*

The Lower and Upper Fars formation consists of gypsum beds interbedded with limestones, clays and marls. It extends over the vast Mesopotamian plain of the Lower Jezira of Syria, and in Iraq from the Belikh River in the west to the Tigris River and Tharthar depression. The southern boundary coincides, more or less, with the middle reach of the Euphrates from Raqqa in Syria to Al-Ramadi in Iraq.

3.2.5 *Western Arabia sandstone aquifer system*

Four principal sandstone aquifers are recognized in the Arabian Peninsula; the Saq, Tabuk, Wajid and Minjur. They range in age from Cambrian to Triassic. Hydrodynamically, they can be subdivided into three major subsystems: 1) The Rum-Saq-Tabuk sandstone aquifer subsystem, extending from Northern Saudi Arabia to Jordan; 2) The Minjur sandstone aquifer subsystem, occupying the middle of the Riyadh area in Saudi Arabia; and 3) The Wajid sandstone aquifer subsystem, which mainly occurs in Southern Saudi Arabia and Northern Yemen.

Water of good quality for domestic, industrial, irrigation and livestock uses is available from various members of the Palaeo-Triassic aquifer system. The salinity of groundwater from the Saq aquifer does not generally exceed 1,000 ppm, although water in the deeper horizons usually has higher salinity and is of a sodium-chloride type. Freshwater from the Wajid aquifer is of a bicarbonate type salinity is commonly less than 1,000 ppm water from the Tabuk aquifer is generally fair to good quality with salinity ranging from 400 to 3,500 ppm. Water from the Minjur aquifer is of a calcium-sodium / sulfate-chloride type. Its sodium and chloride ion concentrations increase with depth. The Rum group, which is underlain by the Araba Complex and Basement rocks, mainly comprises the Disi and Umm Sahm formation of the lower Paleozoic. Its outcrops extend from Central Saudi Arabia westwards and northwards through Tabuk, Disi, and Petra, with the most northwesterly occurrence at the eastern shores of the Dead Sea. In subcropping areas, this formation is known to extend northwards and eastwards underlying the whole of the Rum group aquifer. Structures such as faults, intrusions, and dykes are present in the area. This aquifer has a generally uniform consistent lithology over large areas and attains thickness of over 2,000 m. The depositional environment is fluvial. The overlying Hiswah Shale, which is a confining layer, represents a post transgression, fully marine depositional environment. Groundwater flow in this aquifer commences from beyond Tabuk (Saudi Arabia) moving broadly northwards, crossing into Jordanian territory, and converges towards the Dead Sea. Groundwater extractions since the 1980s have changed the pattern of groundwater flow, with a significant change in the Tabuk area. High rates of extraction for irrigation purposes have produced a very extensive cone of depression, locally diverting the natural northeasterly groundwater flow direction.

3.2.6 *Central Arabia sandstone aquifer system*

The Cretaceous aquifer system comprises the Biyadh and Wasia sandstone in Saudi Arabia. Their combined thickness is about 1,000 m. Groundwater occurs under unconfined conditions, especially in the outcrop of the aquifer, which extends over a vast area (from Wadi Al-Dawasir in Saudi Arabia to Rutba in Iraq). The salt content of the lower member, the aquifer outcrop/recharge area, is about 150 ppm. In the Kharj area, the salinity ranges from 550 to 900 ppm. The water quality of the Wasia sandstone aquifer varies widely from one place to another. The salinity ranges in the outcrop area from 1,000 to 3,000 ppm, while the water in the Biyadh aquifer stagnates and its salinity rises substantially from 4,000 to 150,000 ppm. The Wasia aquifer then flow on with a salinity of 4,000–5,000 ppm. Groundwater resources in the Biyadh and Wasia aquifers are estimated to have a potential annual recharge of 252 and 420 Mm^3, respectively. The water in storage could be as much as 290,000 Mm^3. The hydraulic characteristics of the Cretaceous aquifer system vary widely in the extensive confined and unconfined parts of the hydrogeological systems. For many areas in lraq, Jordan, Kuwait and Northern and Southern Saudi Arabia, information on this aquifer system is scarce or incomplete. In some areas, the aquifer is either saline or unproductive, and its development is consequently not feasible.

3.2.7 *Eastern Arabia Tertiary carbonate aquifer system*

The East Arab Peninsula basin covers an area of about 1,600,000 km^2 extending through the Gulf States, Iraq, Jordan, Syria, and Yemen. Rainfall is the main water resource at the north of the basin and feeds the eastern section of the basin. The aquifers consist primarily of limestone and dolomites. The whole sedimentary complex is hydraulically interconnected and is a recharging-discharging aquifer system. The subdivisions (or main aquifers) are as follows:

- The Umm er Radhuma aquifer, which is composed of limestone and dolomites ranging in thickness between 240 and 700 m (it occurs in 8 MENA countries: Bahrain, Iraq, Kuwait, Oman, Yemen, Qatar, Saudi Arabia, and the UAE).
- The Dammam aquifer, which is composed of limestone and dolomite with shale ranging in thickness between 20 and 500 m (it occurs in Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and the UAE).
- The Neogene aquifer, which is composed of sandstone, sandy marl and chalky limestone of variable thicknesses (it occurs in Bahrain, Kuwait, Oman, Qatar, and the UAE).

Groundwater recharge into the Tertiary carbonate aquifers was estimated at 1,150 Mm^3, while the estimated discharge from the system is 1,200 Mm^3. Other estimates for the annual recharge of the Umm er Radhuma, Dammam, and Neogene aquifers are 406, 200 and 238 Mm^3, respectively. Freshwater is relatively rare in the aquifer complex, occurring in the upper and lower zones of the hydrodynamic system.

3.2.8 *Nubian sandstone aquifer system*

The Nubian sandstone basin covers an area of 2,350,000 km^2 extending through Egypt (850,000 km^2), Sudan (750,000 km^2), Libya (650,000 km^2), and Chad (100,000 km^2). It has a huge groundwater reservoir though limited in the segment from Chad to Sudan, and perhaps the Ethiopian plateau. Springs, oases, and depressions represent the major drainage areas of this basin. This system is made up of a sequence of continental sandstones and sands intercalated with argillaceous beds of the Carboniferous to Middle Cretaceous ages. Its thickness reaches up to several thousand meters. In the eastern desert of Egypt, the Nubian sandstone complex is water bearing formation where groundwater occurs under confined artesian condition (flowing wells). Water can be obtained there from shallow, carbonate and deep sandstone formations. The deeper formations are more extensive and contain larger quantities of groundwater. The thickness of the aquifer complex in the central eastern desert is about 400 m. In the Sinai Peninsula, the Nubian sandstone complex is the principal aquifer. On the average, the depth to the aquifer is 700 to 900 m in Central Sinai, increasing northwestward to about 2,500 m along the Mediterranean coast. Artesian pressure in Central Sinai is about 200 m.a.s.l. Groundwater encountered in this aquifer system is generally of excellent quality (100–800 ppm). The storage volume in the aquifer system in Egypt (western and eastern deserts and Sinai) is estimated at 5,000 km^3. Local groundwater is extracted in the eastern desert, but the annual extraction quantities do not exceed 600 Mm^3. Groundwater extraction for agricultural use in the Sinai occurs predominantly along the northern coastal (Al-Arish) area. Average annual withdrawal is about 30 Mm^3.

3.2.9 *Grand Occidental Erj*

The Grand Occidental Erj, often referred to as the Continental Intercalaire, is located south of the Atlas in Algeria with estimated surface area of 330,000 km^2, of which 180,000 km^2 forms an artesian basin. The average thickness is between 250 and 600 m. The annual natural recharge is estimated at 0.3 Mm^3.

3.2.10 *Grand Oriental Erj*

The Grand Oriental Erj, sometimes referred to as the Complex Terminal, is located to the east of the Occidental Erj and its eastern edge runs along the Algerian-Tunisian frontier. The total surface area is estimated at about 375,000 km^2, 90% of which forms an artesian basin. The depth of the aquifer varies from 100 to 400 m. The annual recharge is estimated at 600 Mm^3.

3.3 *Dependency of the region on groundwater resources*

With little or no surface water resources, the majority of MENA countries depend significantly on groundwater to meet the growing water demands. Table 5 shows estimates of average annual groundwater recharge and groundwater withdrawal. The region's dependency on groundwater is expressed in terms of the ratio of groundwater withdrawal in relation to the annual groundwater recharge as well as the ratio of the contribution of groundwater withdrawals to the total demand in year 2000. The present levels of groundwater abstraction have exceeded the annual groundwater recharge in 50% of MENA countries. As manifested by the data compiled in Table 5, withdrawal in relation to recharge ranged from twofold to sevenfold.

Table 5. Groundwater availability in MENA region.

Country	Annual groundwater recharge (km^3)	Annual groundwater withdrawal		
		Total (km^3)	% Recharge	% Demand 2000
Algeria	1.70	2.90	171	64.44
Bahrain	0.10	0.26	260	91.49
Comoros	—	—	—	—
Cyprus	—	—	—	—
Djibouti	—	—	—	—
Egypt	5.10	4.60	90	7.11
Iran	42.00	29.00	69	41.40
Iraq	13.00	0.20	2	0.78
Israel	0.50	1.20	240	70.18
Jordan	0.30	0.50	167	51.02
Kuwait	0.16	0.30	188	68.64
Lebanon	0.60	0.24	40	17.00
Libya	0.70	3.70	583	95.12
Mauritania	0.30	0.90	300	55.21
Morocco	9.00	2.70	30	24.43
Oman	1.00	1.64	164	89.01
Qatar	0.09	0.19	211	67.86
Saudi Arabia	3.85	14.40	374	84.71
Somalia	3.30	0.30	9	37.04
Sudan	7.00	0.30	4	1.69
Syria	6.60	3.50	53	24.30
Tunisia	4.20	1.60	38	59.71
Turkey	20.00	7.60	38	21.41
UAE	0.13	0.90	692	75.83
Yemen	1.50	1.40	93	61.60

Source: World Resources Institute (2000), UNESCO (1998), and ESCWA (1999).

Thus, the high water stresses are met with varying degrees of groundwater depletion and considerable groundwater mining is taking place in the region. Such process is likely to exacerbate with time. The contribution of groundwater to the total demand in the region amounts to about 41%, and groundwater abstractions are currently the main source of water in 54% of

MENA countries. In quantitative terms, Figure 2 shows that groundwater contribution to total water use in the region in year 2000.

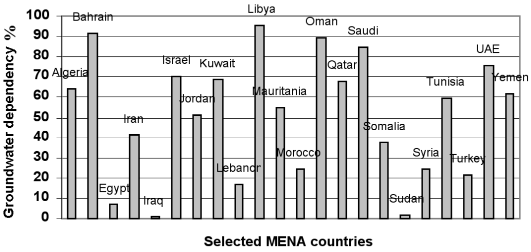

Figure 2. Groundwater dependency ratio.

3.4 *Groundwater quality in the region*

The quality of groundwater in MENA region, expressed in terms of salinity, can be classified into three general categories: freshwater with salinity less than 1,000 ppm, brackish water with salinity between 1,000 and 3,000 ppm, and saline with salinity exceeding 3,000 ppm (Shahin 1996, UNESCO 1998, World Bank 2000). In Mauritania, brackish to saline groundwater generally prevail. In Morocco and Algeria, fresh groundwater can be found in the north, but the salinity increases to the south. Fresh groundwater can hardly be found in Tunisia. In Libya, fresh groundwater is available in the Nubian sandstone aquifer systems. Egypt also obtains fresh groundwater from the Nubian sandstone, as well as the aquifer underlying the Nile Delta and Valley. The fresh groundwater of the Nubian is also obtainable in Sudan. Precipitation in the mountainous areas in Northwest Jordan, North Iraq and Lebanon maintains a fresh quality for the groundwater there. In Iraq, the groundwater quality deteriorates in a southerly direction due to the presence of evaporites. In Syria, the groundwater is generally brackish. In Israel and Palestine, fresh groundwater exists in the coastal plain aquifer extending from Haifa to Gaza, which disappears at the foothills of the West Bank Mountains. The Sinai Peninsula and the Eastern Desert in Egypt hardly contains any fresh groundwater. In Saudi Arabia, fresh groundwater exists in the Riyadh-Wasia-Aruma aquifer. However, it deteriorates eastwards and becomes highly saline near the border of Kuwait. Groundwater salinity in the Umm-er Radhuma aquifer in the eastern part of Saudi Arabia increases from east to west. Groundwater salinity of the Dammam aquifer is generally brackish, and deteriorates rapidly towards the south and the east where it becomes saline. The Dammam aquifer in Kuwait contains groundwater ranging from brackish in the southwest to highly saline in the northeast. In the northern part of Qatar fresh groundwater occurs as floating lenses within the Dammam-Rus formation. In the South of Qatar and all over Bahrain, brackish water covers the entire area. In UAE, groundwater salinity ranges from brackish to saline. In Yemen, fresh groundwater occurs in the high land of Tihama plain and deteriorates in a westerly direction towards the Red Sea.

4 EXAMPLES OF INTENSIVE USE OF GROUNDWATER IN THE REGION

4.1 *Over-abstraction: the case of the Dammam aquifer in Bahrain*

The prevailing climatic conditions and catchments configuration preclude any surface water in Bahrain. The only natural source of water is groundwater from aquifers developed principally in the carbonate rocks of the Dammam formations, which is a small part of the extensive regional aquifer system known as the Eastern Arabian aquifer that extends continuously from outcrops in Central Saudi Arabia towards Bahrain and the Gulf. The Dammam formation in Bahrain consists of two limestone members known as Alat and Khobar aquifers, which are termed as A and B zones, respectively. Zone A has a rather poor groundwater quality and a relatively low transmissivity compared to zone B, which is developed in a highly fractured limestone and dolomite. Therefore, zone B is considered as the principal productive aquifer (Khater *et al.* 1991).

Prior to 1925, Bahrain's population depended on the naturally flowing fresh groundwater from land and offshore springs. The first well in Bahrain was drilled in 1925, and until 1975 all water demand was supplied only from groundwater abstraction. Fast growing population and accelerated development activities resulted in a significant increase in water demand. Accordingly, desalination and reuse of treated sewage effluent have been introduced. Meanwhile, steady increase of the annual groundwater abstractions have taken place, from about 63 Mm^3 in 1952, to 112 Mm^3 in 1967, to about 183 Mm^3 in 1979, and further to 218 Mm^3 in 1999, as illustrated in Figure 3. The Dammam aquifer can potentially provide a sustained annual yield of up to 112 Mm^3. Such natural replenishment rate has been violated since the mid 1960s. Accordingly, the aquifer over-abstraction has led to a sharp decline in the natural flow of springs (Fig. 3). This is because of the significant drop in the aquifer piezometric levels as shown in Figure 4. Such drop in groundwater levels caused marked deterioration of groundwater quality by induced seawater intrusion and upward leakage of saline water from lower aquifer horizons. Changes in groundwater salinity between 1979 and 1992 are shown in Figure 5 (Zubari *et al*. 1997).

At present, groundwater abstraction from the Dammam aquifer provides over 75% of the total water demand in Bahrain.The major limiting factor in the future availability of freshwater supplies in Bahrain is the increasing contamination by saline water, due to excessive withdrawal from the aquifer system. Thus, Bahrain is facing a serious water crisis. Unless the current levels of abstraction are brought back to the level of natural replenishment, the main source of water might be completely damaged. The urgent need for planning and management of groundwater resources in Bahrain is obvious.

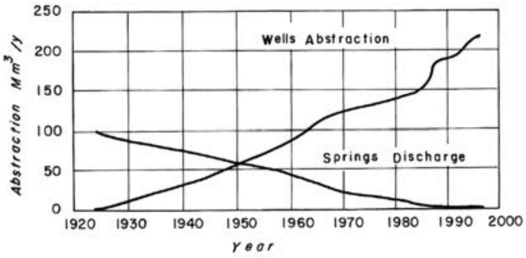

Figure 3. Groundwater withdrawal in Bahrain (1925–1999).

4.2 *Over-exploitation: the case of the New Valley in Egypt*

The Nubian sandstone is one of the world's most extensive aquifers. It is a regional hydrogeological dynamic basin extending into West and East

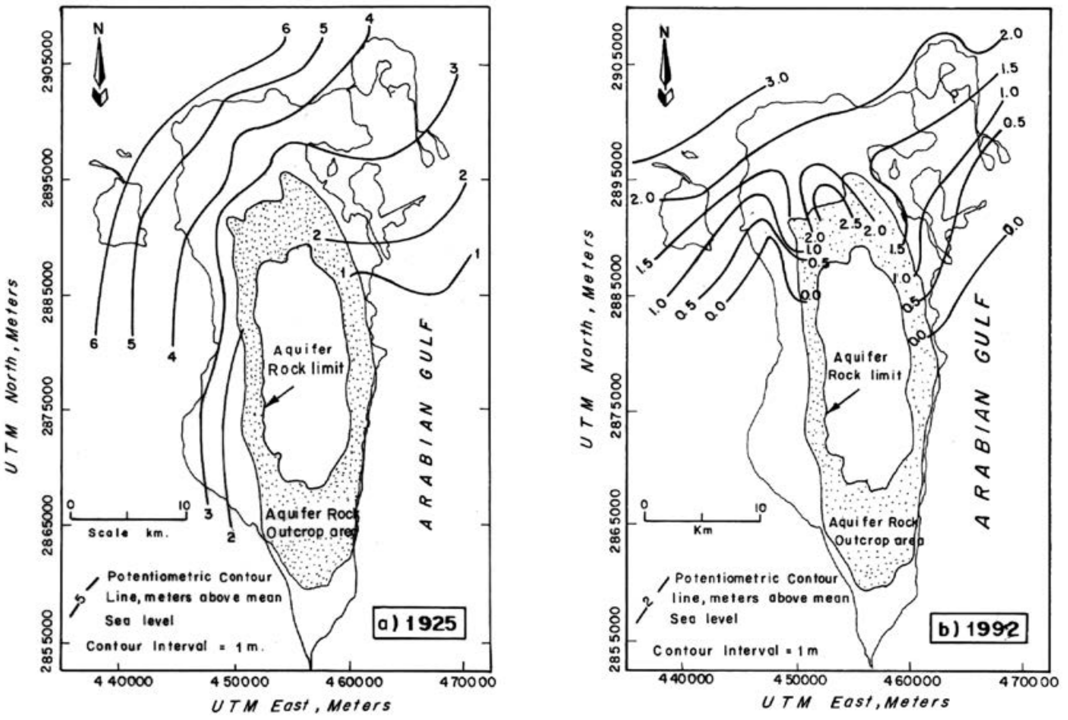

Figure 4. Changes in groundwater levels in Bahrain (1925–1992).

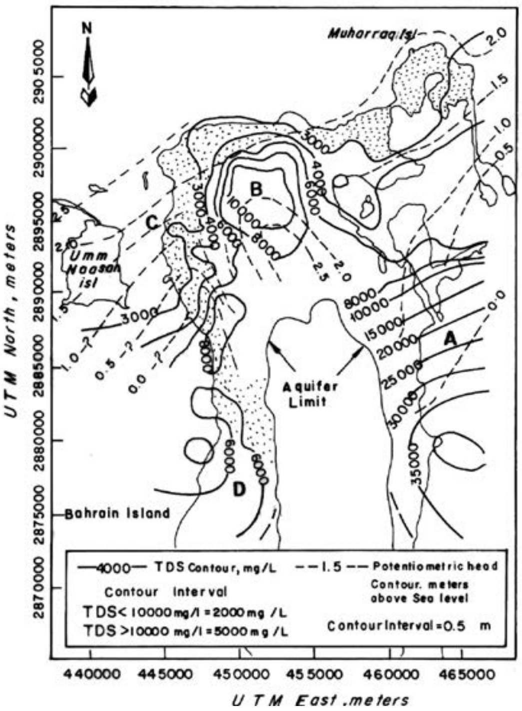

Figure 5. Groundwater salinity changes (1979–1992).

Egypt, South and East Libya, Northwest Sudan, and Northeast Chad (Fig. 6). To the east, the border is formed by basement outcrops of the Nubian Plate; to the south and west by the basement outcrops of the Kordofan Block and the Ennedi or Tibesti Mountains. The saline-freshwater zone forms the northern boundary

In Egypt, the Nubian sandstone aquifer outcrops on 30% of the surface area, and exists in the sub-surface in a larger extent. The majority of it underlies the Western Desert. It also extends to the Eastern Desert and Sinai Peninsula. The thickness of the aquifer varies between a few hundred meters in the south to about 4,000 m in the west. The Nubian sandstone aquifer contains vast amount of mainly fossil water, which most of it has been in the aquifer for at least 30,000 years (Shata 1962). Although the aquifer is almost non-renewable, a minor recharge may occur across the Sudanese and Libyan borders. The main direction of groundwater flow is from southwest to northeast. The discharge from the Nubian Sandstone aquifer takes place by several means: 1) flow from springs; 2) seepage to and subsequent evaporation from depressions; and 3) groundwater abstraction by deep and shallow wells. The salinity of the water in the Nubian Sandstone basin changes both horizontally and vertically. However, south of latitude 29º N the salinity of groundwater is less than 500 ppm, therefore it is perfectly suitable for most uses. Since the recharge to the basin is insignificant, groundwater exploitation comes essentially from storage.

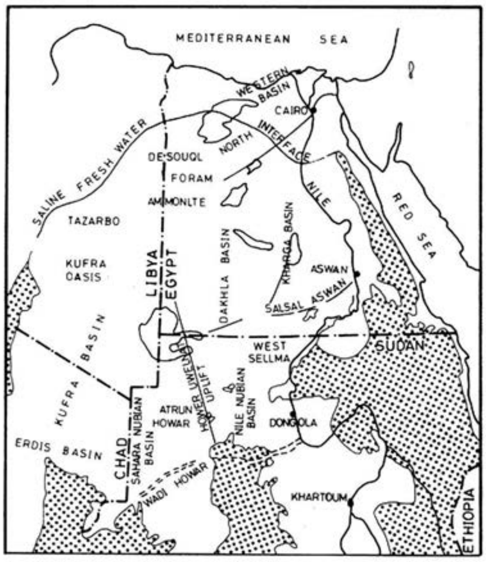

Figure 6. Regional extent of the Nubian Sandstone aquifer.

Exploitation of such system, being basically the only source of water in the Desert, depends on socio-economic conditions and the need for water. On the other hand, over-exploitation would result in reduced pressure of the aquifer system and a constant lowering of groundwater levels that might jeopardize dependent socio-economic development. One example of over-exploitation of the Nubian Sandstone aquifer in Egypt is the project known as the New Valley. The project area is a large depression in the Western Desert, located between the Nile Valley and the Libyan border. In this depression there are four main Oases (Kharga, Dakhla, Farafra and Bahariya). The project aimed at expanding the cultivated land in and around the Kharga and Dakhla Oases by providing them with irrigation water from the available artesian groundwater. To fulfill this objective, hundreds of deep production wells were drilled. The immediate result was that the abstraction from the deep aquifer grew from 20 Mm^3 in 1956 to about 210 Mm^3 in

1968. The obvious consequence was the rapid fall of the groundwater head by almost 30 m in the period between 1962 and 1969 (Margat & Saad 1984). This period followed by a narrow fluctuation in the volume of groundwater abstraction, that the drop in groundwater level did not exceed 3 m in the period between 1970–1975 (Fig. 7). The decline in the groundwater head resulted in substantial reduction of the naturally flowing wells. By the end of the 1970s it became clear that the project could not survive unless pumping is used to supply the extra water needed for irrigation.

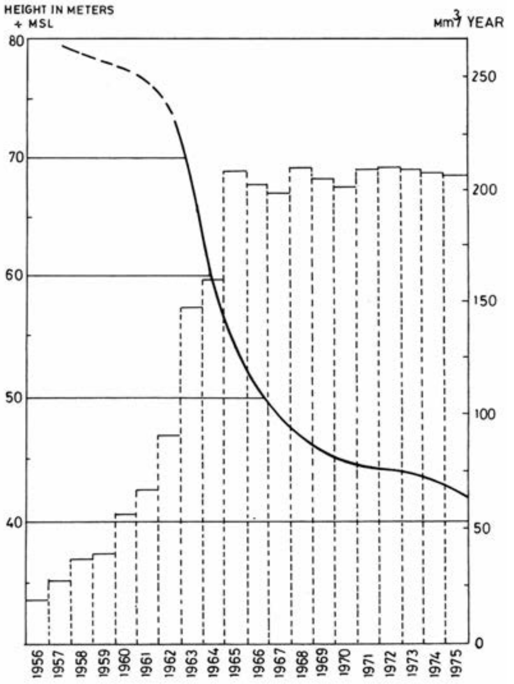

Figure 7. Depletion of the artesian aquifer in the New Valley.

From that time several plans have been proposed for the groundwater development in the New Valley. However, the ever-increasing pumping costs are undermining the economic viability of the existing as well as the projected irrigation schemes.

4.3 *Over-pumping and groundwater deterioration: the case of Gaza Strip*

Groundwater in Gaza Strip is confined in the coastal plain aquifer, which is 7–20 km wide and extends for more than 100 km (Fig. 8). The shallow sandy aquifer is essentially the only source of water. The aquifer is heavily over-pumped and becoming polluted. The natural replenishment rate of the aquifer is estimated at 50–60 Mm^3/yr. Abstraction rates are estimated at 80–130 Mm^3/yr (UNEP 1996). Over-pumping has lowered the water table throughout Gaza Strip. In the southern part, the drop in groundwater levels reached about 2 m during the period 1984–1994 (Al-Jamal 1996). Intensive pumping of groundwater is also causing seawater intrusion, and irrigation with this water is causing soil salinization.

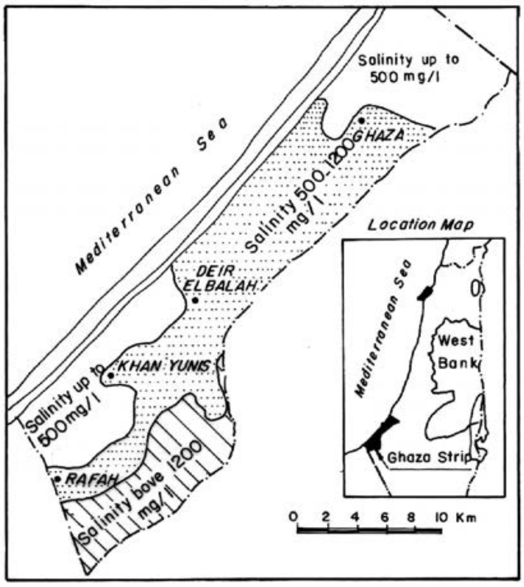

Figure 8. Location map of Gaza Strip.

The strip currently supports 800,000 people and a serious pollution risk is posed by the indiscriminate disposal of liquid and solid wastes. Most of the population is not connected to main sewerage and uses latrines draining to cesspits, many of which overflows into surface drains. Fecal contamination of groundwater is widespread, and nitrate and chloride concentrations in some parts of the aquifer are reported to be 10 times the WHO guideline (Table 6). Pesticide levels are also believed to be high and there is indiscriminate dumping of solid wastes throughout the area. The current water situation in Gaza Strip is expected to worsen unless drastic measures will be undertaken.

Table 6. Percentage of substandard quality for domestic water supply in Gaza Strip (El-Yagoubi 1996).

Region	(%) Chloride > 250 ppm	(%) Nitrate > 50 ppm
Northern area	98	10
Gaza city	23	6
Middle area	4	81
Khan Yunis	1	1
Rafah area	18	47

4.4 *Mining fossil groundwater: the case of Libya*

Groundwater supplies more than 95% of the total water demand in Libya. It occurs in aquifers of varying thickness, age, and lithological composition, which are either renewable or non-renewable. The renewable aquifers, which receive natural recharge, include the Quaternary, Miocene and Upper Cretaceous, and Triassic aquifers in the north. The non-renewable aquifers include the Lower Cretaceous, Triassic and Cambro-Ordivician aquifers in the south, and Tertiary in the Sarir basin.

Demands for water is rapidly increasing in Libya, forcing groundwater resources to be mined. Agriculture, being the major consumer, receives over 85% of the groundwater abstractions. The total irrigated areas in the year 1990 are estimated at 470,000 ha, which represents about 63% of the total irrigable land. Agricultural consumption for the same year was 4,275 Mm^3. Irrigated areas will continue to expand, and by the year 2025, an additional 266,000 ha will be put under full irrigation (require about 2,365 Mm^3/yr). Domestic water consumption in 1999 amounted to about 408 Mm^3/yr, and is expected to reach about 815 Mm^3/yr in the year 2025. Industry has never represented a burden on the total consumption as most industrial activities depend for their water supply on desalination of seawater.

Most of the water requirements are met from the coastal aquifers, which represent the zones of heavy demands. Over-exploitation of these aquifers resulted in continuous water table decline accompanied by an overall deterioration in water quality and seawater intrusion along the coast. Figure 9 shows the extensive decline of water level at Ben Ghashir, the heaviest groundwater extraction zone of the Jefara Plain, where the groundwater level fall from 17 m below the ground surface in 1958, to 37 m in 1970, and to 92 m in 1989 (Salem 1991). As a result of over-abstraction and the marked fall of the water level, water quality has been deteriorated due to seawater intrusion (Fig. 10).

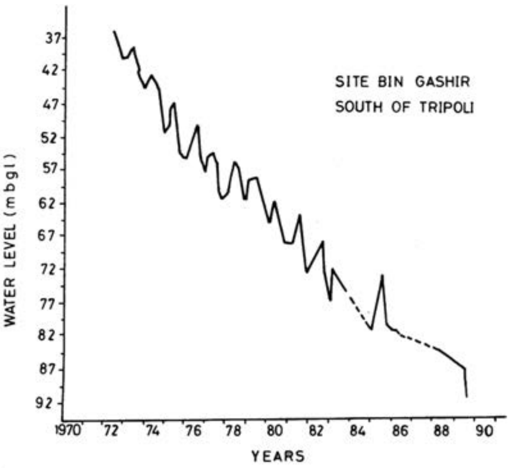

Figure 9. Decline of water level in an observation well, south of Tripoli, Libya.

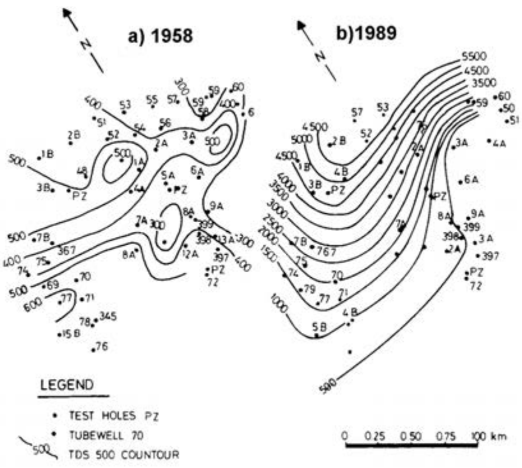

Figure 10. Water quality deterioration in Swani municipal well field, Tripoli, Libya.

The southern part of Libya is overlying two of the largest groundwater basins in the world: Murzuk basin in the southwest and Kufra-Sarir basin in the southeast. Studies indicated the possibility of transferring over 6 Mm^3/d from these aquifers. The *Great Man-Made River Project* was launched in 1983 aiming at utilization of the transported water for agricultural and urban developments, along with the restoration of the affected coastal aquifers (Fig. 11). The project is implemented on five phases. In the first phase, which was opened in 1991, a total of 2 Mm^3/d are conveyed to the coastal area extending from Benghazi to Sirt. Water is supplied from two well fields; the first is located in Sarir area (126 production wells) and the second is located near Tazerbo (108 production wells). In the second phase, additional 1.68 Mm^3/d will be conveyed from two well fields located in Kufra Oasis (137 production wells). This rate of abstraction will cause a drawdown of 50–130 m after 10 years. In the third phase, a total amount of 2.5 Mm^3/d will be conveyed to the Jefara Plain in the Northwest Libya from Marzuq basin (500 production wells). The last two phases are only concerned with further extensions of the conveyance lines.

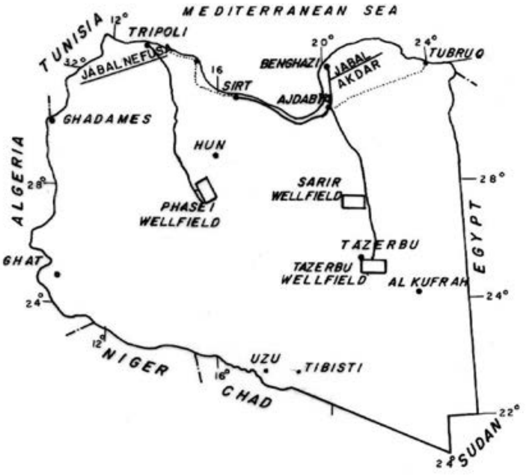

Figure 11. The Great Man-Made River in Libya.

4.5 *Depletion of naturally limited groundwater resources: the case of Qatar*

The geological sequence in Qatar is composed of Tertiary limestones and dolomites with interbedded clays, marls and shales overlain, in some places. Limestone and dolomites of the Rus and Dammam formations form the principal aquifer system in Qatar. They outcrop over the entire Peninsula and overly the older rock units, which contain highly saline water. The extent of the aquifer in Northern Qatar is influenced by seawater intrusion along the coastal areas, especially in the eastern part. The characteristics of the aquifer and the quality of groundwater in the north are distinctly different from those in the south. The northern zone, comprising the northern half of Qatar, constitutes the most important source of fresh groundwater in the country. There, groundwater occurs in the form of fresh floating lenses within the limestone-dolomite succession of the Dammam-Rus formation overlying the saline water in the older rock units. The hydrogeological conditions of the southern zone are more complex and less favourable than the northern zone. Except the well field of Rawdat Rashid there is hardly any freshwater in this zone (Shahin 1996).

The annual abstraction rate of fresh groundwater in Qatar sharply increased from about 20 Mm^3 in 1966 to over 120 Mm^3 by the year 2000, with an average yearly rate of aquifer storage depletion of 20 Mm^3. With such rate of aquifer storage depletion, hydrogeological studies have estimated that the aquifer storage will be fully depleted by the year 2025. On the other hand, the present inland rate of seawater intrusion has been estimated at 1 km/yr. Lloyd (1992) developed three maps illustrating the spatial extent of the fresh groundwater lens in Qatar for the years 1971, 1982 and 1985 (Fig. 12). Comparison of these maps suggests clearly that the extent of the fresh groundwater lens has been reduced by no less than 50% in about 15 years. Several options have recently been considered to deal with the growing depletion of fresh groundwater resources and the quality deterioration problem in order to fulfill Qatar's growing future water demands. These include better supply and demand management, increasing the production of desalinated seawater, reuse of treated sewage effluent and water imports.

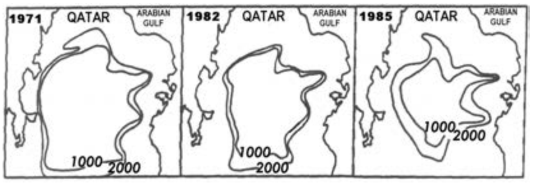

Figure 12. Progressive diminishing of the fresh groundwater in Qatar; contour lines show salinity in mg/L.

4.6 *Extensive abstraction of fossil groundwater for agriculture: the case of Saudi Arabia*

Saudi Arabia is the largest country in the world with no rivers or lakes. It is already one of the world's largest producers of desalinated water.

Nevertheless, a considerable amount of groundwater is exploited each year from its aquifers. The annual groundwater withdrawal reached about 14,000 Mm^3 by the end of the 1990s. This is slightly more than 18% of the total annual abstraction from the MENA region. The population growth, intensified urbanization and the diversification of the economy have led to the increase of water demand in Saudi Arabia. There is also a growing tendency in the country to practice extensive irrigated agriculture. All these aspects of development have exerted tremendous pressure on water resources.

The Paleozoic sandstone aquifer exploited by Jordan and Saudi Arabia has been extensively developed for irrigated agriculture in both Southern Jordan and Northwestern Saudi Arabia. The wells drilled there vary from 150 to 1,500 m in depth, with an average depth of 500 m. The annual withdrawal from the Saq aquifer system amounted to 290 Mm^3 in 1980. Lloyd & Pim (1990) have concluded that "extensive groundwater abstraction from the Cambro-Ordovician Saq sandstone aquifer coupled with hydrogeological analyses of the system indicates that a major groundwater source of good quality exists". This conclusion, however, should not let us lose sight of the problems caused by extensive abstraction of this resource.

Significant abstractions of groundwater in Saudi Arabia began in the 1950s in the Buraydah area and in the 1970s in the other areas. Abstraction increased further in the early 1980s following a decision by the Saudi administration to subsidize wheat production. This has led, among others, to considerable fall in the groundwater levels in several areas. In these areas, excessive drawdowns (Fig. 13) occur because of the combined influences of small storage coefficient, small transmissivity, and large abstractions (Lloyd 1994). In the Riyadh area the Menjor sandstone aquifer has been exploited intensively by wells drilled to depths up to 1,200–1,400 m for the water supply of Riyadh and its surroundings. As a consequence to the continuous abstraction of some 70 Mm^3/yr, the water level has fallen by no less than 10 m during the last three decades. Adverse effects include increase of the water salinity and corrosion of the well casing by thermal sulphonated water drawn from the deep aquifer system. In the oasis of Al-Kharj, southeast of Riyadh, the recharge is small and water is extensively abstracted for agriculture. Surface rock strata have collapsed, and the water level has fallen by 4–5 m between 1970 and 1980. The water table in the areas of Wadi Fatima and Wadi Khulys (around Jeddah) has dropped rapidly in the past few years with the growth of Jeddah.

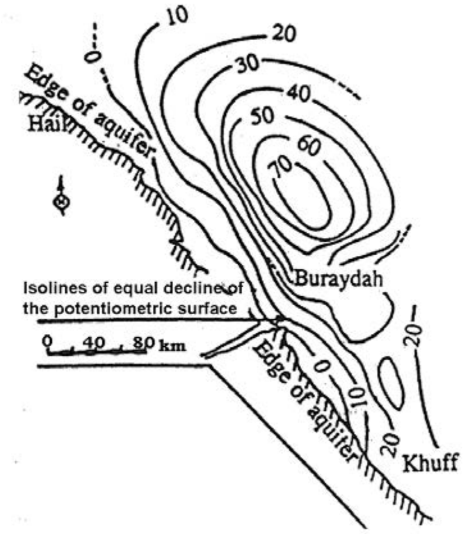

Figure 13. Decline of groundwater levels in Buraydah area as a result of extensive abstraction, Northwestern Saudi Arabia.

As result, deeper wells and more powerful pumps are badly needed to support agriculture in the *wadis*. Withdrawal of such huge quantities of groundwater from the lower Wadi Fatima in the western region reduced the water table rapidly, causing all springs to dry up (Mohorijy 1988).

Aspirations to attain food security in Saudi Arabia have increased the agricultural water demand substantially over the last two decades, leading to extensive mining of fossil groundwater. It is reported that water use for agriculture in Saudi Arabia has risen from 2,000 Mm^3 in 1980 to about 14,000 Mm^3 in 1995. This has caused a depletion of about 35% of the non-renewable groundwater resources estimated at 500,000 Mm^3 (ESCWA 1999).

4.7 *Over-exploitation of Wadi aquifers: the case of Yemen*

Based on the prevailing climatic and topographic characteristics, Yemen is divided into a number of physiographical units. These are: the Coastal Plain of Tihama, the foothills and western mountains' slopes, the central highlands, and the eastern mountains' slopes. With the exception of local occurrences of groundwater in the highlands, groundwater occurs essentially in alluvial aquifers in major *wadis* and piedmont zones. The Tihama Plain together with Hadramout, Tuban and Abian *wadi* basins are by far the most important groundwater basins in Yemen.

The Tihama coastal plain has a total area of about 20,000 km^2, stretching over a distance of 400–450 km along the Red Sea. Its width varies between about 30 km, near Bab Al-Mandeb, to 60 km, in the coastal zone where the city of Hodeidah is situated. A total of about 20 *wadis* traverse this plain; eight of them being major ones with catchment areas ranging between 1,000 km^2 and 8,000 km^2. During the two main seasons of monsoon rains (March-May and July-September), the major *wadis* transport large quantities of water and sediments from the catchment zones onto the plain. The mean annual runoff recorded from the major *wadis* ranges from about 12 Mm^3 to 160 Mm^3. However, a significant variation in the volume of this water has been observed over the last few decades. An estimated average of 550 Mm^3/yr is brought by these *wadis*, together with an average rainfall volume of 4,100 Mm^3/yr, makes a total surface water flux of about 4,600 Mm^3/yr into the Tihama. However, only about 700 Mm^3/yr of this water is estimated to recharge the extensive thick alluvial deposits (over 400 m), which underlie the entire region. This freshwater replenishes the Upper Quaternary layers (about 200 m maximum thickness), which represent the effective aquifer presently under exploitation. Current abstractions from this aquifer, close to 2,000 Mm^3/yr (IFAD 1992), are far in excess of recharge.

Figure 14 shows the increase of the number of the pumping wells in the Tihama Plain from 1960 to 1982 (Van der Gun *et al*. 1992). These wells are supporting groundwater-based irrigated agriculture. The upcoming of saline or brackish water in some wells and the need to deepen those wells, which have become dry, and the increase in the cost of pumping resulting from declining water levels, are among the adverse effects caused by intensive aquifer exploitation. This significant overdraft makes the aquifer highly unsustainable for future developments.

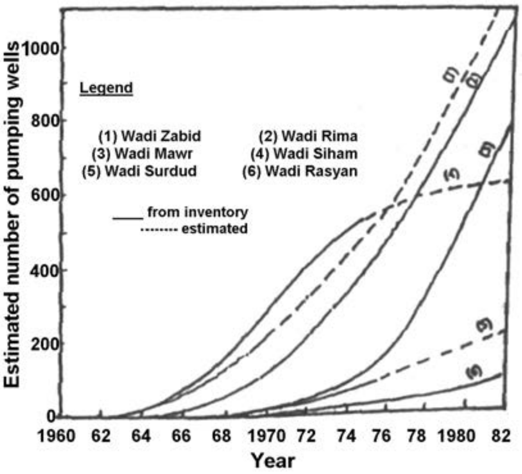

Figure 14. Increase in number of wells pumping from the *wadi* aquifers in Tihama plain, Yemen.

The absence of management control measures as well as inadequate knowledge of the aquifer aggravate groundwater over-exploitation problems in the region. The effects of these factors are further magnified by the complex nature of the geological setting of the aquifer system. Progressive overdraft since the early 1980s has resulted in a significant lowering of the water table as a result of which a large number of wells has gone dry. At present, 70% of the approximately 15,000–20,000 wells (estimated to be withdrawing water out of the aquifer) are equipped with pumps. A general decline of 0.5–1 m/yr is observed due to abstraction by these wells; but a lowering of 2–3 m/yr is not uncommon locally. Maximum declines occur in the central regions of the plain where agricultural development is concentrated. Groundwater quality deterioration is observed across the entire region from the coastal zone to the foothills. The increasing salinity in the shallow *wadi* aquifer system is occurring due to both seawater intrusion (restricted mainly to the coastal zones of the northern *wadis*) as well as the upconing of deeper saline water from Tertiary evaporite and/or older sedimentary formations.

Another example of uncontrolled abstraction from Yemen, where limited aquifer recharge occurs and over-exploitation of groundwater resources takes place, is the Sana'a basin. As in the previous example, groundwater is abstracted for domestic as well as agricultural purposes. Analyses of the pumping tests have shown that the transmissivity varies from 10 to 500 m^2/d. The aquifer is highly anisotropic and the permeability probably decreases with depth. Furthermore, the storage coefficient appears to in the order of 10^{-4} in the confined part of the aquifer and about 10^{-2} in the unconfined part. The annual recharge has been estimated at 28 Mm^3. Whereas, the corresponding annual abstraction has been estimated at 30 Mm^3. During the 1980s the groundwater levels have been declining generally at the rate of 0.2–0.5 m/yr, and at 6 m near the well fields. Thus, over-exploitation is causing widespread and substantial drawdown, although some recharge occurs in the basin. Similar to the case of Tihama plain, the main problem relates to uncontrolled irrigation abstraction for certain high cash crops. The response of the aquifer in the Sana'a Basin to alternative abstraction options for future management, in terms of predicted drawdowns, is graphically illustrated in Figure 15 (UNDP 1992).

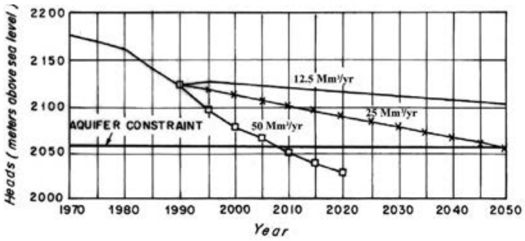

Figure 15. Predicted drawdowns for various modeled abstraction options, Sana'a Basin, Yemen.

4.8 *Over-exploitation of shallow coastal aquifers: the case of Tunisia*

In Tunisia, the groundwater resources are classified as aquifers with shallow water table (unconfined), deep groundwater aquifers with renewable resources, and deep groundwater aquifers with fossil water. Since the annual and seasonal rainfall is irregular, groundwater resources are exploited intensively during dry seasons in the southern, central and the coastal area *Sahel* of the country. With the economic and social development of the country, groundwater exploitation has increased significantly.

Even though, there has been increase in the exploitation of deep groundwater aquifers, the potential of deep groundwater resources is still much higher than their exploitation. This is not the case for shallow aquifers, where groundwater withdrawals exceed renewable recharge. The over-exploitation of these aquifers started on the northeastern part of Tunisia in 1940. At present, several shallow aquifers are already over-exploited which has caused a marked drop in the piezometric levels for some aquifers and salt-water intrusion for others. To minimize the effect of over-exploitation and to improve the resources of shallow water table aquifers, several technical and legislative measures have been undertaken.

One example of the over-exploited shallow coastal aquifers in the country is the case of Ras el Jebel aquifer situated in the northeast of Tunisia. It has a surface area of 35 km^2. The average annual rainfall is estimated at 570 mm. The aquifer is alternately composed of sand and clay. Its thickness ranges from 10 to 30 m. The aquifer is exploited by 1,372 wells with depths ranging from 5 to 20 m. The resources of this aquifer are estimated at 8.5 Mm^3/yr, which are provided, by rainfall infiltration and drainage water.

Over the period 1980–1990, a maximum exploitation of this aquifer reached 13 Mm^3/yr. During the 1990s, after the stored water was transported from dams for irrigation purpose, the exploitation was lowered to 11 Mm^3/yr. However, due to the over-exploitation of this aquifer throughout the period 1969–1993, the piezometric level dropped by 3 m on the coast and 10 m on the land. This drawdown has forced the farmers to deepen their wells and change the pumping equipment. Also, the water quality has degraded significantly in the coastal region due to seawater intrusion. Where the range of groundwater salinity has increased from 1.5–4 g/L in 1969 to 5–10 g/L in the 1990s.

To protect Ras el Jebel groundwater resources, and to sustain the irrigated areas in the region, the transport of stored water has been planned for irrigation purposes and possible artificial recharge of the aquifer system. In 1989, surface water was diverted to irrigate an area of 2,040 ha, with a water consumption of 2 Mm^3/yr. Also, an artificial recharge experiment has been introduced in 1993. The recharge site is situated on the north of the aquifer, 2 km away from the sea. It is an old sand quarry with an area of 1,000 m^2 and an average depth of 4 m.

In this area the piezometric level is at 8 m. The aquifer is composed of sand and gravel which make it easier for the infiltration process. The piezometric level is measured on 60 observation wells distributed over an area of 6 km^2. The recharge process affected an area of 400 m towards the north in the direction of the sea, and 600 m towards the east. The artificial recharge achieved a 4 m maximum rise in groundwater levels (Fig. 16), that is to say an average daily rise of 0.94 m. On the other hand, the groundwater quality in the recharge site has improved, and the salinity, which was ranging between 4 and 8 g/L, has been found to range between 1 and 3 g/L (Fig. 17). It can be concluded that the experiment of artificial recharge has proved to be an efficient mean to protect Ras el Jebel water resources and control the saline intrusion.

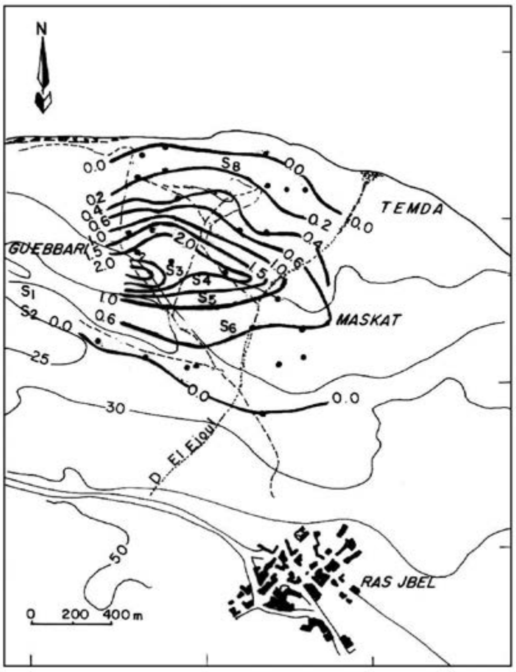

Figure 16. Lines of equal rise in groundwater levels, artificial recharge experiment, Ras el Jebel aquifer, Tunisia.

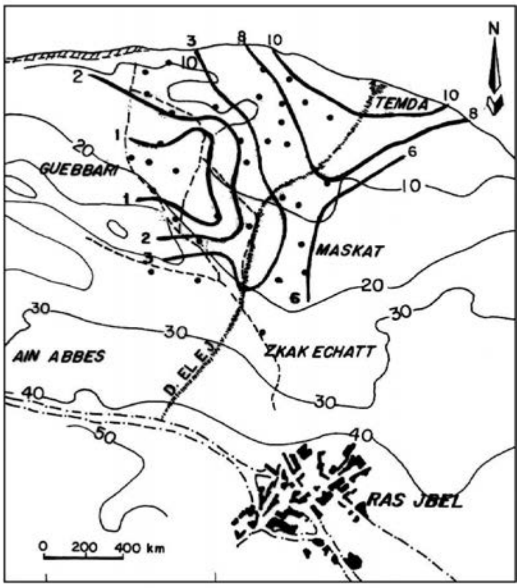

Figure 17. Lines of equal salinity levels (g/L), artificial recharge experiment, Ras el Jebel aquifer, Tunisia.

5 WATER RESOURCES MANAGEMENT: CHALLENGES AND OPPORTUNITIES

5.1 *Integrated approach to water resources management*

The growing demand for water and socio-economic development in the region, coupled with limited available water supplies, represent a serious problem for most of the MENA countries. Governments in the region are increasingly recognizing the urgency of addressing water issues, and policy and institutional reforms are being considered in most countries. Accordingly, decision-makers in the region are faced with major challenges of managing their water resources. Water resource management can be conveniently considered as a twofold undertaking; supply management (which covers those activities required to locate, develop and exploit new sources), and demand management (which addresses measures and mechanisms to promote more desirable levels and patterns of water use).

The adoption of a comprehensive policy framework and treatment of water as an economic good, combined with decentralized management and delivery structures, is the basis for integrated water resources management. So long as water is abundant and of good quality, interaction between different water users and stakeholders may not be so essential, and water project could be implemented with little regard to their impacts elsewhere. But as pressures mount, so does the need for such interaction. Users compete for the same resource and water quality is modified in ways that may affect water's value to other users. Fragmented management approaches essentially fail to account for these factors, and the result could incur rapidly increasing cost of water quality deterioration, water allocation to low-value uses, and overall aggravation of the water situation. Therefore, governments need to establish a policy framework that takes a long-term perspective for the management of water demand and supply. An integrated approach to water resources management calls for giving due consideration to technical, economic, social and environmental requirements during the planning of water resources development programs, as well as implementing inter-related activities in an efficient integrated and comprehensive manner. It also calls for setting priorities that meet social expectations and the availability of financial resources.

Thus, integrated water resources management implies an approach that is interactive, flexible and dynamic in the area of policy planning, analysis and strategy implementation. It also calls for promoting and strengthening perception, particularly at the decision-making level, that water resources development should become an integral part of many other socioeconomic development activities. The integrated approach encourages the establishment of dialogue with policy makers in order to identify problems, potential, and constraints, as well as formulating strategies that are consistent with government policies, social setting, and types of resources available, especially in the early stages of planning and development. It emphasizes the need for water to be regarded as a finite and scarce resource that constitutes a portion of infrastructural input in development activities. Meanwhile, the integrated water resources management approach must be achieved according to established water policies and strategies.

5.2 *Water resources planning*

Planning is the process that integrates the two aspects of supply and demand in the context of water resources management, and provides the analytical basis for choosing between alternatives. Goals and objectives, which are set by government on behalf of their peoples, can be expressed in political, social, economic, or environmental terms. The planner's role is to evaluate the effects of alternative strategies on a consistent basis and to suggest policies and actions that can best achieve desired objectives. This requires exploration of a range of feasible and realistic scenarios, and formulation of a set of alternative courses of action for implementation. Time frames for plans of action to implement strategies need to include not only short-term horizons, but long-term implications as well. Short time frames provide the opportunity to adjust strategies and subsequent implementation in order to deal with changing circumstances and priorities, as well as budget constraints. Thus, in its broadest sense, water resources planning provides the analytical basis for all policy formulation and for linking water resources issues to policies at the macroeconomic, regional, and sectoral levels. Comprehensive water resource planning requires government intervention in the management of the resources. Government is inevitably required to establish the policy, legislative, and regulatory framework for managing water supply and demand. It is also the role of government to ensure that water services are provided, notably by constructing large projects for which economies of scale or social externalities preclude private supply. This does not mean that governments must control each and every aspect of resources management. Many important activities are preferably decentralized to autonomous local, private, and user group entities. Indeed as a general principle, functions that can be done better at a lower level should not be done at a higher level. Nor does it mean that governments alone should set objectives and priorities. Evidence worldwide suggests that participatory approaches involving stakeholders in decision-making result in more efficient and resilient solutions than those implemented by governments in isolation from public opinion.

Though most of the MENA countries conduct water resources planning, planning processes are still fragmented and have not evolved to a level sufficient for effective management of water resources. Therefore, the current planning practices should be modified to account for the requirements of integrated water resources management. Most of the countries conduct water resources planning within the context of five-year development plans. In some countries, efforts have been made in the past to adopt a national water plan, however, urban migration and rapid development in the agricultural sector rendered the plans obsolete before they could be put into effect. The need to revise water policies to accommodate such rapid development resulted in continual delays in their implementation. Major deficiencies in the region typically reside in long-term resource planning at the regional and basin levels, and their aggregation into national resources plans and long-term strategies. Strategies that have been implemented in many countries in the region focused on balancing supply and demand through increasing reliance on desalinated water to meet domestic water requirements, and mining of groundwater reserves to meet irrigation requirements. Meanwhile, few countries in the region have established effective mechanisms for public participation and consultation, and this again undermines commitment and implementation. Through the planning process, programs in the region should focus on restraining losses and unsustainable use of renewable and fossil groundwater resources. Economic criteria for project selection and allocation of water to different water use sectors should be incorporated during the planning phase.

Water policy in the past has targeted short-term objectives. Favorable economic conditions during the late 1970s and 1980s fostered water policies that focused mainly on the development of water resources in most of MENA countries. Implementation of these policies required substantial capital investment for the development, construction, and operation of water infrastructures, to meet expanding water quantity and quality requirements. Currently, the water situation is dramatically different as a result of policies that have encouraged over-exploitation of groundwater resources, resulting in deterioration of water quality. Increasing competition among water use sectors, fragmented management practices, and lack of financial resources all contribute to diminishing supply. Water policy reform in the region must involve review of activities within the water sector, as well as other water-related sectors of the economy. Policy reform must include revision of current agricultural policies where different types of subsidies have encouraged over-exploitation of resources. Reform should involve formulation and enforcement of comprehensive regulations and improvement of institutional structure in order to achieve efficient management and development of scarce water resources. Policy reform based on the concern of integrated approach should also define water-planning procedures, level of planning and the extent of involvement of specialists and decision-makers, and relation and relationship of water to other national resources and water sector users.

5.3 *Supply management*

Surface water supplies are typically exploited first. As accessibility to new surface sources decreases, and projects become more expensive, other sources including groundwater become of greater significance. Ultimately, as renewable freshwater approaches full exploitation non-conventional sources such as wastewater treatment, desalination, and water imports, may become the only sources of new supply. Surface storage adds to freshwater supply to the extent that it controls flooding and captures water otherwise lost to the sea and other sinks but, as rivers approach full exploitation, the additional yield from providing storage may be more than offset by evaporation losses from reservoir surfaces. Even so, although the potential for further dam construction in MENA is limited, where justified, the control they provide over the timing and location of water can be critical to converting uncertain water endowments into reliable supplies.

Relative to many other parts of the world, MENA is already critically dependent on groundwater, at least outside the major river valleys of the Nile and the Tigris/Euphrates. In some countries, it is already the predominant source of supply. It comprises essentially the only naturally occurring freshwater resource in the Gulf States, and accounts for about 95% of freshwater abstractions in Libya, 70% in Israel, 64% in Algeria, 61% in Yemen, 60% in Tunisia, 51% in Jordan, 55% in Mauritania, and 41% in Iran. Though recharge rates and flows are not always well known, the quantity and quality of groundwater is of increasing concern. Overpumping has led to rapid declines in groundwater levels in many locations. Saline intrusion and pollution from urban and industrial wastewater are commonly encountered and reversible only at great cost. Groundwater abstractions approach or exceed renewable limits in many countries including Algeria, the Gulf States, Israel, Jordan, Libya, Mauritania, and Yemen. Potential for further abstractions still exists, for instance, in some parts of Iran, Turkey, Iraq, and Egypt. But in the latter two countries recharge is almost wholly from major rivers and, through a shift from surface supplies to groundwater may reduce evaporation losses from waterlogged areas, it does not otherwise add to supply.

Management of natural groundwater recharge and enhancement of magnitude by artificial means is one important method of increasing water supply availability in the region. Seasonal storage takes advantage of the availability of excess water during the wet season. Large volumes of surface runoff are lost to the sea from coastal drainage basins and evaporation from inland drainage basins can be utilized for recharge purposes. Runoff utilization techniques are currently being practiced to augment groundwater supply through artificial means, in Jordan, Saudi Arabia, Yemen, Oman, UAE, and Qatar. These practices include storage facilities such as dams and dikes, water spreading basins, and depression lowlands with recharge wells. In some cases where these practices have not served their intended purposes, problems were attributable to inadequate operation and maintenance procedures. There were also problems associated with high evaporation losses resulting from prolonged storage of water. Long-term storage can be utilized in the Gulf States when desalination capacity is in excess of water demand. The other important aspect of artificial recharge is the storage of reclaimed wastewater. Large volume of treated wastewater is being disposed off to the sea in many parts of the region. The availability of treated wastewater which, is being disposed along coastal zones or into *wadi* channels, can be put to beneficial use through recharging alluvial aquifers. In addition to increasing water supply availability, advantages of artificial recharge include restoration of groundwater levels, and improvement water quality. Artificial recharge is also an effective means to combat saline intrusion, and can be used to control the movement of contaminant plumes. Though the advent of artificial recharge may seem to have many benefits, problems still may be encountered in some countries. Land to construct recharge facilities may not be available or may be too expensive to acquire. Artificial recharge may increase the danger of aquifer contamination, especially when the source is reclaimed effluent that fails to meet quality standards.

Non-conventional water sources include wastewater treatment and reuse, desalination, and water imports. They are typically much more expensive than conventional sources although, in the case of wastewater treatment, costs may largely be offset against environmental objectives and the need to safeguard other sources of supply. Political objections to large water transfer projects from outside the region and/or across national boundaries may prove insurmountable, and their financing and implementation would in any case pose formidable problems. The potential for the use of treated wastewater in irrigation can both add to water supply and have important environmental benefits provided that use is carefully controlled. Total wastewater flows are rising rapidly, and although in most countries they will remain small relative to total renewable resources, in the water short countries of the Arabian Peninsula they may represent the predominant long-term water supply for intensive irrigated agriculture. Substantial areas are already developed in several countries (Israel, Jordan, and Saudi Arabia) and pilot projects are spread widely throughout the region. In some countries (Morocco, Egypt) untreated wastewater is used despite its health impacts. The costs of wastewater treatment are quoted in the report at between US$ 0.12–0.40 per m^3 depending on the technologies employed, which compares favorably not only with desalination but also with the more expensive interbasin transfer schemes (World Bank 1993). While health standards must be met if water is to be used directly in irrigation, the additional costs in some circumstances may be little more than required to meet normal environmental standards.

Desalination is already an important source of supply in the Gulf States. Saudi Arabia alone accounts for 30% of world capacity with the rest of the region accounting for a comparable amount. Desalination remains expensive although recent cost reductions combined with the rising cost of conventional sources are making it surprisingly competitive in some situations. Since costs increase with the salinity of the water used, brackish waters, widely dispersed in MENA, provide a less costly alternative than seawater. Many factors, including the cost of capital and energy and the quality of the raw water, influence the choice of technology. Distillation is usually preferred for seawater (costs are currently about US$ 1–1.50 per m^3), and reverse osmosis and electrodialysis for brackish waters (US$ 0.40–0.80 per m^3). Large-scale desalination is invariably associated with low-cost energy and use of solar energy may one day become competitive. Provided that energy is assured, desalinated water provides a very much more predictable and reliable source than renewable supplies and avoids many of the management problems associated with the latter.

Various alternatives have been suggested for importing water into the region. They include the alternative *peace* pipeline projects for delivering water from surplus river basins in Turkey to various locations in the region; importation of water by tug or tanker or even icebergs towed from arctic regions. Each of these alternatives carries with it high costs. Moreover, on the case of the pipeline and tanker alternatives, the recipient country is dependent on others and many countries may be unwilling to expose themselves to implied risks, given the difficult political problems facing the region. Nevertheless, as conventional sources are exploited, they may become economic in the longer term. Broad preliminary estimates of the costs of the peace pipeline suggest that they might be in the order of US$ 0.80–1 per m^3, which could make deliveries competitive with desalinated supplies even though financing problems will be formidable, and construction could take a decade. A feasibility study of the import of water from Turkey to Israel by sea estimated costs at US$ 0.22 per m^3 although the proposed method, tugs dragging water in bags, has still to be proven technically feasible. The alternative of conventional tankers is estimated at more than US$ 1 per m^3 (World Bank 1994). Improved management of existing supplies can often be a partial alternative to investment in new supply. Reallocation between uses is a key mechanism for adjusting to water constrains. Irrigation in the region accounts for some 82% of water use, so relatively small transfers from agriculture would substantially increase availability to other sectors. However, few countries have been willing to commit themselves to a policy for the planned reallocation of water from irrigation to domestic and industrial use, even where governments recognize in principle the long-term inevitability of such a trend. Reasons vary but are often compelling. Withdrawal of water from irrigation in arid areas destroys the viability of agriculture. Moreover, most MENA countries are already deficient in basic food production and further dependence on imports carries risks that are politically very difficult to accept. Thus, many governments continue to project increases in irrigated areas, despite also recognizing the severity of water constraints, arguing that this is essential for food security and regional development. It is often impossible to know whether the externalities associated with retaining water in irrigation will be positive or negative. Where irrigated agriculture provides the basis for regional economic activity, a full equilibrium analysis of the regional economy and its relationship to the national economy may in principle be required to be certain whether reallocation is economically justified although, in practice, such an exercise is seldom practicable. In some cases the spread of urban areas on to irrigated land will itself release irrigated water for other uses. However, in most MENA countries, reallocation of water from agriculture will be inevitable.

5.4 *Demand management*

Demand management means the application of a range of physical and economic measures to achieve higher efficiency in the way water is utilized. Such measures are usually implemented to curtail and control demand in order to ensure that a limited supply will be able to satisfy demand. Demand management can take many forms, from direct measures to control water use, to indirect measures that affect voluntary behavior (market mechanisms, financial incentives, public awareness programs). Price distortions in particular often magnify both scarcity and water quality problems. Low water charges encourage consumption and waste. Low water charges also put pressure on operation and maintenance budgets, leading to poor water treatment and further deterioration in water quality. Trade, macro, and input pricing distortions also can pose a threat to water supplies and water quality, for instance by failing to discourage industrial pollution (hazardous waste and wastewater discharges). Inefficiently low fertilizer prices similarly lead to increased fertilizer consumption and degradation of water supplies (World Bank 1994).

Failure to implement demand management measures in the past does not negate their essential justification. The mix of possible measures will of course vary according to the circumstances but in all cases the aim should be to increase the efficiency, and perhaps equity of water use. Efficiency is, however, a relative concept and must reflect all the interactions in the water cycle (Bhatia & Winpenny 1993). For instance, irrigation efficiencies at the farm or scheme level may be relatively low, but, if losses recharge groundwater are reused via the drainage system, basin efficiency can be much higher. For instance, scheme-level efficiencies in Egypt are comparatively low by the standards of other countries in the region, but annual average efficiency in the Nile basin from Aswan to the sea is estimated at 65%, which is comparable to the efficiency of modern pipe systems at the project level, and this reaches 80% in summer when water demands reach their peak. The potential for water savings in irrigation, although considerable, may thus in some cases be lower than is anticipated.

Transparency and accountability are best established within the context of participatory approaches designed to ensure that stakeholder views are reflected in decision-making and to secure public awareness campaigns, education programs, and similar initiatives have also led to significant changes in human behavior related to water conservation and use, notably in developed countries. While their potential is less well established in developing countries, they clearly have an important role to play and, since they are in large measure costless, they should invariably receive priority and should always accompany other programs to increase efficiency and/or conserve supplies.

Reduction in water losses is important to any demand management program. In the domestic sector, unaccounted-for-water can reach high as 50%–60% in urban delivery systems. Leak detection and repair programs, identification of illegal connections, and reduction in system pressure can all play a part. In most MENA countries, leakage from the delivery system caused losses ranging 20%–50%. In some of the countries lack of funds for leak detection and maintenance prevent systematic monitoring. Reduction of leakage increases water supply availability, reduces urban water table rise and cost saving specially in countries that depend on costly desalinated water. Implementation of limited leakage detection programs in the Gulf States succeeded to reduce leakage by 8% in Bahrain and 15% in Qatar. Various low water-use devices and technologies are available; however, adoption of such devices in MENA countries has to date been limited. A system of restrictions and/or penalties designed to enforce compliance with regulations is required to ensure successful reduction in water consumption. Existing housing subsidies and loans practiced in the region can be used as incentives to enforce water saving regulations.

Efficiency in industrial uses in developed countries has been typically forced by water quality standards that have led many industries to recirculate their process water, resulting in substantial reductions in industrial water demand. The introduction of water saving technology in the existing large industries often requires production process modification with little return on investment. However, it can be cost effective if emphasis is placed on water recycling within the facility. Strict pollution control standards, in combination with adequate pricing schemes for the cost of water, will force industries in the region to implement recycling programs, especially for cooling purposes. In most instances, the cost of recycling is offset by recovery of production materials from the effluent.

Technical interventions to reduce water use have particular potential in irrigation. Canal lining and improved conveyance technologies can save water in the order of 10%–30% (whether similar savings are achieved at the basin level is a matter for specific study). At the farm level, surface irrigation can be improved through land leveling and the introduction of better on farm practices or can be replaced by modern irrigation techniques. However, modern irrigation systems are capital intensive when compared to surface irrigation. Accordingly, it is difficult to persuade farmers who are used to receiving their water free or nearly free of charge to switch to more efficient systems, which are considerably more costly to install and maintain. Governments can assist in this respect by providing farmers with long-term loans at zero or very low interest rates for the purpose of installing water efficient delivery systems. Yield increase associated with the use of modern irrigation techniques has proven to be the decisive incentive for the spread of modern systems, where conditions are appropriate. For instance, drip irrigation now accounts for more than 90% of all irrigation in Israel and has resulted in sharp reductions in agricultural water use. Comparable trends are occurring in Jordan, Egypt, Saudi Arabia, and Oman. Pilot projects are widely spread throughout the region and both government and private sector initiatives are beginning to have considerable impact. The most direct regulation is to mandate water use. Quantitative restrictions are, however, difficult to administer or to police. Rationing or rotational deliveries can achieve a comparable effect and are commonly adopted during droughts or where demand exceeds the physical capacity of the system. In surface irrigation schemes, rotational delivery can become more permanent, and provided farmers know in advance the expected pattern of delivery, creates a strong incentive to maximize the returns to limited supplies. Direct controls on cropping are an alternative, which in principle could reduce water consumption at the farm level. However, mandated cropping patterns constrain a farmer's ability to respond to market signals and may thus have perverse effects on agricultural value added.

The regulation of groundwater exploitation is a universal but often intractable problem. Most countries issue extraction permits although, with the partial exceptions of Israel, Jordan, and Cyprus, these have seldom been able to prevent uncontrolled overdrafts, since only a few countries in the region have the administrative capacity for direct controls. Groundwater regulation can also be approached indirectly (e.g. by regulating the spacing of wells or the number of drilling rigs). However, there are few examples in the region, or other regions in the world, where such approaches have proved entirely satisfactory. Financial constraints related to the costs of pumping and well yield are thus normally the ultimate control. Provided that inputs (equipment, power, energy, and credit) and outputs (crops, industrial products) are priced at their true cost, and there are no adverse externalities such as saline intrusion, this may indeed result in an economically efficient solution. In some cases, this will lead to the mining of the resource. While this may be economically justified, it is inherently temporary and, if the activity is to continue, replacement resources will ultimately have to be found (World Bank 1994).

All water uses require that water quality falls within a range specific to that use. When water quality is outside this range, for example, when salinity is above the tolerance of crops, or contamination makes water unsuitable for industrial processes, or the level of biological or other contamination renders it unsafe for drinking, then the user must identify and develop an alternate source or reduce contamination to acceptable level. These conditions impose large costs on water users. If there are no practical or economic treatment technologies, or if costs are greater than users can afford, then economic activities such as tourism, agriculture, or industry may be forced to move or cease operations. Issues of quantity and quality are thus inseparable. But as water scarcity grows, investment options diminish and contaminants are concentrated. In a free market, water would shift from low-value to high-value uses; and incentives would be provided for efficient use and the preservation of water quality. However, market mechanisms are particularly problematic in water, and it is unrealistic to expect that a general reallocation between sectors or improvements in water quality can be effected through the market. Governments must therefore assume ultimate responsibility for reallocation and preservation of environmental standards. Mechanisms include measures that influence user behavior through direct regulation, technical innovation, financial incentive, or appeals for voluntary restraint. Regulation of water quality standards has been widely adopted; indeed many governments have adopted over ambitious targets that they have found difficult to enforce. Point sources of pollution are relatively easy to monitor by an Environment Ministry or agency although, if standards are set too high, the costs of meeting them can create strong incentives for non-compliance. Non-point pollution, notably from fertilizers and pesticides, has proven a much more intractable problem worldwide. Specific pesticides can be banned, and prices can be set at levels which discourage excessive use, but few mechanisms are available that account in full for all externalities.

Financial interventions should typically be governed by two important principles; the *user-pays principle* and the *polluter-pays principle*. In most cases, not only are these seen to be equitable and therefore gain public acceptance, but they also tend to result in economically efficient solutions. Few MENA countries have, however, made systematic use of such mechanisms and, where they have attempted to do so, administrative weaknesses have often resulted in failure in implementation. Israel is an exception that has adopted rigid demand-side measures dating at least from the early 1970s; Cyprus is also another exception (World Bank 1993). Water charges have typically been looked at as a mechanism for financing the operation and maintenance costs of the water agency rather than as a demand management measure to encourage efficiency in water use or reallocate water from low-return to high-return uses. So long as extraction costs remain reasonably constant and externalities are limited, pricing to meet full cost recovery approximates to marginal cost pricing. But as costs rise and external impacts mount, the efficiency or opportunity cost price typically rises well above the level needed to meet cost recovery objectives. Market failure limits the role of price in allocation and precludes the emergence of a clearing price that equates the real costs of its extraction with its value in the marginal use. Pricing that allows for externalities would, nevertheless, still provide the correct incentives for efficient use, and the World Bank has long encouraged governments to bring resource pricing progressively closer to real economic levels on the *user-pays* and *polluter-pays principles*.

In practice, water charges are normally well below levels needed to recover financial costs. In Algeria the long run marginal cost of water to urban consumers, including both raw water supply and distribution is about US$ 0.52 per m^3 compared to the average water charge of US$ 0.12 per m^3. The contrast is even more striking in irrigation: current water charges average US$ 0.02 per m^3 compared to an average marginal water cost of US$ 0.32 per m^3. In Egypt the combined marginal cost of raw water supply and distribution ranges from US$ 0.03 per m^3 for rural areas to US$ 0.25 in major urban centers though water charges for domestic consumers average no more than US$ 0.03 per m^3. To these costs must be added the cost of treating the wastewater collected by the sewer system: these costs range from an estimated US$ 0.12 per m^3 in Morocco to US$ 0.37 per m^3 in Jordan (for water reuse) and US$ 0.40 per m^3 in the Gulf States (World Bank 1994). In MENA countries that depend mainly on groundwater, such as Jordan, Gaza Strip, and the Gulf States, production costs are much higher than that reported for countries that depend on surface water. Groundwater development costs in areas under the Palestinian Authority, including pumping costs, ranged from US$ 0.10–0.20 per m^3 for shallow wells, while for deep wells, the range was US$ 0.28–0.34 per m^3. In Yemen, costs associated with the development of groundwater resources from the alluvial *wadi* formations ranged from US$ 0.02–0.10 per m^3. In Syria, costs of groundwater production from major aquifers ranged from US$ 0.03–0.34 per m^3. The costs of groundwater development for municipal purposes in Qatar were estimated at US$ 0.17 per m^3, while for the agricultural sector costs were estimated at US$ 0.30 per m^3. The public is therefore not aware of the economic value of water, has no incentive to conserve, and therefore cannot be expected to take responsibility for its protection or conservation. The concept of marginal or use cost may be appropriate for countries that depend on groundwater, especially from non-renewable sources. The true cost of water would reflect the future costs of subsidizing a new source such as desalination. However, political objections and constraints to increasing water charges are often seen as insurmountable.

Any meaningful increase in water charges would encourage economies in water use, for instance by encouraging farmers to invest in water-saving devices and technologies or to shift cropping patterns out of high water-using crops. Even satisfying cost recovery criteria would go some way to attaining demand management objectives. Moreover, the structure of charges can be designed to encourage water savings, besides reflecting differences in the level of service and/or equity objectives. Possibilities include decreasing or increasing block tariffs, seasonal or spatial differences, and contingent charges triggered by an external event such as a drought. Increasing block tariffs can provide for basic needs for the population at large and can be made compatible with opportunity cost principles at the margin, thus providing an important mechanism for reducing demand while satisfying social objectives. Other financial incentives can also encourage appropriate action by private interests and consumers. Subsidies or tax rebates can encourage investment in water quality treatment, financed either through the general budget or from levies on water users, and penalties can be imposed on those that do not meet quality standards or quantity restrictions.

The need to formulate and implement appropriate pricing policies constitute one of the major challenges to decision-makers throughout the region; a challenge which must be overcome in the context of political, social and economic circumstances, due to the sensitivity of attaching economic value to water. However, the implementation of efficient pricing policy requires modification of existing water laws and regulations, taking into account water market requirements and enforcement mechanisms.

5.5 *Institutional and legal aspects*

In most of the countries in the region there is a great deal of fragmentation of authority in the water sector due to the numerous agencies that deal with water resources, as well as lack of cooperation and coordination of activities. In general, however, governments have dominated both water development and the provision of water services even if private initiative has often been significant at the local level. Historically, most public water agencies were established to meet a specific need, generally focusing on a single use; thus a country may typically have ministries or departments dealing with irrigation, agriculture, fisheries and wildlife, transport, energy, environment, health and human resources, and so on, each involved with one aspect of water use. At the local level, current administrative aspects of water allocation and distribution, and organizational frameworks differ between countries, ranging from old traditional practices to complex regulations. In larger cities, municipality, water authorities or departments manage water for domestic and industrial use. In most towns and villages of the region, however, water is managed and administrated by government appointed administrators, especially for water and sewage services.

Delivery of water services in MENA countries has predominantly been undertaken by public agencies. However, emphasis on private participation has grown worldwide, and increased private sector involvement is warranted especially in the operation of water and sewerage utilities. Private firms depend for their survival on their reputation for performance; they assume legal liability for the consequences of any professional negligence; and, by definition, they are financially autonomous. These factors provide powerful incentives for supplying cost effective and high quality services. Such incentives are weak or non-existent in most public sector agencies, which usually feature nearly total employment security, promotion by seniority, and lack of accountability and appropriate sanctions in the case of poor performance. The direct consequences can include the construction of high cost, low quality facilities and the poor delivery of service. Indirect effects can include weak professional labor force. Privatization in the water supply and sanitation thus could have a major role in greatly improving efficiency. However, appropriate and effective safeguards must be in place to prevent private monopolies for abusing the public in terms of charges and reliability of service and quality. Privatization can be considered as away of shifting the heavy burden of future water supply costs from the public to the private sector. While privatization may be desirable in some circumstances, it is not always feasible. Switching public water utilities to the private sector requires the establishment of well-defined policies and legal and administrative regulations in order to control both the water supply and public demand. In many countries in the region, private administration and/or management may prove to be more appropriate than total privatization, and would be an initial step in the direction of total privatization in the future.

In contrast to the urban sector, there are few opportunities for private commercial involvement in provision of irrigation services, though there is a long history of schemes managed by farmers in the region (e.g. in Morocco and Yemen). The transfer of smaller public schemes to farmer management, and delegation of operation and maintenance responsibilities to water-user groups in larger schemes, both have considerable potential. Moreover in some countries (e.g. Morocco), it is possible to envisage the long-term transformation of autonomous public bodies into private entities managed by users along commercial lines in a manner comparable to the irrigation districts typically of many developed countries.

Enhancement of institutional arrangements can be achieved through defining legal responsibilities and granting power to water authority to exercise rights and implement their duties. In the context of drafting a modern water law, there is a need to address the issues of the type, legal power and jurisdiction of water institutions. The water code must define the function of the water authority with regard to water resources investigations, development, utilization, monitoring, protection, management, and provision of services. The law must grant provisions for these institutions to accord permits, licenses, concessions, or rights, and the power of enforcement for the purpose of extraction and use. These provisions may include supervision and the enforced distribution among users in accordance with legal rights. Water resources institutions should be empowered by the water law to act when emergency situations arise; they should be able to declare certain areas to be protected, restricted, and water rationed in regard to water development and management. The mandate may also include limitation of existing rights to use water, the imposition of limits on water withdrawal, and the prohibition of certain uses.

Institutional reform must be responsive to traditional norms and practices and, to the extent possible, should integrate these within new institutional structures. However, pressures of population and economic development have created unprecedented problems, and new regulatory and incentive practices are almost invariably required. Continued adoption of fragmented approaches would incur unacceptable costs. Coordinated approaches are thus universally essential even if details of reform programs must respond to the stage of development reached and the characteristics of the country concerned. In many countries, legislation has tended to evolve *ad hoc* although those influenced by the French legal tradition often adopt comprehensive water codes. With growing scarcity, *ad hoc* approaches become increasingly unsatisfactory, and coherent management of the resource needs to be supported by coherent legislation. Indeed "recognition of water resource planning in legislation is perhaps the single most significant mechanism for sound decision-making in the management of water resources in the long run" (Burchi 1989).

Review of the status of water legislation and institutional arrangement in the region reveals that most of the countries have enacted laws, which explicitly specify that water resources are public property, while others imply that water is either state or publicly owned. However, private ownership of water rights is being practiced in most of the countries by attaching it to the land ownership, or adding value to it by invested labor, or by selling it in containers, or through distribution infrastructures. Ownership of water rights in some cases is taking place through water sharing principles that are inherent in traditional customs with acknowledgement of a right of prior appropriation. Countries depend largely on surface water have enacted individual laws designed to regulate river flow diversion and to establish water quality standards for drinking purposes, and to some extent, pollution control, and guidelines for water allocation. On the other hand, countries that rely mostly on groundwater have mainly issued directive or separate laws aimed at regulating groundwater development and extraction through well drilling permits or licenses. However, as far as protection of groundwater is concerned, these directives and individual laws fall short of the needed comprehensive water code.

Integrated development and management of water resources in the region is contingent upon the development of an effective legislative framework and sound institutional directives to ensure that the formulated policies are implemented. Comprehensive water legislation needs to incorporate guidelines for the national utilization of water, including protection, water use priorities, water ownership, jurisdiction of authorities responsible for controlling utilization, pricing, issuance of permits and the resolution of conflicts. In addition, appropriate water legislation should provide mechanisms for ensuring the most equitable economic and sustainable use of available water resources, taking into consideration socio-economic conditions and the goals of national development. Most of the countries in the region have begun to realize the importance of comprehensive water legislation, and have consequently taken steps to update existing laws or are in the process of introducing new ones to cope with development activities and experienced problems. Lack of law enforcement, however, constitutes a major stumbling block. Enforcement of existing or planned water legislation has not received proper consideration. This can be attributed to the need to establish effective judicial water systems, organized and mandatory inspections, legislative enforcement of power delegated to concerned authorities, manpower, and financial resources. Existing institutions lack the legal authority to enter and inspect premises, and suspend or revoke permits, and the judiciary system lack the power to prosecute offenders. Obviously, a great deal still remains to be accomplished, particularly with regard to the regulation and monitoring of water use and pollution. The incorporation of these two important aspects into water legislation, together with effective enforcement mechanisms, will contribute significantly towards comprehensive and workable water resources development and management in the region.

5.6 *International issues*

Many water issues in MENA are international in nature. More than one third of MENA's renewable water resources come from outside the region, so MENA countries need water strategies that look beyond their borders. As water scarcity becomes more acute, regional perspectives and initiatives will become more important, and national, regional, and international partnerships will be key to successful regional water management. To harmonize policies and coordinate development approaches, such partnership will need to address joint planning of river basins and shared aquifer systems.

Formal treaties in principle can provide a mechanism for establishing water rights and making productive coordinated development possible. However, out of the 286 international water treaties world wide, only one major agreement is from the MENA region, that for the Nile. In the case of other systems notably the Tigris/Euphrates, the Jordan, and the Orontes, partial understandings between the riparian have played some role but there are few legally binding treaties. There are no significant agreements for shared aquifers and development of these resources by one or more riparian can therefore take place without regard to any impact on others. The lack of international treaties for the shared water resources in the region will be a significant constraint on optimizing the development and management of these resources. Besides questions of water rights and allocations, deterioration in surface and groundwater quality due to upstream diversions, depletions, and return flows will become an international issue of increasing concerns. This issue is highly affected by the prevailing relations in the region, as well as within adjacent regions. Mutual cooperation and coordination in managing the shared surface and groundwater basins would help to achieve sustainable development within the region.

5.7 *Human resources development*

Human resources development is essential for integrated water resources management, and the need for the development of manpower and promotion of capacity building in the water sector has been widely recognized at national, regional and international levels. In the MENA region, human resources capability in the public water sector varies considerably from country to country. Generally, water staff members are educated as engineers and openings for those with other required disciplines are severely limited with few opportunities for promotion. The level of staff capability and motivation varies but low salaries and benefits generally discourage adoption of modern technologies and management systems. Poor compensation frequently results in adverse effects on efficiency. In some countries, it is particularly difficult to get qualified staff posted to important planning, and research positions. As a result, consultants do much of the planning and many countries do not have sufficient qualified interdisciplinary staff even to review and comment on the work of consultants. Indeed, in some countries, governments may have surprisingly limited input into development plans that go forward for authorization, and then implementation.

There is a need to promote and strengthen training capacity at all levels throughout the region. Identification of training needs is an important phase of professional water resources development and management. Emphasis should be placed on formulating efficient training programs for new recruits as well as keeping existing professionals updated and informed on new techniques and management procedures. Department managers and staff responsible for projects should receive management training in addition to their technical background.

It is essential to recruit personnel in deficient areas of specialization such as water resources planning, policy, and strategy formulation, mathematical modeling, pollution, and water legislation, in order to maintain well balanced interdisciplinary staff. The existing educational infrastructure in hydrology and water resources in each country should be utilized for training courses, workshops, and degree programs in water resources planning and management. Thus, training and staff development should undoubtedly have high priority. However, they are unlikely to be fully effective if they are not associated with incentives that motivate staff to improve performance. This is an important issue that cannot be avoided. If incentives are inadequate to attract and maintain high-caliber interdisciplinary staff, MENA countries cannot be expected to overcome their complex water resource management problems.

Integrated water resources development and management calls for efforts to be devoted to research and development in all facets of the water field. There is a need to identify research priorities and apply the results of these studies through coordination between research bodies and government agencies. Encouraging research and development in each country, and technical cooperation between countries is an effective way of focusing on the problems being faced, and the need to find cost effective solutions. The provision of financial resources for field experiments and pilot projects is also an important element in the adoption of new technologies. In arid environments, efforts need to be focused on the improvement of assessment and monitoring methodologies, management techniques that are socially and economically acceptable, and implementation of various supply augmentation schemes including non-conventional water resources.

6 CONCLUDING REMARKS

The Middle East and North Africa (MENA) is a regional grouping of countries defined primarily by its history and culture, comprising that expanse of territory in which Asia, Africa, and Europe converge. The countries of the MENA region are home to about 6% of the world's population. Most MENA countries are experiencing rapid population growth, and the region's population has quadrupled over the past half century. Because of the extreme aridity of much of the region, the population is distributed very unevenly among countries and within them. It is the relative availability of water that determines population distribution and density. MENA's size and population alone make the region economically significant, and its vast human, financial and natural resources endowments enhance this significance. The region also possesses numerous fuel, non-fuel mineral, and non-mineral resources. However, countries vary substantially in resources, economic and geographical size, population, and standard of living. Of paramount importance to the region's sustainable development is preservation of its natural resource base. Agriculture and rural economy is still a significant activity in the region in terms of the number of people it employs, and in some countries it still provides a substantial part of the gross domestic product.

Annual renewable water resources in MENA region average about 590,000 Mm^3. This is equivalent to some 1.4% of the world's annual renewable water resources. Water withdrawals in several countries already exceed renewable supplies; others appear to be essentially at the limit or soon will be. The current *per capita* availability has fallen below the line of absolute water scarcity of 500 m^3/yr in 50% of MENA countries. Furthermore, by the year 2025, over 80% of the countries would have crossed the water poverty threshold of less than 1,000 m^3/yr. It is evident that water scarcity will remain the dominant state in the MENA region. Declining water quality caused by contamination from fertilizers and pesticides, dumping of municipal and industrial wastewater into water bodies, solid waste deposits along riverbanks, uncontrolled seepage from unsanitary landfills, and saline intrusion into aquifer systems, is affecting the productivity of resources, public health, and the quality of life. Accordingly, water shortages in the MENA region are compounded by water quality degradation and pollution.

Groundwater in the MENA region is found in numerous aquifer systems; with storage and yield characteristics depending on the areal extent and the hydrologic and hydrogeologic properties of the system. Because of the similarity in the geologic history of the region, the same rock unit would often form a producing aquifer in two or more countries of the region. Some hydrogeological units in the region are also vertically interconnected. That is why many of the major aquifers in the region are shared between two or more countries. The majority of MENA countries, with little or no surface water resources, depend significantly on groundwater to meet the growing water demands. At present, the contribution of groundwater to the total demand in the region amounts to about 41%, and groundwater abstractions are currently the main source of water in 54% of MENA countries (where the ratio of the contribution of groundwater withdrawals to the total demand range from 50% to more than 90%). The present levels of groundwater abstraction have exceeded the annual groundwater recharge in 50% of MENA countries (withdrawal in relation to recharge ranged from twofold to sevenfold).

Thus, the scarcity and high water stresses are met with varying degrees of groundwater depletion and considerable groundwater mining is taking place in the region. Such process is likely to exacerbate with time. This clearly manifested by significant examples of intensive groundwater use in the region. Bahrain is facing a serious water crisis, and the major limiting factor in the future availability of freshwater supplies is the increasing contamination by saline water, due to excessive withdrawal from the Dammam aquifer system. Expanding the cultivated land in and around the Oases in the Western Desert of Egypt resulted in a marked decline in the groundwater head and substantial reduction of the naturally flowing wells. The project could not survive unless pumping is used to supply the extra water needed for irrigation. The ever-increasing pumping costs are undermining the economic viability of the existing as well as the projected irrigation schemes. The shallow coastal aquifer underlying Gaza Strip is heavily over-pumped and polluted by saline intrusion. Over-exploitation of the coastal aquifers in Libya has resulted in continuous water table decline accompanied by an overall deterioration in water quality and seawater intrusion along the coast. Accordingly, Libya launched the *Great Man-made River Project*, transferring over 6 Mm^3/d from the fossil groundwater, for agricultural and urban developments, along with the restoration of the affected coastal aquifers. In Qatar, with the present rate of aquifer storage depletion, hydrogeological studies have estimated that the aquifer storage will be fully depleted by the year 2025. Agricultural development has caused a depletion of about 35% of the non-renewable groundwater resources in Saudi Arabia. Current abstractions from the *wadi* aquifers in Yemen far exceed the renewable recharge. This significant overdraft makes the aquifer highly unsustainable for future developments. In Tunisia, over-exploitation of the shallow coastal aquifers induced seawater intrusion and forced farmers to deepen their wells and change the pumping equipment. Thus, groundwater resources throughout the region are over-exploited. Such over-exploitation risks further damage to groundwater reserves through saline intrusion and leaking pollutants. The urgent need for planning and management of water resources in the region is obvious.

Water resource problems in MENA are among the most urgent, complex, and intractable of any region in the world. MENA's dwindling water resources are threatening the region's economic growth. The critical situation calls for immediate actions by governments and water users. The fragmented supply oriented approach to water development must give way to integrated water resources management. Challenges and opportunities for integrated water resources management include modification of the current planning practices to account for the adoption of a comprehensive policy framework and treatment of water as an economic good, combined with decentralized management and delivery structures. Improved management of existing supplies can often be a partial alternative to investment in new supply. Management of natural groundwater recharge and enhancement of magnitude by artificial means is one important method of increasing water supply availability in the region. Reallocation between uses is a key mechanism for adjusting to water constrains. Ultimately, as renewable freshwater approaches full exploitation, non-conventional sources may become the only sources of new supply. Demand management can take many forms, from direct measures to control water use, to indirect measures that affect voluntary behavior. The need to formulate and implement appropriate pricing policies constitute one of the major challenges to decision-makers throughout the region. However, the implementation of efficient pricing policy requires modification of existing water laws and regulations, taking into account water market requirements and enforcement mechanisms. Integrated development and management of water resources in the region is contingent upon the development of an effective legislative framework and sound institutional directives to ensure that the formulated policies are implemented. Institutional reform must be responsive to traditional norms and practices and, to the extent possible, should integrate these within new institutional structures. Water legislation, together with effective enforcement mechanisms, will contribute significantly towards comprehensive and workable water resources development and management in the region. National, regional, and international partnerships will be key to successful regional water management. To harmonize policies and coordinate development approaches, such partnership will need to address joint planning of river basins and shared aquifer systems. Integrated management of water resources calls for human resources development, and research and development in all aspects of the water field.

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