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Water Resources in the GCC Countries: An Overview

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Abstract. One of the critical problems that hinders the sustainable development in the Gulf Cooperation Council (GCC) countries is the lack of renewable water resources. Rainfall in the Arabian Peninsula is scarce and infrequent. Over-exploitation of fossil groundwater resources, mostly to meet the irrigation demands and create greenery lands, has already affected the aquifer's productivity both quantitatively and qualitatively. A great portion of the freshwater demands in the GCC countries is covered by desalinated water. Recently, after the Gulf war and uncertainty of oil prices, the expansion in the construction of desalination plants may not be economically feasible. This article investigates the water availability and assesses the water demands in the GCC countries. It emphasizes the need for the adaptation of an efficient and integrated policy for water utilization and application of relevant conservation techniques in various water consumption sectors. Water of higher quality should be preserved for drinking purposes and should not be utilized for other purposes that may tolerate water of lower quality. Recycling of water and artificial recharge of groundwater by surface water and treated wastewater should be adapted at a larger scale.

Key words: assessment, demands, Gulf Cooperation Council, management, prediction, water resources.

1. Introduction

In arid regions, where drought conditions prevail, water is ultimately precious. The issue of water shortage is likely to approach the crisis level in the arid countries where surface water resources are mostly absent and groundwater resources are often nonrenewable. The scarcity of fresh water around the world is becoming more pronounced due to the tremendous increase in the population over the last few decades. The renewable water resources remained constant, if not decreasing as a result of the widely reported decrease in the annual rainfall. The quality of the available water is, on the other hand, deteriorating. The Gulf Cooperation Council, GCC, countries experience a severe water shortage problem, that threatens the sustainable development and hinders the national plans for human, industrial and agricultural development.

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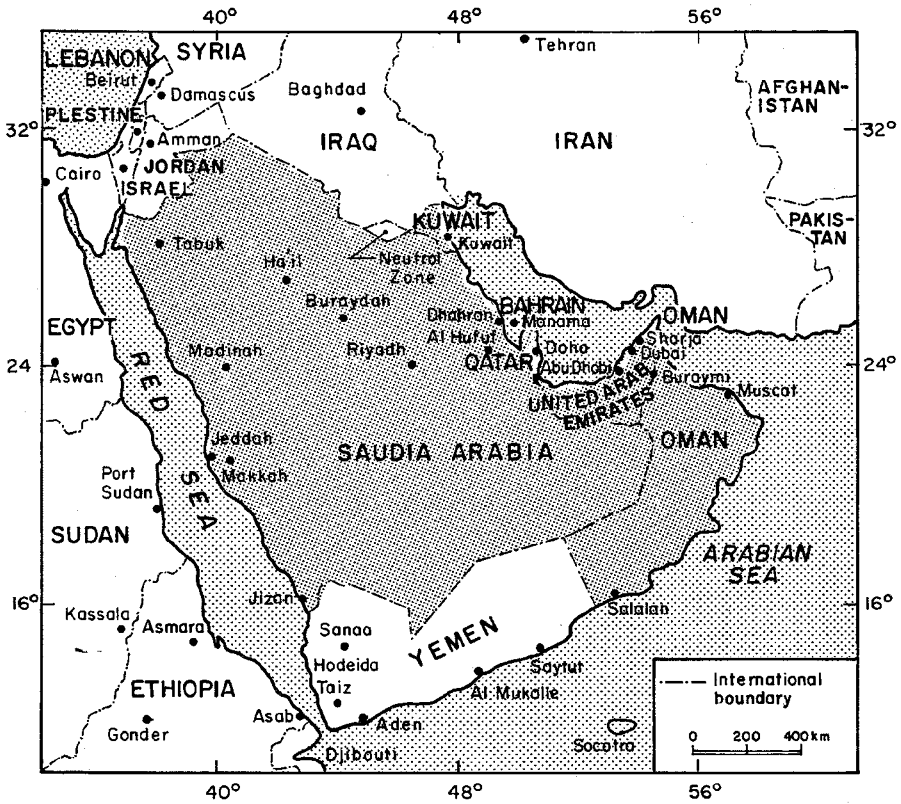

Figure 1. Geographical location of the GCC countries.

The territories of the member states of GCC countries (Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, and the United Arab Emirates) occupy most of the Arabian Peninsula; an area of huge reserves of crude oil and gas. Figure 1 presents the geographical location of the GCC countries in the Arabian Peninsula. Oil production constitutes the cornerstone for the economic strength of this region. The living standard in the GCC countries is relatively high.

The rapid development in the agricultural and industrial activities in the GCC countries has imposed additional stresses on the water demand. Vast green areas have been developed over the last few years. Private gardens are heavily irrigated to encounter the harsh climate. In many cases, such as in the cities of Kuwait and Arriyadh, over irrigation practices of private gardens and leakage from distribution networks have led to a groundwater rise problem in the residential areas. Various water distribution arrangements and charging policies are currently under study to minimize the leakage and waste and ensure the conservation of the water resources. More emphasis has been recently devoted to water reuse and recycling either directly to develop green lands or indirectly to recharge the depleting aquifers. Concerned ministries, organizations and research institutes devote considerable efforts to bridge the gap between water demands and water availability.

This article assesses the renewable and nonrenewable water potentialities and defines the water demands in the GCC countries. It highlights the need to adapt an integrated water strategy encompassing the six GCC countries. The GCC countries share the same groundwater basins and face similar kinds of water shortage problems. This situation addresses the need for more integration and cooperation in the field of water resources among the Arabian Gulf countries. Efficient and integrated water policies and conservation techniques, along with wastewater recycling and artificial recharge of groundwater, should be employed at a larger scale.

2. Physical Setting

The GCC countries share the same climatic conditions, marked by scarce and infrequent rainfall and long summer with high temperatures. The average annual rainfall in the GCC countries varies between 70 and 140 mm. The geomorphology is typical in the desert surroundings. Different topographical features, that reveal the availability of surface water resources, are encountered at the Oman Mountains to the east and Asir Mountains to the southwest of Saudi Arabia. The precipitation is noticeably higher at these two specific areas, reaching about 500 mm yr^{-1}, which causes occasional runoff. The surface water runoff from the western slopes of the Oman Mountains benefits areas in Oman and the United Arab Emirates (De Jong, 1989).

The total area of the GCC countries is 2 557 470 km^2, while the total population is estimated at about 20.2 million. Saudi Arabia occupies about 85% of this area, Figure 1, with a population of about 14 million. Bahrain is the smallest in area with a population of about 0.55 million. It is an archipelago composed of 36 islands with a total area of 695 km^2. The population intensity in Bahrain (800 inhabitants km^{-2}) is relatively high, compared to other GCC countries. Kuwait and Oman have approximately the same population (1.5 and 1.65 million, respectively), while the area of Oman (300 000 km^2) is almost 17 times the area of Kuwait (17 818 km^2). The population of Qatar is 0.7 million and it occupies an area of 11 610 km^2. The United Arab Emirates have a population of about 1.8 million and occupy an area of 77 700 km^2.

3. Water Resources Availability

Water resources in the GCC countries are generally scarce due to the low average annual rainfall and high evaporation. Groundwater is encountered in shallow and deep aquifers with various potentialities. Desalination plants are established to substitute for water deficiency. Reuse of treated wastewater is practiced at a limited scale. An assessment for water resources potentiality in the GCC countries is given hereafter.

3.1. SURFACE WATER

Perennial rivers and lakes do not exist in any of the GCC countries. Surface water resources are scarce to absent with the exception of the mountainous areas in southwestern part of Saudi Arabia, southern part of United Arab Emirates and northern and southern parts of Oman. The average annual volume of rainwater in the GCC countries is estimated at 205.93 billion m^3 (ACSAD, 1997). Saudi Arabi and Oman hold the highest share of 158.47 and 37.60 billion m^3, respectively. UAE and Kuwait receive 6.72 and 2.27 billion m^3 of annual rainwater, respectively. Qatar and Bahrain receive very nominal quantities of rainwater. The evaporation rate in the GCC countries varies between 2.5 mm day^{-1} in December and January to about 17 mm day^{-1} in July and August. The annual evaporation varies between 2500 mm yr^{-1} in the coastal areas to about 4500 mm in the central parts of the desert of Saudi Arabia.

Because of the flat nature of most of the lands of GCC countries along with the high evaporation rate, it is difficult to directly harvest and utilize the surface water runoff. Limited amounts of this water recharge the groundwater resources. The total surface runoff generated from rainfall is estimated as 4.83 billion m^3 yr^{-1}, of which 3.21 and 1.47 billion m^3 yr^{-1} are generated in Saudi Arabia and Oman, respectively (Khouri and Deroubi, 1990; Al-Zubari, 1997). About 0.15 billion m^3 yr^{-1} of surface runoff are generated within the territory of the UAE. The total amount of surface runoff in Kuwait, Bahrain and Qatar is less than 2 million m^3 yr^{-1} (Abdulrazzak, 1995). Limited amounts (less than 20%) of surface water runoff are utilized either directly for irrigation purposes or indirectly to recharge the aquifers.

Some of the rainfall events develop flash floods as they are of heavy intensity and short duration. Rainfall events are of random frequency. Vast areas in the region may not receive any rainfall for several successive years. However, when encountered, rainfall produces large volumes of surface runoff in a relatively short period of time, which may cause serious damage to life and properties. Examples of such severe rainfall include the two events encountered on 2 and 11 November, 1997 at the Kuwait City in which 72 and 105 mm, respectively, were received in few hours. As a result of these two rainfall events, groundwater levels in many areas in Kuwait rose by about 1.1 m (El-Nahhas *et al.*, 1998). During the winter season (November 1997 – March 1998), the Kuwait City received a total rainfall of 290.2 mm. The average rainfall, in 1997/1998 season, throughout Kuwait was estimated at 210 mm. Most of the events were of short duration. According to the available historical data, Kuwait has not witnessed such heavy rainfall events over the last 50 yr.

Contrary to the 1997/1998 season, the 1998/1999 winter season was relatively dry. Groundwater levels were not affected by any of the rainfall events of 1998/1999.

In recognition of the importance of increasing the recharge of groundwater reservoirs in the Arabian Gulf region, water-harvesting schemes were constructed.

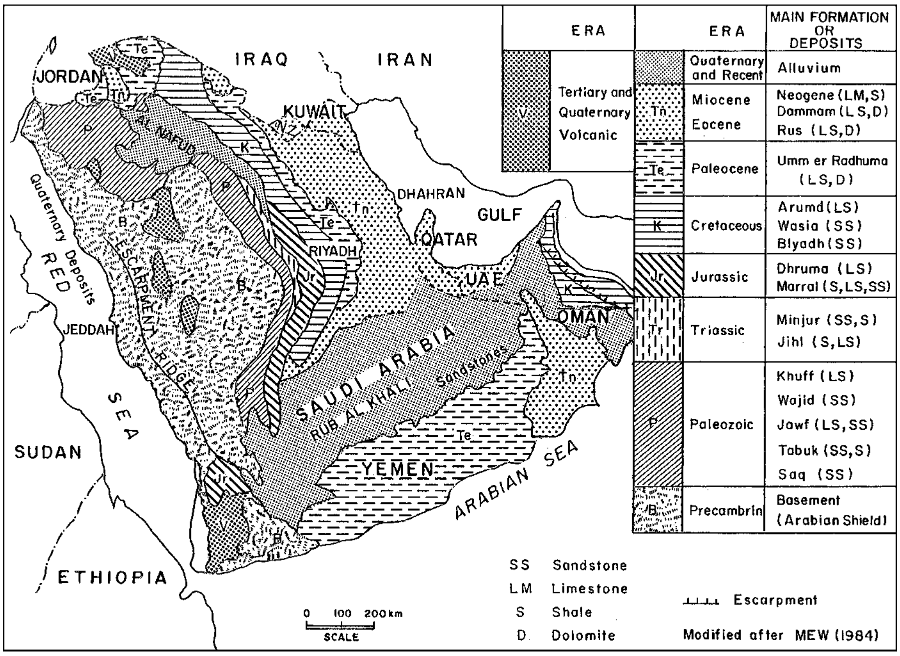

Figure 2. Generalized geological map of the Arabian Peninsula (source: Al-Sayari and Zotl, 1978).

A total of 186 retention and detention dams of different sizes were built in Saudi Arabia (65 earthfill dams, 37 rockfill dams and 84 concrete dams) with a combined storage capacity of 0.775 billion m^3. In Oman, 13 dams were constructed along with several recharge schemes, while six dams were built in the United Arab Emirates for protection and recharge purposes. Qatar implemented a national project through which 341 recharge wells scattered in depression zones all over Qatar were drilled and completed in 1995. Qutib (1998) concluded that the groundwater recharge in Qatar was, therefore, enhanced and reached 155 million m^3 yr^{-1} after the completion of the project.

3.2. GROUNDWATER

Groundwater resources in the GCC countries can be classified into renewable resources, which are mostly encountered in shallow alluvial aquifers, and non-renewable resources (or fossil water) which are encountered in the deep aquifers. The potentiality of the shallow aquifers is relatively small. It depends on the rainfall events and surface runoff, and thus may vary considerably from one year to the other. The dependable groundwater reserves are those encountered in the thick extensive sequences of sedimentary formations of the Arabian Shelf underlying two-third of the Peninsula (Figure 2).

Four main tectonic units are encountered in the GCC countries (Mukhopadhyay *et al*., 1996). The Precambrian Shield of western Saudi Arabia mainly composes of igneous and metamorphic rocks. The Stable Shelf covers eastern Saudi Arabia, United Arab Emirates, Qatar, Bahrain, and Kuwait. The Unstable Self covers a small area northeast of Kuwait. The Tethyan Geosyncline occupies the Oman Mountain belt.

A comprehensive investigation at the regional scale of the Arabian Peninsula was conducted by FAO (1979). Two main aquifer systems in the post-Jurassic sediments were identified: System A and System B. System A, Figure 3, is the main aquifer in which recharge occurs in Saudi Arabia from rainfall and Wadi flows. In this system the recharged water flows to the north, northwest and east following the regional dip and eventually discharges to the Arabian Gulf. System B is a collection of discontinuous freshwater lenses occurring in different locations in the GCC countries. Two geological sections in the Arabian Peninsula are given in Figure 3. System A was further divided into three main units as follows (FAO, 1979):

(a) Upper Aquifer: including those aquifers over-laying the Rus Formation.
(b) Middle Aquifer: encompassing the Rus Formation, Umm Er Radhuma Formation and the Upper permeable part of the Aruma Group.
(c) Lower Aquifer: including the Wasia-Biyadh complex.

The thickness of the alluvial deposits varies from about 20 to 200 m with the exception of the aquifer in the coastal area of Oman where it reaches about 400 m. The width of these alluvial deposits varies from few hundred meters to several kilometers. The quality of water in the alluvial aquifers is generally good with total dissolved solids between 250 and 4000 ppm. Seawater intrusion is encountered along the coastline of the Arabian Gulf due to intensive development activities and groundwater exploitation in the coastal areas. The total reserve in the alluvial deposits is estimated at 115.5 billion m^3, of which 84 billion m^3 are encountered in the largest single alluvial reservoir of Saudi Arabia (Khouri *et al*., 1986; Ukayli and Husain, 1988; Abdulrazzak, 1993).

Fossil groundwater in the deep sedimentary formations, known as the Arabian Shelf, that covers about two-thirds of the Arabian Peninsula, is the main source of water in the GCC countries. Currently, irrigation practices depend mainly on these nonrenewable resources. However, it should be recognized that relying on fossil water provides a short-term solution for the water shortage problem. The sedimentary formations compose of sandstone, limestone and dolomite and overlay basement rock formations known as the Arabian Shield. The Arabian Shield covers one-third of the Peninsula (Abdulrazzak, 1994). More than 20 formations are classified as either major or secondary aquifers (Authman, 1983; BAAC, 1980; MAW, 1984). Table I lists the reserves in the main and secondary deep aquifers, their annual recharge and water quality.

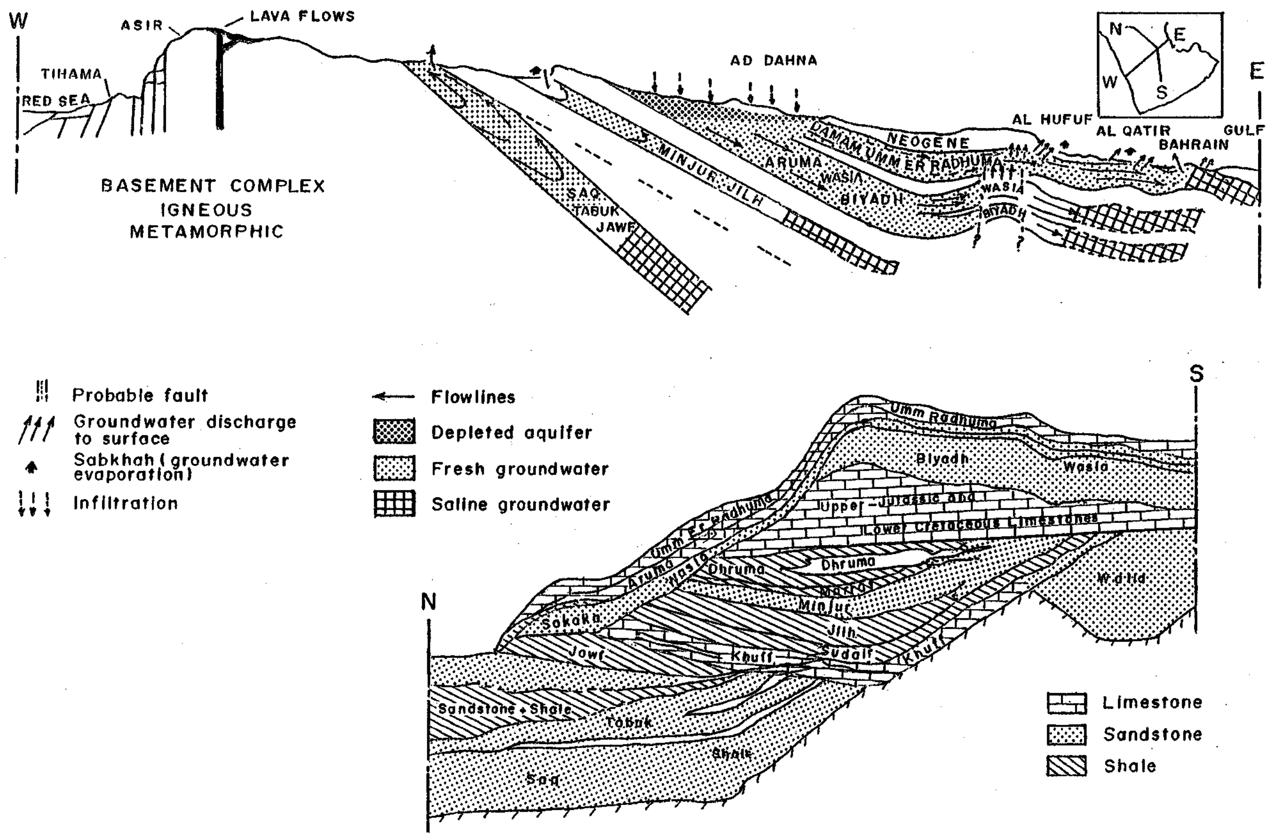

Figure 3. Two geological cross sections in the Arabian Peninsula (Al-Alawi and Abdulrazzak, 1994).

Table I. Groundwater reserves in the deep aquifers, estimated annual recharge and total dissolved solids

Aquifer name	Total reserve (mcm)	Annual recharge (mcm)	Total dissolved solids (mg L^{-1})
Main aquifers			
Saq	277 000	310	300–1500
Tabuk	205 000	455	200–3500
Wajid	255 000	104	500–1200
Minjur-Dhruma	182 000	80	1100–20000
Wasia-Biyadh	740 000	480	900–10000
Um Er Radhuma	188 000	406	2500–15000
Dammam	25 000	200	2600–60000
Neogene	130 000	290	3700–4000
Secondary aquifers			
Khuff and Tuwail	30 000	132	3800–6000
Aruma	85 000	80	1600–2000
Jauf and Sakaka	100 000	95	400–5000
Jilh	113 000	60	3800–5000
Total	**2 330 000**	**2692**	

Source: MAW, 1984; Khouri *et al*., 1986; Edgell, 1987; De Jong, 1989; Lloyd and Rim, 1990; Danish *et al*., 1992; Abdulrazzak, 1994, 1995.

Groundwater reserves in the deep aquifers of the Arabian Shelf are estimated at 2330 billion m^3, while the average annual recharge rate is estimated at 2.7 billion m^3 (Table I). Over 30% (740 billion m^3) of groundwater reserves is encountered in the Wasia-Biyahd aquifer. The groundwater reserves, in this context, are estimated as the volume of pumped water when the water levels or piezometric heads are lowered to a level of 300 m below the land surface.

The total volume of groundwater extracted from the deep aquifers in the area over the last two decades is estimated around 300 billion m^3, of which 254.5 billion m^3 were pumped from Saudi Arabia alone to satisfy the needs for the expansion in the agriculture sector. The recharge of the deep aquifers during the last two decades was limited to 54.0 billion m^3. About 76% of the total groundwater recharge in the GCC countries is encountered in Saudi Arabia, while 15% is encountered in Oman.

In the central and northern parts of the Arabian Peninsula sandstone aquifers dominate, while carbonate aquifers prevail in the eastern part of the peninsula. The quality of the groundwater varies considerably from one aquifer to another and is generally better in the sandstone aquifers, with specific reference to the central

Table II. Capacities and productions of desalination stations of the GCC countries

Country	No. of plants	Capacity (million m^3 yr^{-1})	Production (million m^3 yr^{-1})
Bahrain	3	72	59
Kuwait	6	388	331
Oman	2	39.1	32
Qatar	2	425	110
Saudi Arabia	23	874	795
United Arab Emirates	8	–	342
Total	**44**	**>2140**	**1669**

part of Saudi Arabia. The Saq and Wajid aquifers in Saudi Arabia have the best water quality (of TDS less than 1500 ppm) as compared to the other deep aquifers in the area (Table I). The quality of water in the carbonate aquifer is ranked fair to poor where the salinity may reach 15 000 ppm in the eastern part toward the Arabian Gulf. Isotope dating indicated that the water in the sedimentary aquifers of the Arabian Shelf is 15–35 thousand years old (Abdulrazzak, 1994).

3.3. DESALINATED WATER

Due to the severe shortage in freshwater resources and despite the higher cost of the desalinated water, as compared to other conventional water resources, the GCC countries have constructed a large number of desalination plants, since the early seventies. These facilities were constructed to bridge the gap between fresh water availability and drinking water demands. These desalination facilities consume huge amounts of fossil energy; mostly natural gas, and release enormous quantities of CO_2. The release of CO_2 has some adverse impacts on the environment that might lead to an increase in the average temperature and a decrease in the precipitation quantities. Desalinated water is mixed with small amounts of groundwater to achieve the required TDS level.

Desalination production in the GCC countries ranges between 78 and 88% of the designated plant capacity. The combined capacities of all desalination plants in the GCC countries reached 2.14 billion m^3 in 1997. While the total volume of produced desalinated water during the same year reached about 1.7 billion m^3.

Saudi Arabia alone produces around 0.795 billion m^3 yr^{-1}, while Kuwait produces 0.331 billion m^3 yr^{-1} (MEW, 1998). By the year 2000 and 2010 Saudi Arabia will produce 0.91 and 1.1 billion m^3 yr^{-1} (Sahlawi, 1999). In combination, Saudi Arabia, United Arab Emirates and Kuwait produce about 1.5 billion m^3 yr^{-1}; about one third of the total world water production from desalination plants. The production of Qatar has reached 0.11 billion m^3 yr^{-1} from desalination plants in 1997. The total capacity of the installed plants in Qatar is 0.149 billion m^3 yr^{-1} (Acer, 1997). According to the records of the Ministry of Electricity and Water in Bahrain, 61.35 and 58.93 million m^3 of desalinated water were produced in 1992 and 1997, respectively. The reduction in the production rate of the desalinated water is attributed to the increase of groundwater pumping from 43.32 to 53.94 million m^3 yr^{-1} during the same period. By the year 2001 and 2004, the capacities of desalination plants in Bahrain will reach 114.81 and 164.59 million m^3, respectively (Abd Al-Ghafar, 1999). The current capacities and productions of desalination stations of the GCC countries are given in Table II.

3.4. WASTEWATER

Large and small treatment plants were constructed in the GCC countries for wastewater treatment at the tertiary and secondary level (Al-Saati, 1995; Al-Muzaini and Ismail, 1994; Al-Hajj, 1995; Al-Zubari, 1997). The total capacity of the treatment plants at Bahrain is 58 million m^3 yr^{-1}. Currently, 56 million m^3 yr^{-1} of wastewater are treated at the tertiary level, of which 11 million m^3 yr^{-1} are used for gardening and highway landscaping. The capacity of the tertiary treatment plants in Kuwait is estimated at 130 million m^3 yr^{-1}. About 91 million m^3 yr^{-1} are currently treated, of which 48 million m^3 yr^{-1} are utilized in developing greenery lands, irrigation of coastal areas, and Kuwait zoo. Oman and Qatar utilize much of their tertiary treated wastewater. Treated wastewater in Oman is estimated at 7.5 million m^3 yr^{-1}, most of which (6.4 million m^3 yr^{-1}) is utilized to irrigate landscapes, parks, and recreational activities. Qatar develops 32 million m^3 yr^{-1} of wastewater (Al-Sulaiti, 1999) and utilizes 25 million m^3 yr^{-1}. Due to its relatively larger population, Saudi Arabia produces 0.483 billion m^3 yr^{-1} of wastewater (Hussain and Al-Saati, 1999), of which 0.418 billion m^3 yr^{-1} are treated using the secondary treatment or better (Al-Turbak, 1999). The UAE develop 106 million m^3 yr^{-1} of wastewater and use 63 million m^3 yr^{-1} to irrigate golf courses, parks, and highways.

As many rural areas in the GCC countries are not connected to sewerage systems, the wastewater that is currently available for treatment constitutes about 25% only of domestic and industrial demands. The total volume of developed wastewater in the GCC countries is estimated as 0.82 billion m^3 yr^{-1}, while the current production volume of treated wastewater is estimated at 0.74 billion m^3 yr^{-1}. The annual recycled volume of the treated wastewater is 0.254 billion m^3; about one-third of the available wastewater. The remaining water (0.486 billion m^3 yr^{-1}) is spilled into the sea. The recycled water is mostly used in developing greenery areas, road ornamentals, and highways landscaping. Several treatment plants are currently under construction in the different GCC countries. By the year 2000 and 2010, the availability of the reclaimed water will reach 1.161 and 1.57 billion m^3 yr^{-1}, respectively.

Table III. Water consumption of various sectors (mcm) in the GCC countries in 1990

Country	Domestic	Industry	Agriculture	**Total**
Bahrain	86	17	113	**216**
Kuwait	295	8	80	**383**
Oman	81	5	1150	**1236**
Qatar	76	9	109	**194**
Saudi Arabia	1508	192	14600	**16300**
United Arab Emirates	513	27	950	**1490**
Total	**2559**	**258**	**17002**	**19819**

Source: Al Mahmoud, 1992; Bushnak, 1990; Uqba, 1992; El-Zawahry and Ibrahim, 1992.

All the GCC countries have prepared ambitious plans for full utilization of the products of their wastewater plants. However, The wastewater will not be used directly for irrigation of crops and food products. For example, in Kuwait the second and third stages of the greenery plan will consume almost all the available treated wastewater by the year 2001. Similar strategies for wastewater utilization exist in the other GCC countries. A pilot project for groundwater recharge by wastewater through surface basins and injection wells was initiated in 1998 (Viswanathan and Al-Otaibi, 1999).

4. Projected Water Demands for the Years 2000 and 2010

The GCC countries have witnessed a remarkable increase in their water demand during the last two decades that is not consistent with the increase in the population during the same period. The population increased by less than two folds during the last two decades, while the water consumption has increased by over four folds during the same period. This increase in water consumption is attributed to the wide expansion in agriculture practices and developing of greenery lands. On the other hands the living standards have been raised considerably during this period. Most of the GCC countries have experienced a 20 to 30% annual increase in the domestic and industrial water demands over the last 10 yr. Substantial increase in the agricultural requirements was also encountered particularly in Saudi Arabia.

Despite the lack of potable water, the per capita consumption is quite high (over 700 L day^{-1} in the UAE, and over 400 L day^{-1} in Kuwait and Qatar). Domestic and industrial demands are generally met through desalination water. Agricultural requirements, which constitute about 88% of the total water consumption in the GCC countries, are met mostly by groundwater. The total water consumption in the GCC countries in 1990 reached 19.819 billion m^3. Of which, 17.0 billion m^3 were devoted for the agricultural practices and 2.817 billion m^3 were utilized

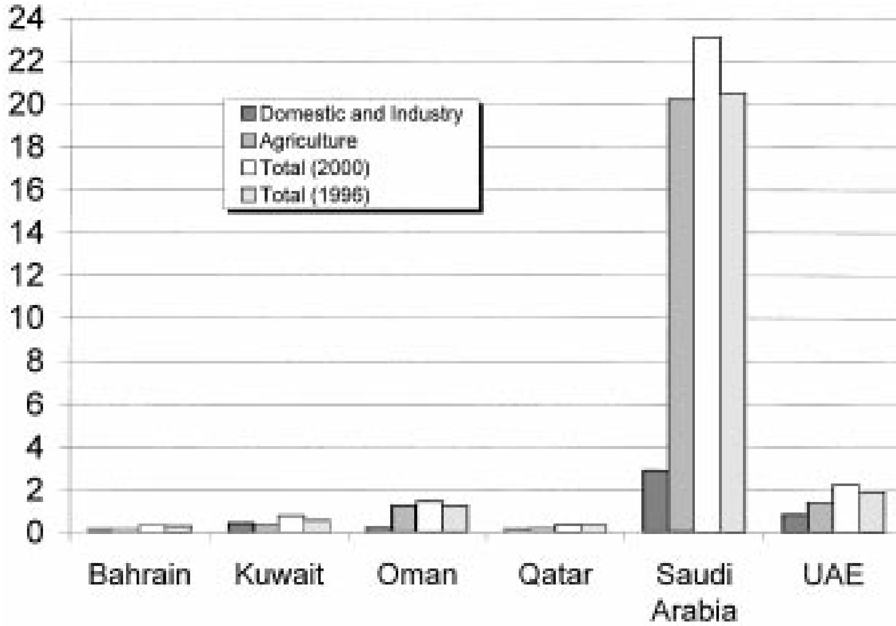

Figure 4. Predicted water demands in the GCC countries for the year 2000.

by domestic and industrial sectors. The distribution of water consumption among different sectors in the GCC countries in 1990 is given in Table III.

The domestic and industrial demands in Saudi Arabia are expected to reach 2.9 billion m^3 by the year 2000, while the agricultural demand is expected to reach 20.2 billion m^3 bringing the total demand to 23.1 billion m^3 (Abdurazaak, 1995). In Kuwait, the demands for domestic and industrial sectors for the year 2000 are projected as 0.41 billion m^3. For the agricultural sector the demand is estimated as 0.35 billion m^3, which will be covered mostly by groundwater and treated wastewater (MEW, 1998). The total water demand in Qatar by the same year is expected to be 0.325 billion m^3 distributed as 0.14 and 0.185 billion m^3 for the domestic and agricultural sectors, respectively (Al-Mahmoud, 1992).

Because of its small territory and limited number of population, the water demand in Bahrain is relatively small. This is attributed to the implementation of conservation measures in the domestic sector along with the limited land available for agriculture practices. The total water demand as projected for the year 2000 is 0.3 billion m^3 with a domestic and industrial share of about 0.155 billion m^3. In recognition of its agricultural practices, water demand in the United Arab Emirates is relatively high. By the year 2000, the domestic and industrial demands in the United Arab Emirates are expected to sum 0.83 billion m^3, while 1.4 billion m^3 will be required for irrigation. The water demands in Oman are satisfied mainly through shallow alluvial aquifers along with spring discharges, flood water, and desalination plants. Traditional drainage gallery systems (Aflaj) provide 50 and

Table IV. Projected population and water demands in the GCC countries

Country	Population (millions)		Domestic and industrial (mcm)		Agriculture (mcm)		Total demand (mcm)	
	2000	2010	2000	2010	2000	2010	2000	2010
Bahrain	0.654	0.981	155	180	145	150	**300**	**330**
Kuwait	1.511	1.710	410	550	350	400	**760**	**950**
Oman	1.826	2.262	200	270	1250	1417	**1450**	**1687**
Qatar	0.700	0.725	140	184	185	204	**325**	**388**
Saudi Arabia	15.553	19.315	2900	3600	20211	21700	**23111**	**25300**
UAE	1.922	2.104	832	911	1400	1545	**2232**	**2456**
Total	**22.166**	**27.097**	**4637**	**5695**	**23541**	**25416**	**28178**	**31111**

Revised after Al Alawi and Abdulrazzak (1994).

70% of the irrigation and domestic requirements, respectively (El-Zawahry and Ibrahim, 1992). The water demands for domestic and agricultural sectors for the year 2000 are expected to reach 0.2 and 1.25 billion m^3, respectively. The projected population and water demands in the GCC countries for the years 2000 and 2010 are given in Table IV. Figure 4 presents the predicted water consumption in the GCC countries for the year 2000 versus the total actual demands in 1996. Agricultural demands are assumed to increase by 10% (Al Alawi and Abdulrazzak, 1994). The total water demand for the year 2000 in the GCC countries is estimated at 28.178 billion m^3, while the same is projected for the year 2010 as 31.111 billion m^3.

Pumping of fossil groundwater is mainly practiced in Saudi Arabia to meet the agricultural demands. The expansion in agricultural activities along with the type of crops to be cultivated is currently under review by the authorities in Saudi Arabia to minimize the pumping and reduce the depletion of the groundwater resources.

5. Future Assessment and Management

The renewable water resources in the GCC countries are confined to the small amounts of surface runoff and the limited recharge to the shallow and deep aquifers. The average annual surface runoff generated from rainfall is estimated at 4.83 billion m^3. Annual recharge to the shallow aquifers is estimated at 1.3 billion m^3, of which 0.9 billion m^3 recharge the shallow aquifers in Saudi Arabia and 0.25 billion m^3 recharge the shallow aquifers in Oman annually (Abu Rizaiza and Allam, 1989). The annual recharge of the deep aquifers is estimated at 2.7 billion m^3, Table I. The total renewable water resources in the GCC countries is therefore estimated at 8.83 billion m^3.

The bottom line below which a country is considered poor with respect to water availability is 1000 $m^3\ yr^{-1}$ per capita (Shiklomanov, 1990). The annual per capita share of renewable water resources in the GCC countries is 435 m^3. In comparison with other countries, this figure is 200×10^3 in Canada, 5.9×10^3 in the United States. At the global scale, the per capita share of world's water resources is $7.4 \times 10^3\ m^3\ yr^{-1}$. At the scale of the Arab countries this figure drops to $1.2 \times 10^3\ m^3\ yr^{-1}$; 2.75 times the per capita share of the renewable water resources in the GCC countries.

Currently, the GCC countries produce around 1.67 billion $m^3\ yr^{-1}$ of freshwater from desalination plants and recycle 0.254 billion $m^3\ yr^{-1}$ of wastewater mostly in developing green areas. Hence, renewable water, desalinated and recycled water in the GCC countries currently sum 10.754 billion $m^3\ yr^{-1}$. By the year 2000, this amount is estimated at 11.2 billion $m^3\ yr^{-1}$, while the total demands will be 28.178 billion $m^3\ yr^{-1}$, as given in Table IV. The difference between the demands and availability, which amounts to about 17.0 billion $m^3\ yr^{-1}$ will be supplemented from the fossil groundwater. By the year 2010 and with the anticipated increase in the production of desalinated and recycled waters, 19.5 billion of fossil groundwater will be pumped to bridge the gap between water demands and water availability in the GCC countries. Groundwater levels will therefore decline and its quality will deteriorate under the continuous pumping from the fossil water. Saudi Arabia alone pumps over 85% of the fossil groundwater that is pumped in the GCC countries.

Groundwater systems in the GCC countries are hydrogeologically connected. Over pumping from one area may affect the productivity of the aquifers in other areas. Groundwater pumping should, therefore, be practiced within a framework of an integrated groundwater policy in the region. Every country may, however, adopt its own policy for expansion in desalination plants, wastewater treatment and utilization facilities, and surface water harvesting. Artificial recharge of groundwater should be practiced whenever possible.

Conservation techniques should therefore be enforced in the various water consumption sectors with specific reference to the agriculture sector. Domestic and industrial sectors consume about 15% of the total water consumption in the GCC countries. Agriculture should be practiced using the drip or sprinkler systems. Cultivation of crops of high water demands may not be economically feasible in the Arabian Gulf region. Water pricing for the different consumption sectors in which the tariff increases with the increase of the consumption rate will certainly benefit the water conservation exercise.

6. Conclusions

This article emphasizes the importance of water in the GCC countries. The lack of fresh water resources constitutes the main obstacle against the sustainable development in the region. Over 60% of the demands are covered by fossil groundwater. Due to its larger population along with the adaptation of huge agricultural programs, Saudi Arabia alone consumes about 82% of the total water supply. Bahrain, Qatar and Kuwait, respectively, consume less water. The major item of water consumption is the agriculture sector in Saudi Arabia (about 20 billion m^3 yr^{-1} by the year 2000). Any conservation plan should therefore focus on this sector.

An integrated and comprehensive policy for groundwater pumping is needed for the sustainability of the hydrogeological system. The production of desalinated water is quite costly and, hence, its use should be limited for drinking purposes. Treatment and recycling of wastewater should be applied to a greater extent. Detention and retention dams should be constructed in the main Wadis of the region. Different schemes for the artificial recharge of groundwater should be employed according to the nature of the hydrogeological systems under consideration.

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