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Excessive Use of Groundwater Resources in Saudi Arabia: Impacts and Policy Options

Saudi Arabia is an arid country with limited water supplies. About 80-85% of water supplies come from groundwater which is essentially classified as a nonrenewable water resource. The annual extraction of groundwater is far in excess of natural replenishment. This groundwater mining can not continue indefinitely. Excessive use of groundwater has created major problems such as depletion of aquifers and deterioration of groundwater quality. Some of these problems are already occurring and others are expected to occur. The result may be adverse economic consequences coupled with negative environmental and social effects. Therefore, immediate public action is imperative to prevent or minimize the impacts of the depletion of groundwater resources. This paper provides a brief overview of groundwater use; identifies and highlights major problems resulting from the excessive use of groundwater; discusses some possible economic impacts of groundwater depletion; and suggests some policy options to protect and prolong the life of groundwater resources.

INTRODUCTION

Saudi Arabia is the largest arid country in the Middle East, covering 2.24 million km^2 of the Arabian Peninsula (Fig. 1). Rainfall is scanty and there are no lakes, rivers, or streams. Faced with a steadily rising demand and inadequate and unreliable sources of surface water, the country is increasingly dependent on groundwater resources. About 75–85% of the total water supply comes form groundwater which receives very limited natural recharge and is, thus, classified as fossil or nonrenewable water.

When the rate of water withdrawal exceeds the net recharge, mining of groundwater occurs which may result in a variety of major problems including fast depletion of groundwater resources and deterioration of their quality. For Saudi Arabia, groundwater is the most valuable water resource and its rapid depletion and deterioration in quality may have serious socioeconomic implications.

WATER RESOURCES

There are two natural sources of water: surface water and groundwater.

Surface water. Due to low precipitation and high evaporation rates, surface water is limited, and Saudi Arabia has no perennial rivers or lakes. Data provided by 449 meteorological and rainfall stations in Saudi Arabia indicate that the average annual rainfall is about 90 mm (1). This average, however, significantly varies among regions. The rainfall varies from 20 mm in the North to 500 mm in the South.

Rainfall is also highly irregular. For instance, the Riyadh area received 13.5 mm of rainfall in 1966 and in 1967 received 216.2 mm (2). Nearly all precipitation occurs between the months of November and April while the rest of the year is dry and hot. As a result of the desert climate, a large portion of the rainfall evaporates; sometimes 15–30 times the annual rainfall (3). Evaporation figures for Saudi Arabia can be as high as 3000 mm per year for open water surfaces (4).

Surface runoff, however, can occur during rainstorms. Estimates of runoff water range between 2000–2400 million $m^3 \cdot yr^{-1}$. Most of it occurs in the coastal areas and highlands of the southwest where the rainfall is relatively abundant and regular. The government has constructed 181 dams throughout the country to utilize the surface runoff water. It is expected that the efficient use of these dams will provide a potential surface water supply of up to $900 \cdot 10^9 m^3 \cdot yr^{-1}$.

Groundwater. The absence of a reliable and adequate surface water supply has resulted in a heavy reliance on groundwater. Groundwater is obtained from two types of aquifers: shallow aquifers and deep aquifers. The first, shallow aquifers, contain a renewable water supply charged by infiltration from rainfall and surface runoff water while flowing over wadis (dry water courses). The renewable groundwater is estimated at around $950 \cdot 10^9 m^3 \cdot yr^{-1}$.

The other type, deep and confined aquifers, contains a reservoir of water formed during the last Ice Age, 15 000 to 30 000 years ago, when climatic conditions in the Arabian Peninsula were different with greater rainfall than at present (6). Deep aquifers consist of seven principal aquifers and a series of secondary aquifers; collectively these aquifers contain about $500\,000 \cdot 10^9 m^3$ of proven water reserves (7). The principal aquifers hold approximately $335\,000 \cdot 10^9 m^3$ and receive minor natural recharge of about $1270 \cdot 10^9 m^3 \cdot yr^{-1}$ (8). The extensive use of the water stored in these deep aquifers (far in excess of natural recharge) makes this a nonrenewable water supply.

The quality of groundwater resources in Saudi Arabia varies from area to area, however, most groundwater is classified as brackish and contains over 1000 ppm of total dissolved solids (TDS) (9).

THE NATURE OF THE PROBLEM

There has been a dramatic increase in the demand for water in recent years. Table 1 shows that water demand increased from

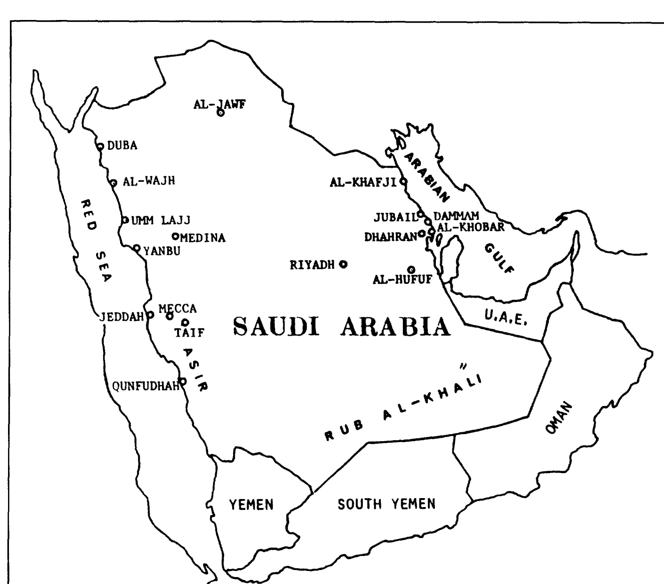

Figure 1. Map of Saudi Arabia.

2362 to 8830 · 10^9 $cm^3 \cdot yr^{-1}$ between 1980 and 1985. This amounts to a 264% increase over the five-year period. Water demand is projected to reach 20 000 · 10^9 $cm^3 \cdot yr^{-1}$ in 2010, as shown in Table 2.

The rapid growth of demand for water has created a significant imbalance between water needs and the availability of renewable water supplies. Figure 2 shows the magnitude of water deficit and Figure 3 depicts the projected increase in the use of nonrenewable water supplies.

Faced with the rapidly growing demand and inadequate surface water supply, Saudi Arabia has become increasingly dependent on groundwater resources. Currently, around 75% of the country's water needs is obtained from nonrenewable groundwater resources, and by 2010 this figure will rise to about 80% as shown in Tables 1 and 2.

Annual withdrawals of groundwater are far in excess of natural recharge as shown in Table 3. Groundwater is then being mined and when mining continues on a sustained basis and at an ever increasing pace, several major problems may result (10, 11). These problems include: significant depletion of aquifers; decline of water tables; compaction of aquifers; deterioration of water quality due to saltwater intrusion and subsidence of land. Some of these problems are occuring in Saudi Arabia while others are expected to occur as mining of groundwater continues.

Groundwater Depletion

No sudden depletion of aquifers has occurred, nor is it expected to occur. Depletion is a gradual process indicated by two common and interrelated symptoms: decline of water levels and decrease in well yields (12). In many areas of Saudi Arabia, the watertable of deep aquifers has steadily and rapidly been declining resulting in decreased water withdrawals and increased pumping costs. In some areas of the country, wells have been abandoned, while in other areas, wells had to be deepened and pumps had to be lowered to reach lower water levels. For example, the groundwater level around Riyadh has dropped c. 10 meters during the last three decades (2). In Wadi Fatima, 354 of 360 natural springs have dried up (13). Also in the Qatif and Hassa region, several large natural springs have gone dry (14).

Due to the excessive extraction and limited replenishment, Saudi Arabia is faced with ultimate depletion of groundwater resources. At the present or projected extraction rates, groundwater resources will be significantly depleted within or in less than a century. It is not known how much of the nonrenewable groundwater researches, estimated at 500 000 · 10^9 m^3 in 1985, is recoverable using the available extraction technology. If we assume that 80% can be economically recovered, then considering the depletion rate during 1985–1990, groundwater resources will be exhausted within 77 years. However, if the projected use of water in 1990 or in 2000 is considered, then water resources will run out in a much shorter time. As Table 3 indicates, by the year 2000, the volume of water stored in the deep aquifer (500 000 · 10^9 m^3) would decrease by 77 300 · 10^9 m^3, or by 15%, and by 2010 they would contain 42% less than in 1985. Even if water reserves last longer, as water level declines, water may become too saline to be used directly without further processing and the cost of pumping it will increase.

Groundwater is the most important water resource for Saudi Arabia. Nearly 80% of the total cultivated area is irrigated with groundwater. About 50% of municipal water in large cities is obtained from groundwater, while small cities, towns and villages depend entirely on wells and natural springs.

As groundwater reserves are depleted and quality deteriorates, adverse economic consequences and environmental and social effects will develop.

With a diminishing groundwater supply it is expected that agricultural output and farmers' income would decline, especially in water-shortage areas. In fact, in some areas farms and palm-fields have already been abandoned due to the decrease in well yield, increasing cost of pumping, or dry up of natural springs.

The impacts of the loss of irrigation agriculture include: reduced agricultural employment; abandonment of farm areas; increased rural to urban migration; decreased national production of food; and massive desertification. These potential adverse impacts will further be intensified by the inevitable depletion of the country's oil reserves. Moreover, the decrease in agricultural output and farming income may spill over to non-farm sectors. About 25–30% of the national labor force is engaged in farming activities. Through the expenditure multiplier effect and sectoral linkages effect, manufacturing and services sectors would be adversely affected.

In addition, the decrease in groundwater

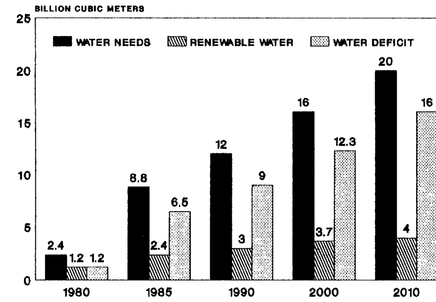

Figure 2. Water balance for the period 1980–2010.

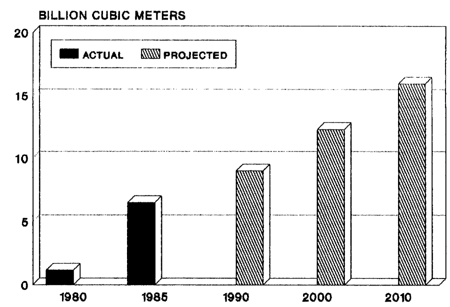

Figure 3. Non-renewable groundwater use for the period 1980–2010.

Table 1. Current water demand and supply (mill. $m^3 \cdot yr^{-1}$) (7).

	1980	%	1985	%
Demand				
Agriculture	1860	79	7430	84
Domestic, industrial, other	503	21	1400	16
Total	2362	100	8830	100
Supply				
Surface water	485	20	900	10
Groundwater				
– Renewable	660	28	950	11
– Nonrenewable	1154	49	6480	73
Desalinated seawater	63	3	400	5
Reclaimed wastewater	–	–	100	1
Total	2362	100	8830	100

Table 2. Projected water demand and supply 1990–2010 (mill. $m^3 \cdot yr^{-1}$) (7).

	1990	%	2000	%	2010	%
User						
Agriculture	10 600	88.3	13 500	84.4	17 000	85
Urban	1125	9.4	2000	12.5	2200	11
Industrial and other	275	2.3	500	3.1	800	4
Total	12 000	100.0	16 000	100.0	20 000	100
Source						
Nonrenewable	9000	75	12 300	76.9	16 000	80
Renewable (including surface water)	1800	15	1800	11.3	1800	9
Desalination	865	7.2	1190	7.4	1200	6
Reclaimed wastewater	335	2.8	710	4.4	1000	5
Total	12 000	100.0	16 000	100.0	20 000	100

Table 3. Nonrenewable groundwater balance 1985–2010 (mill. m^3) (8).

Year	Estimated recharge[1]	Extraction	Depletion
1985–1990	6350	32 400	–26 050
1990–2000	12 700	90 000	–77 300
2000–2010	12 700	123 000	–110 300
Total	31 750	245 400	–213 650
Annual Average	1270	9816	–8546

[1] The annual natural recharge of deep aquifers is estimated at 1270 mill. m^3.

supplies implies an increasing dependency on non-conventional and expensive water sources such as desalination and wastewater reclamation to satisfy the increasing demand for municipal and industrial water. For example, the Saudi government spent 33.5 billion Riyals (One US Dollar = 3.75 Riyals) on building and operating desalination plants between 1970 and 1985 (15). An increasing dependency on desalination will impose a heavy burden on the country's financial resources, especially during a period of declining oil revenues.

Degradation of Water Quality

Deterioration of water quality results from a wide variety of causes, both natural and man-made (11). The excessive use of groundwater and the steady decline of water levels lead to the intrusion of seawater into aquifers increasing the TDS content and making water too saline for direct use. Wells in many areas of Saudi Arabia have been affected by the intrusion of saline water. For example, salinity maps showing TDS content of the groundwater in the Eastern region, especially near the coast, indicate the occurrence of saltwater intrusion (16). Also, several wells in this region show large responses to tidal movements in the Arabian Gulf, suggesting an encroachment of saline water. Studies also indicate that the area of Wadi Fatima has experienced seawater intrusion due to declining water levels (13).

Groundwater quality is also threatened by percolation of concentrated wastewater. Leakages from domestic sewage and sanitary dumps and landfills increase the concentration of nitrates in the groundwater which adversely affects the chemical character of water (17). Little is known about groundwater contamination and pollution in Saudi Arabia. However, in many areas of the country cesspools or septic tanks are used to dispose wastewater. In most instances tanks may not have been constructed and maintained properly resulting in overflows and contamination of nearby wells. It has been reported that groundwater in several areas around Riyadh has been contaminated by wastewater (2).

Inefficient Use of Groundwater Resources

The agricultural sector is the major user of groundwater; more than 70% of the total groundwater withdrawal is used for irrigation. As shown in Table 1, during the 1980–1985 period agricultural water use increased from $2000 \cdot 10^9 m^3 \cdot yr^{-1}$ in 1980 to $7430 \cdot 10^9 m^3 \cdot yr^{-1}$ in 1985. The average annual growth rate of water use during this period was 60%, four times greater than that anticipated by the Third Development Plan (7). The present consumption level is projected to increase by 2.3 times by the year 2010, as Table 2 indicates. The substantial increase in the use of agricultural water is shown in Figure 4.

The rapid use of irrigation water is not only the result of increasing agricultural activities but also, and probably to a larger extent, due to the existence of wasteful and inefficient water uses. Irrigation efficiency is substantially low. A study estimated that the average coefficient of efficiency in agriculture is about 0.55, indicating that 0.45 of water used for irrigation is lost (8). This low efficiency is attributed to the prevailing and widespread use of surface and flood irrigation methods. Irrigation by these methods involves flooding the cultivated area by water delivered from natural springs, wells, or artesian wells through open and unlined ditches by gravity or water pumps. Since most of the soil is sandy and the climate is hot, a significant percentage of water is lost through evaporation, percolation, and seepage while running through the long ditches. For example, about 70% of water used to plant one hectare of dates or alfalfa represents conveyance and in-farm losses (16).

There is also a lack of incentive for farmers to use water efficiently. Irrigation water is either provided free by the government or comes from privately-owned wells. Groundwater is the property of the owner of the land, and accordingly he has unlimited rights to extract as much water as he wishes without being liable for the damage excessive extraction may cause to his neighbours or the environment. Moreover, the water authorities in Saudi Arabia have no legislation for administrating and controlling the use of irrigation water.

Water Logging and Salinity

Another problem resulting from the excessive use of groundwater is water logging and salinity. Local farmers, due to lack of training, economic incentives, and water legislation, have developed a tendency to over-irrigate. It is reported that local farmers in the Arabian Gulf region use three times the amount of water needed by plants and trees (18). Over-irrigation is not only wasteful but is also harmful and damaging to the environment. Over-irrigation is a major cause of water logging and salinity in may countries in the Middle East (19).

In Saudi Arabia, water used for irrigation is mostly of poor quality and mostly saline. Furthermore, because of the lack of adequate drainage systems, irrigation canals are also used as drainage ditches. Therefore, overirrigation, in quantity or frequency, contributes to water logging and to increased salinity which may not only reduce soil fertility but also lead to the eventual loss of good agricultural land.

Land Subsidence

Another problem associated with the progressive decline of water level due to water mining is subsidence of land. Land subsidence due to excessive extraction of groundwater has been reported from several countries such as Japan, Mexico, England, and the US (11). The potential cost of land subsidence could be substantial. For example, the total estimated damages caused by subsidence of land at the Houston-Baytown area, US, between 1943–1973 were over USD 113 million (20). In Saudi Arabia, so far no cases of land subsidence have been reported, although, as water level steadily declines, this might be expected.

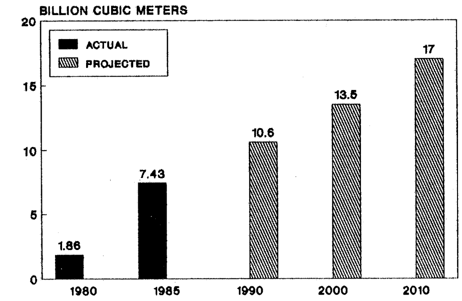

Figure 4. Agricultural water use for the period 1980–2010.

POLICY OPTIONS

The excessive use of groundwater and associated problems make it imperative to adopt a comprehensive groundwater-management program to minimize the social, economic, and environmental impacts of the detoriation of groundwater quality and depletion of groundwater quantity. The main objective of this program is twofold: 1) To identify the problems threatening the groundwater supply, and 2) to develop policies to solve these problems or mitigate their adverse effects.

Two general policy approaches can be identified to deal with the groundwater problems: supply augmentation and demand modification. Under each approach there are several policy options which can be considered for adaption.

Supply Augmentation Options

Supply augmentation options may include, among others, the following:

Developing new water supplies. To reduce pumping of groundwater, additional water resources must be developed. This option for Saudi Arabia is quite limited and expensive due to the scarcity of surface water and the high and increasing costs of nonconventional water supplies such as seawater desalination. Therefore, when costs of developing additional water supplies are considered, the benefits of other supply augmentation options are quite evident.

Use of Agricultural Drainage Water. Agricultural drainage water can be used as an additional source of water supply. One study investigated the possible uses of agricultural drainage water in Qatif, Saudi Arabia (16). According to this study, a large amount of drainage water (400 000 m^3 per day) is discharged into the Arabian Gulf. This quantity of water can be used to augment the region's limited resources. However, due to the high salinity of the water (3500–4500 ppm), salts must be removed by some desalination methods. Of the six desalination methods investigated, reverse osmosis was found to be the most economically feasible method. This study suggests that treated drainage water can be used for various purposes: agricultural, industrial, and artificial recharge. If the treatment of drainage water is applied and used in major agricultural areas of the country a significant amount of groundwater can be saved.

Use of Wastewater. Municipal wastewater could be a valuable water resource. In major cities a large quantity of wastewater from treatment plants is discharged into coastal water or left to evaporate in desert lagoons. This treated sewage water can be used for irrigation and landscaping. A field experiment conducted in Saudi Arabia recommends the use of secondary treated wastewater to grow alfalfa, onions and summer squash. It also suggests the possibility of using this water for urban landscaping (21). In Riyadh, the capital, the use of treated sewage water for irrigation is being practiced on a limited scale where 200 000 m^3 per day is used to irrigate 175 farms covering an area of 12 000 ha (15). In addition, tertiary treated sewage water is used for landscaping and domestic irrigation in two other Saudi cities, Jubail and Yanbu. Utilization of sewage water can be extended to include all Saudi cities and towns with sewage treatment facilities.

Artificial Recharge. Artificial recharge of aquifers could prove to be an important method to tackle the problems of groundwater depletion and degradation. Artificial recharge has been defined as "the process of replenishment of water retained in the groundwater storage through works provided primarily for that purpose" (11). The primary goals of artificial recharge are to: augment the insufficient natural recharge of aquifers to meet the current and future demands for groundwater, thus extending the life of these aquifers; and combat the adverse effects accompanying the excessive use of groundwater such as seawater intrusion, land subsidence, and deepening of wells.

There are several methods of artificial recharge such as spreading, pounding, and flooding (11). The injection of abandoned, or specially designed, wells might be an appropriate method to minimize the evaporation and transmission losses generally associated with other methods such as flooding and spreading. The injection method has been proposed for Qatar which has similar hydrologic and geologic conditions to Saudi Arabia (22). Artificial recharge water can be supplied from various sources such as reclaimed agricultural drainage water and treated municipal and industrial waste water. Even desalinated seawater can be considered as a potential source. For instance, in Quata artificial recharge of distillate has been suggested as a solution to the mining of groundwater (22).

Demand Modification and Management Policies

There are various measures that can be adopted to reduce the excessive use of groundwater and preserve and protect its quality; such measures may include:

Farmers Education. It is highly desirable to educate the local farmers about the water requirements of plants and the potential harm that overirrigation may cause. In the state of Texas, USA, there has been some success in eliminating the wasteful practices of the local farmers (23). Farmers should be informed and warned that groundwater resources are limited, and if the present rate of use continues, these resources are subject to total depletion in relatively few years.

Improving Irrigation Efficiency. Since more than 75% of non-renewable groundwater resources is used by the agricultural sector, a better management of agricultural water is of great importance. A significant amount of irrigation water can be saved by improving the traditional irrigation system, and adopting modern irrigation techniques. Field experiments in Saudi Arabia showed that compared to surface irrigation the use of the sprinkler and drip irrigation would save 42% and 62% of water, respectively, (24).

Mandatory Regulations. Due to the depletion of groundwater supplies and a subsequent water shortage, Saudi Arabia may have to accept lower annual water withdrawals. The optimal use of an aquifer from the quantity point of view is determined by its safe yield defined as "the maximum annual withdrawals which will not produce undesired results." (10). Since the major aquifers in Saudi Arabia receive little natural recharge, restricting water pumping according to a safe yield level would extend aquifer life, but at substantial economic and social costs. Such restrictions would result in a major decline in agricultural production and farming income. However, this option may be necessary in areas where there are signs of significant depletion of aquifers.

Modifying Water Rights. As indicated earlier, groundwater is the property of the landowner. Accordingly, owners have unlimited rights to use water as they wish which can result in excessive and wasteful pumping. The Ministry of Agriculture and Water requires drilling permits, but the lack of effective monitoring means that many wells are drilled without permission. Moreover, there is no law governing the use of water. The government, can and should, establish laws and regulations to administer and control its use.

Preserving and Monitoring Groundwater Quality

Several preventive measures protect groundwater resources from pollution, contamination and degradation. These include:

- Preventing seawater intrusion by injecting reclaimed water or desalinated water into wells in the coastal areas to form freshwater barriers. In Los Angeles, USA, seawater encroachment has been significantly controlled by constructing freshwater barriers through artificial recharge (11).
- In areas which still lack municipal sewage systems, building codes have to be established to ensure that septic tanks and cesspools are properly built and maintained to prevent wastewater overflows.
- Closely monitoring solid-waste discharges at municipal dump grounds to prevent leak of toxic substances.
- Conducting systematic surveys of groundwater quality to detect the presence of contaminants.

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