CHAPTER 9
Should intensive use of non-renewable groundwater resources always be rejected?

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ABSTRACT: The conventional understanding that the sustainability of groundwater resources does not allow them to be used with levels exceeding natural replenishment seems unrealistic in arid regions. An example is Saudi Arabia, which witnessed, in 1975, a major threshold increase in its oil revenues by about twenty to forty times. The use of about 19% of the stored non-renewable groundwater resources in the upper 300 m below ground levels for irrigated agriculture, between 1975 and 2000, has enabled the country to support major socio-economic developments in rural areas. About US$ 25,000 million were spent as free of interest loans and price support for wheat production during that period. This has helped the rural population and nomads to be converted into skilled agricultural communities in prosperous villages and towns with effective public services. These communities have provided valuable support to food production and to the security of the country in remote areas. The Kingdom has been dynamic in changing the agricultural policies to minimise negative impacts on aquifers. The above experience indicates that, the carefully planned intensive use of non-renewable groundwater resources for socio-economic developments, during a limited number of years, should not be always rejected.

1 INTRODUCTION

In arid regions where average annual rainfall is less than 200 mm, recharge to local and regional aquifers is mostly indirect, very limited and insignificant (Lloyd 1999). Apart from the limited groundwater in shallow alluvial aquifers, most of the stored groundwater in local and regional sedimentary aquifers is non-renewable fossil water with varying ages between about 10,000–32,000 years. With rapid socio-economic developments and an increasing population coupled with agricultural and industrial growth in these regions, water demands have increased drastically. This has put increasing pressure on water authorities and decision-makers to satisfy growing demands from available limited renewable water resources and non-renewable groundwater resources. Water demands have far exceeded the quantities of renewable water resources from conventional resources, such as surface flows and natural recharge. Consequently, the annual water share *per capita* from renewable water resources in arid countries has declined significantly. For example, in Yemen, Libya, United Arab Emirates (UAE), Saudi Arabia and Oman, the renewable water share dropped from about 480, 538, 3,000, 537 and 4,000 m^3/yr *per capita* respectively in 1960, to about 263, 154, 129, 277 and 583 m^3/yr *per capita* respectively in 2000 (World Bank 1993, Khouri 2001). There has been controversy over the conventional understanding that long-term sustainability of groundwater resources does not allow the use of groundwater with levels exceeding natural recharge, especially in arid countries.

However, this conventional understanding has been violated, because it has been unrealistic and not practical, and it has represented a serious challenge to socio-economic developments. The extensive use of groundwater, including the non-renewable part, has been heavily practised in several countries such as USA, Australia, Spain, India, Jordan, Oman, Libya, Bahrain, UAE, Egypt and Saudi Arabia, to support, agricultural and domestic activities. The impacts of these experiences on the sustainability of groundwater resources and on the economic and social sectors vary among countries. Carefully planned intensive use of groundwater on the bases of a good understanding of aquifer geometry and socio-economic conditions are expected to have acceptable negative impacts to support national developments.

Saudi Arabia's intensive use of groundwater, including non-renewable fossil water, especially after the increase in its oil revenues in 1974, is an example for intensive utilisation of groundwater for irrigated agriculture to support socio-economic developments of rural communities. The country witnessed, in 1975, a major threshold increase in its oil revenues by about twenty to forty times (Fig. 1). Annual oil revenues have increased after 1974 from less than Saudi Riyals (SR) 5,000 million (US$ 1,325 million), to about SR 100–220 billion (US$ 26.5–58.3 billion). This has enabled the government to start the execution of comprehensive and ambitious plans to build modern infrastructures for health, transportation, and education sectors, coupled with extensive developments in industrial and agricultural sectors. The irrigated agriculture was used as an effective mean for converting nomads into settled and prosperous agricultural communities. To achieve this goal, the country has to depend on the available groundwater as a major water supply source. This chapter describes available water resources in Saudi Arabia and the growth in water demands, and how the country managed to satisfy growing requirements by planned intensive use of groundwater, especially for irrigated agriculture in rural areas, and its impacts on socio-economic developments of rural communities. This might help to understand and to justify the intensive use of non-renewable groundwater resources under certain socio-economic and hydrogeological conditions in arid countries, such as Saudi Arabia.

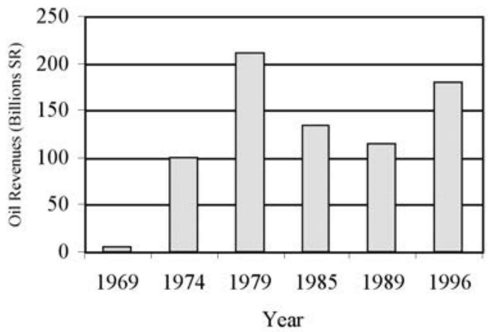

Figure 1. Growth in the annual oil revenues in Saudi Arabia.
(SR 1 = US$ 0.265)

2 WATER RESOURCES IN SAUDI ARABIA

Most of the Kingdom of Saudi Arabia is located in arid regions where the average annual rainfall ranges from 25 mm to 150 mm (MAW 1984). The average annual evaporation ranges from 2,500 mm to about 4,500 mm. The country has an area of 2,250,000 km^2, of which about 40% are desert lands. It lies within Latitudes 16^o and 32^{o}12'N, and longitudes 34^{o}36'E (Fig. 2). The population increased from about 7.74 million in 1970 to about 20 million in 2000 and it is expected to exceed 40 million in 2025. The rapid population growth is due to the high growth rate of about 3.4%, especially after 1975. This high growth rate is due to major improvements in public health services in urban and rural areas coupled with a better standard of living.

To understand the availability of water resources in supporting the development of the country, assessments of water resources were started in 1965. The country was divided into eleven hydrological regions and comprehensive investigations were carried out on regional and national levels between 1965 and 1985 (Fig. 2) (MAW 1984). The results of these studies revealed that surface water is limited, while non-renewable groundwater represents most of the conventional water resources in the country.

2.1 *Surface water*

The low rainfall quantities in most of the Kingdom are expected to create limited surface

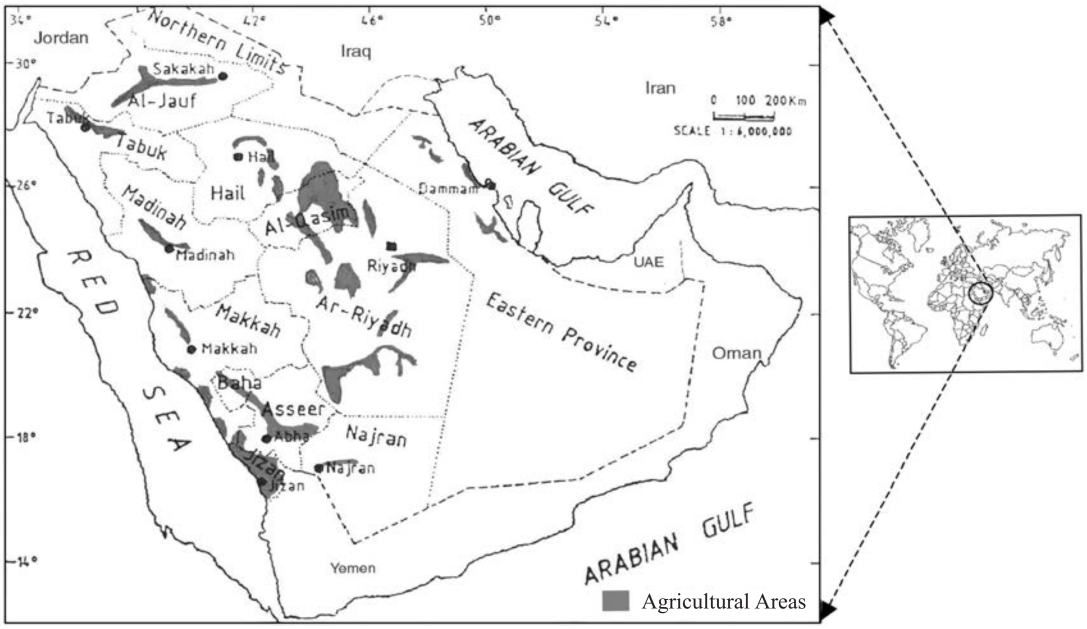

Figure 2. Location map of Saudi Arabia and its agriculture areas.

runoff. The quantities of the annual runoff are estimated to be about 2,230 Mm^3 of which 1,450 Mm^3 are produced in the western coastal parts of the Kingdom. The storage capacity of 197 constructed dams of different shapes and sizes is 809 Mm^3. These dams were constructed for groundwater recharge and flood control purposes.

2.2 *Groundwater*

Groundwater in Saudi Arabia is found almost entirely in the many thick, highly permeable aquifers of large sedimentary basins to the north, east, and groundwater occurs in the fractured, Precambrian crystalline rocks of the Arabian Shield, which is more significant in providing extensive, higher, relatively impermeable areas for surface runoff, and localised, shallow *wadi* underflow, according to Burden (1982). While the major aquifers in the north of the country consist of multiple, Lower Palaeozoic arenaceous permeable formations with interdigitated impermeable argillaceous strata, those in the eastern part include both karstified Tertiary carbonates and Mesozoic to basal Palaeozoic arenaceous formations. To the south of the Arabian Shelf, a single thick basal Lower Palaeozoic sandstone formation constitutes a high yield aquifer. Groundwater is stored in more than 20-layered principal and secondary aquifers of different geological ages (Fig. 3) (MAW 1984). The Arabian Shelf includes the deep sedimentary aquifers, which are formed mostly of limestone and sandstone that overlay the basement rock formation known as the Arabian Shield, and covers about two thirds of Saudi Arabia or 1,485,000 km^2 (MAW 1984). These aquifers crop out in the western parts of the Shelf and extend towards the eastern parts. The total thickness varies between a few hundred to more than 5,000 m (MAW 1984). The principal aquifers are: Saq, Wajid, Tabuk, Minjur, Dhruma, Biyadh, Wasia, Dammam, Umm Er Radhuma and Neogene. The secondary aquifers are: Al-Jauf, Al-Khuf, Al-Jilh, the Upper Jurassic, Sakaka, the Lower Cretaceous, Aruma, Basalts and Wadi Sediments (Fig. 3). Apart from the last two, groundwater resources stored in these aquifers are non-renewable. The groundwater quality varies between sites and among aquifers (Table 1). The isotopic analyses showed that the fossil groundwater in the above aquifers is 10,000–32,000 years old. Large volumes of

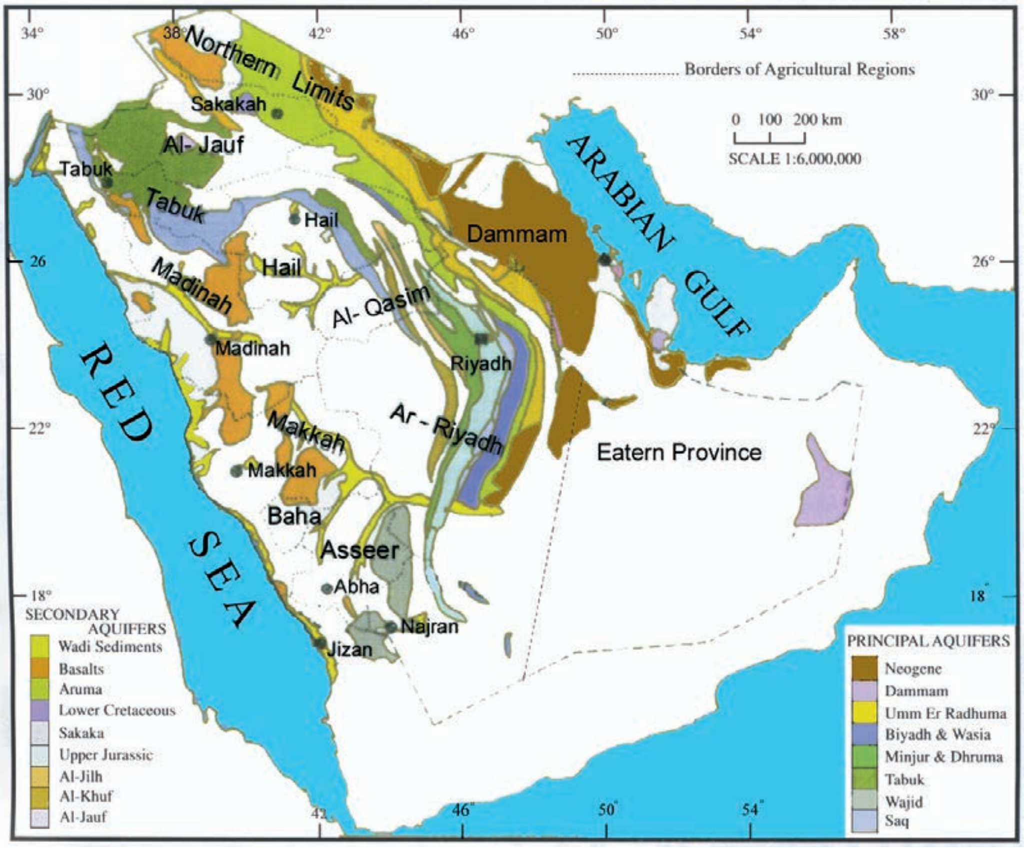

Figure 3. The extension of the outcrop areas of principle and secondary aquifers in agricultural regions in Saudi Arabia.

groundwater are stored in the sedimentary aquifers (KFUPM/RI 1988). The estimated groundwater reserves to a depth of 300 meters below ground surface is about 2,185 km^3, with a total annual recharge of 2,762 Mm^3 based on several hydrogeological studies as given in KFUPM/RI (1988) and Alawi & Abdulrazzak (1994) (Table 1). Renewable groundwater resources are mainly stored in the shallow alluvial aquifers and within Basalts, which extend mostly in the south-western parts of Saudi Arabia with varying thickness and width (MAW 1990). These aquifers store about 84,000 Mm^3, with an average annual recharge of 1,196 Mm^3 (BAAC 1980).

The total national groundwater reserves in the shallow and deep aquifers to a depth of 300 m below ground surface is about 2,259 km^3. These volumes of renewable and non-renewable groundwater resources represent a dependable source for different purposes, including irrigation in the Kingdom, if properly managed.

2.3 *Non-conventional water resources*

2.3.1 *Treated wastewater*

It is estimated that about 1,400 Mm^3 of wastewater were generated in the country in the year 2000. The volumes of collected and treated wastewater were about 560 Mm^3, which represent about 40% of the total municipal water. About 240 Mm^3 are reused for landscape and crop irrigation purposes. The treated wastewater for reuse in the Kingdom is expected to reach about 1,000 Mm^3 in 2010.

2.3.2 *Desalination water*

Large seawater desalination plants were constructed on the Gulf and Red Sea coasts to produce suitable drinking water. Water transportation pipelines were implemented to convey the desalinated seawater from the coasts to coastal and inland cities and towns, such as Riyadh, Makkah, Medina and Taif. In 1997, about 88%

Table 1. The estimated groundwater reserves in Saudi Arabia to a depth of 300 meters below ground level in Mm^3.

Aquifer	Reserve (Mm^3)	Recharge (Mm^3)	Total dissolved solids (ppm)
Saq	290,000	310	300–3,000
Tabuk	210,000	455	250–2,500
Wajid	220,000	104	500–1,200
Minjur-Dhruma	180,000	80	1,100–20,000
Wasia-Biyadh	590,000	480	900–10,000
Umm Er Radhuma	190,000	406	2,000–5,000
Dammam	45,000	200	2,600–6,000
Khuf & Tuwal	30,000	132	3,800–6,000
Aruma	85,000	80	1,600–3,000
Jauf & Sakaka	100,000	95	400–5,000
Jilh	115,000	60	3,800–5,000
Neogene	130,000	360	2,400–4,000
Total	2,185,000	2,762	

of the desalination capacity in Saudi Arabia used multi-stage flash systems (MSF), while the remaining plants used reverse osmosis (RO) (Bushnak 1997). The total number of desalination plants in 1997 was 35 plants: 17 MSF and 18 RO plants. The desalination plants capacity range from 1,000 to 789,864 m^3/d. Saudi Arabia became the largest desalinated water producer in the world. The total water production of desalination plants increased from about 200 Mm^3 in 1980, to 540 Mm^3, and 785 Mm^3 in 1990 and 1997, respectively. The rest of the domestic water supplies are from limited surface water and mostly from groundwater resources in shallow and deep aquifers. The present desalinated water production is about 1,000 Mm^3 and it is expected to reach about 1,800 Mm^3 in 2010, and more than 3,000 Mm^3 in 2025. In 1990 and 1997, the desalination water production was about 33% and 38% of the total domestic and industrial demands, respectively. By 2025, the desalination production is expected to be about 54% of the total domestic and industrial demands.

Available water resources in the country from conventional and non-conventional resources are summarised in Table 2.

Table 2. Water resources in Saudi Arabia in 2000 (Mm^3).

Surface water	2,230
Groundwater resources	2,003,000 (84,000 in shallow aquifers)
Groundwater recharge	3,860 (1,196 to shallow aquifers)
Desalination	1,000
Treated wastewater	240

3 GROWTH IN WATER DEMANDS IN SAUDI ARABIA

3.1 *Growth in domestic water demands*

In Saudi Arabia, the population of the Kingdom increased from about 7.7 million in 1970 to about 10.7, 15 and 21 million in 1980, 1990 and 2000, respectively, and it is expected to reach about 40 million by 2020. The urban population increased from about 3.74 million in 1970 to about 6.4, 10.5 and 15 million in 1980, 1990 and 2000, respectively (Fig. 4). The urban population is expected to reach about 32 million in 2020 or about 80% of the total population of the country. Consequently, it is observed that the domestic water ratio increased from about 6% of the total national water use in 1990 to about 10% in 2000, and it is expected to rise to about 17% and 30% in 2010 and 2020. Domestic water demands in the Kingdom were about 446 and 2,350 Mm^3 in 1980 and 2000, respectively, and they are expected to be 2,800 and 6,450 Mm^3 in 2010 and 2020, respectively (Table 3).

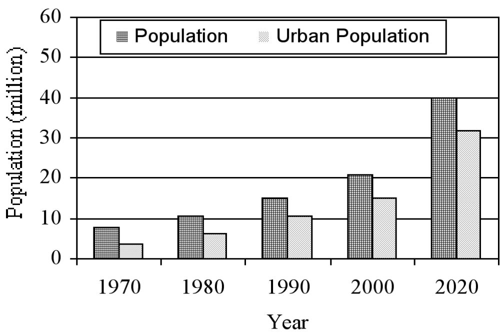

Figure 4. Growth in total and urban population in Saudi Arabia.

Table 3. Growth of domestic water demands in the Kingdom of Saudi Arabia, in Mm^3/yr (Alawi & Abdulrazzak 1994, Al-Tokais 1997).

YEAR	Water demands
1980	446
1990	1,508
1997	1,563
2000	2,350
2010	2,800

3.2 *Industrial water demands*

Industrial water demands in Saudi Arabia have grown rapidly during the last two decades due to significant industrial developments. The industrial sector consists mostly of petrochemicals, cement, steel, fertilisers, mining, basic metals, textiles, food and beverage production. In Saudi Arabia, industrial demands increased from 190 Mm^3 in 1990 to 415 Mm^3 in 2000, and they are expected to increase to 1,450 Mm^3 in 2010. Growing industrial water demands are mainly met by desalination plants and by non-renewable groundwater resources.

3.3 *Growth in irrigated agriculture and irrigation water consumption in rural areas*

After the increase in annual oil revenues in 1974, the government used irrigated agriculture as an effective tool to support socio-economic developments in rural areas and to settle nomads into agricultural and prosperous communities. In addition, this was also used to alleviate the low income in rural communities and to provide them with effective health and education services. To achieve these goals, the intensive use of groundwater was adopted and implemented successfully. This was based on the knowledge of the geometry of aquifers in different regions and their capabilities of supporting expansion in agricultural activities. Several water management measures were also adopted to minimise the negative impacts of long-term water pumping on aquifer conditions. Specialised water offices were established. Legislation and regulations were developed to organise water management issues, including the licensing of well location, drilling and design. Thousands of deep and shallow wells were drilled under the supervision and the support of the Ministry of Agriculture and Water for irrigation purposes. Advanced irrigation systems were used to minimise irrigation water losses. Dynamic actions were introduced to lower irrigation water demands by changing agricultural policies. Modern irrigation techniques have been practised to reduce water losses and demands. The Council of Islamic Leading Scholars gave a pioneering example of the wisdom of Islam by issuing a special Fatwa to regulate the reuse of treated wastewater effluents for different purposes, especially irrigation. This has promoted wastewater recycling by the public.

The threshold increase in agricultural areas started after 1979 (Fig. 7). New agricultural infrastructures, including wells, pumps, sprinkler irrigation and drip systems, were introduced in remote areas, and hundreds of thousands of hectares of desert lands were reclaimed and converted into productive farms. More than 100,000 wells were drilled in different regions of the country for agricultural purposes (MAW 2001). The new irrigated areas were spread over the rural areas in different regions, especially with the availability of groundwater in local aquifers (Figs. 2, 3). Cultivated areas expanded from fewer than 400,000 ha in 1971 to 1,620,000 ha in 1992, and started to decrease in 1993, until they reached about 1,210,000 ha in 2000 (Fig. 5). The reduction was mainly in wheat areas as a result of changing the price support policy to wheat to limit its production to the level of national needs and to reduce irrigation water consumption (MAW 2001). The total wheat area had increased from about 62,000 ha in

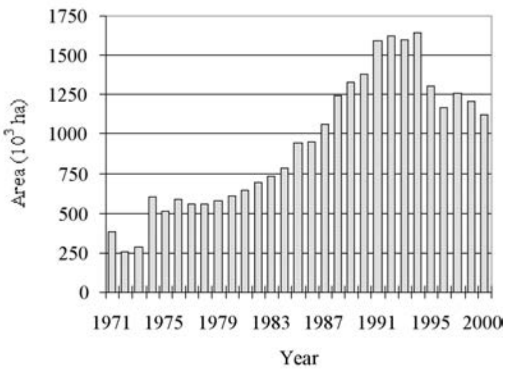

Figure 5. Growth in agriculture area (1971–2001).

1975 to 924,000 ha in 1992, then decreased to about 410,000 ha in 2000 (MAW 2001). Wheat production reached about 4 million tons in 1992 and decreased to about 1.7 million tons in 2000 (Fig. 6).

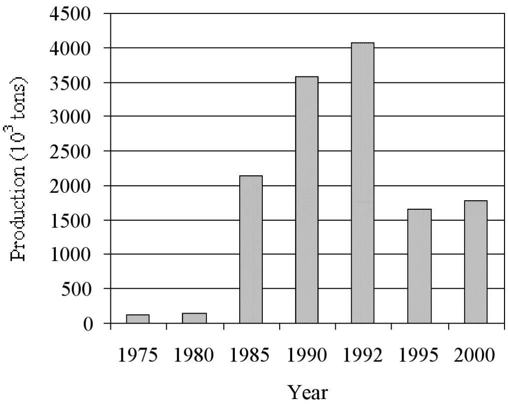

Figure 6. Wheat production in the Kingdom (1975–2000).

Irrigation water consumption, which is mainly from groundwater resources in the Kingdom, has also increased drastically due to the large expansion in agricultural areas. The annual irrigation water use increased from about 4,600 Mm^3 in 1973 to about 9,800, 22,300 and 20,800 Mm^3 in 1980, 1990 and 2000, respectively (Fig. 7 and Table 4). Irrigation water consumption represented about 95%, 93% and 87% of the national water use in 1980, 1990 and 2000, respectively.

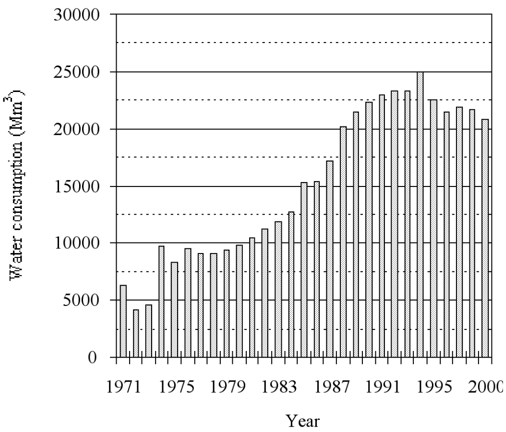

Figure 7. Irrigation water consumption in the Kingdom (1971–2001).

Table 4. Growth of water use in Saudi Arabia (Mm^3).

Year	Domestic & Industrial	Agricultural	Total
1980	502	9,846	10,348
1990	1,650*	22,312	23,962
1992	1,870*	22,943	24,813
1997	2,063*	21,881	23,944*
2000*	2,900*	20,804	23,704
2010*	3,600*	13,000*	16,600

* MOP (1990, 1998), Dabbagh & Abderrahman, 1997; and personal estimation.

4 WATER SUPPLY SOURCES IN SAUDI ARABIA

The major source of consumed irrigation water is non-renewable groundwater resources from shallow and deep aquifers in the Arabian Shield and Arabian Shelf (Table 5 and Fig. 3). Non-renewable groundwater resources supplied about 81%, 95% and 98% in 1980, 1990 and 2000, respectively. The dependence on non-renewable groundwater resources has increased with time due to higher dependence of domestic and industrial water use on renewable groundwater in addition to desalination processes (Fig. 8). The domestic and industrial water use depends mainly on desalination plants and renewable groundwater, while non-renewable groundwater water has been a secondary supplier to meet these demands.

The distribution pattern of agricultural areas in the Kingdom has resulted in excessive groundwater consumption in certain areas, such as Al-Hassa, Al-Qaseem and Wadi Ad-Dwasir (BRGM 1985, Al-Kaltham & Al-Tokais 1986, KFUPM/RI 1987, 1990, Al-Tokais 1992). The magnitude of the impacts of irrigation water use on groundwater conditions varies among regions due to variation in the quantities of water pumping and the hydraulic properties of the aquifers in each region. Consequently, several measures were taken to improve groundwater management and to reduce irrigation water consumption to maintain the long-term productivity and quality of the aquifers.

Table 5. Source aquifer and irrigation water consumption in different agricultural regions of Saudi Arabia.

Regions	Aquifers	Water consumption 2000 (Mm^3)
Eastern Region	UER, Dammam, Neogene	1,020
Riyadh	Biyadh, Wasia, Minjur, Dhruma,Wajid, Upper Jurassic - Middle Cretaceous	6,999
Qaseem & Hail	Saq, Tabuk, Shallow Alluvial aquifers, Jilh, Khuf	5,217
Northern Region	Saq, Tabuk, Basaltic aquifers, Al-jauf, Aruma, Sakaka	1,571
Madinah	Basaltic aquifers, Shallow Alluvial aquifers	799
Makkah	Shallow Alluvial aquifers, Basaltic aquifers	1,395
Aseer	Shallow Alluvial aquifers	279
Al-Baha	Shallow Alluvial aquifers	47
Jizan	Shallow Alluvial aquifers	3,073
Najran	Wajid, Shallow Alluvial aquifers	406

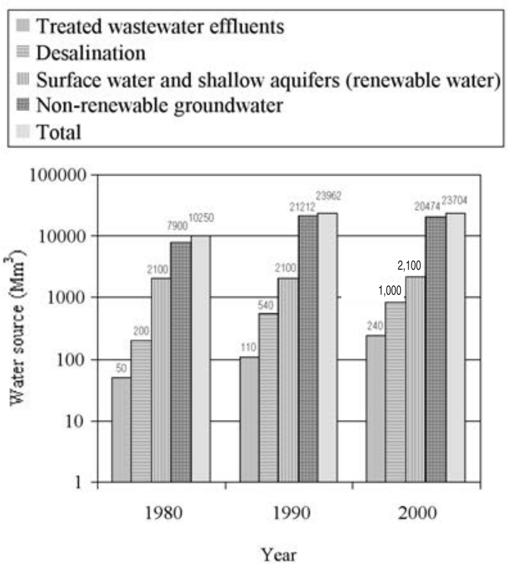

Figure 8. Sources of water supplies in the Kingdom.

Examples of these measures are the reduction of the wheat support policy by 75%, and the reduction of the areas of forage crops by 40% and the total ban on their export. It is expected to reduce the total irrigation water consumption to less than 13,000 Mm^3 within the coming ten years. The contribution to irrigation water supplies from renewable resources is expected to increase to 7,000 and 9,000 Mm^3 in 2010 and 2020 respectively. About 2,000 Mm^3 is expected to be generated from treated effluents, and the share of water supplies from surface water and aquifer recharge is expected to be expanded. This will limit dependence on non-renewable groundwater resources to an acceptable level of about 4,000 to 6,000 Mm^3/yr.

The total consumed quantities of non-renewable groundwater resources for irrigated agriculture in the last 25 years are about 380,000 Mm^3 or 19% of the total reserves in the top 300 m of the aquifers in the Kingdom. The remaining volumes can support the Kingdoms agricultural activities for hundreds of years if properly managed.

5 SOCIO-ECONOMIC DEVELOPMENTS AND THEIR IMPACTS ON THE RURAL POPULATION

In a low populated and vast country, which shares its borders with eight neighbouring countries such as Saudi Arabia, the balanced distribution of population between urban and rural areas is important for social progress, and security of the country. Prior to 1974, about 51% of the total population, used to live in rural areas. The average income *per capita* was less than US$ 1,000, especially in rural areas before 1974. This was due to low national revenues especially from oil, and due to lack of job opportunities. More than 40% of the inhabitants of rural areas used to live as nomads. Difficulties were experienced in providing effective health and education services to this sector because of the unsettled nature of the communities. Prior to 1974, several attempts were not effective in attracting them to settle in villages due to the lack of a sufficient and permanent source of income in these remote areas. This used to cause negative impacts on these communities in rural areas.

With major rise in oil revenues, the government started comprehensive developments in agricultural, industrial and social sectors coupled with building modern infrastructures for transportation, health and education. The improvement in health services and standard of living resulted in increasing the population growth rate to more than 3%. The population of the Kingdom increased from about 7.7 million in 1970 to about 10.7, 15 and 21 million in 1980, 1990 and 2000, respectively, and it is expected to reach about 40 million by 2020. The rapid and intensive developments created tens of thousands of jobs in public services and private sectors within and around major cities. This has attracted thousands of inhabitants from rural areas to move to major cities such as Riyadh, Jeddah and Dammam. The cities started to have fast growth in space and population. The urban population increased from about 3.74 million in 1970 to about 6.4, 10.5 and 15 million in 1980, 1990 and 2000, respectively. The urban population used to be less than 50% until 1974, and increased to 65% and 70% in the early 1980s and early 1990s, respectively, and it is expected to reach about 32 million in 2020 or about 80% of the total population of the country. The rapid growth of cities created pressure on water and wastewater authorities, electricity companies, education offices and health services. Simultaneously, rural areas started to suffer from the intensive movement of local inhabitants to cities. This could have disrupted the social system and created a vacuum in remote areas if not managed properly. To protect the structure of local communities and to minimise the impacts of urbanisation on rural areas, the government encouraged the development of agricultural communities in rural areas, and started a major support program for the establishment of an agricultural infrastructure. This has resulted in the improvement of the standard of living through a stable and better source of income, and effective public services and commercial facilities.

Support given to agriculture included free of interest loans, price supports to agricultural products, such as wheat and barley, and about 40% support to the costs of machinery and farm equipment, including pumps, irrigation systems, generators and tractors. The government's support to farmers increased significantly after 1974. The number of annual loans increased from 119 loans with a total value of about SR 20 million (US$ 5.3 million) in 1973 to about 25,000 loans in 1983 with a total value of SR 5,166 million (US$ 1,377 million) (Figs. 9, 10). The total loans given between 1974 and 1998 were 178,624 loans for a total value of SR 29,500 million (US$ 7,700 million). The price support policy to wheat for small farms ranged from SR 2.0 to 3.5 per kg (US$ 0.57–0.93 per kg) between 1980 and 2000. The total support given for wheat production was about SR 65,000 million (US$ 17,300 million) between 1974 and 2000. This is in addition to support to agricultural inputs, such as fertilisers and machinery.

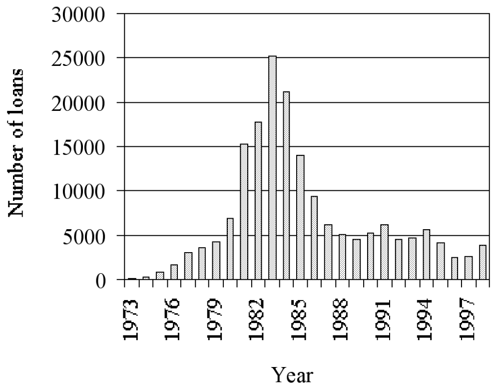

Figure 9. Growth in number of loans (1973–1998).

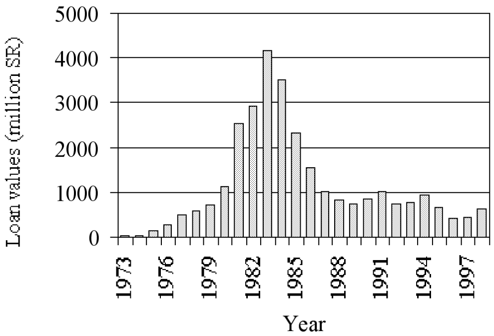

Figure 10. Growth in the annual values of loans. (SR 1 = US$ 0.265)

The intensive use of groundwater for irrigated agriculture has been instrumental in the creation of green belts in northern, southern eastern, western and central parts of the Kingdom (Fig. 2). Most nomads and rural communities were converted to active farmers. New towns and villages have been created with effective public and commercial services. This has resulted in the generation of attractive income for inhabitants of rural areas.

6 SOCIO-ECONOMIC IMPACTS OF THE USE OF NON-RENEWABLE GROUNDWATER RESOURCES IN SAUDI ARABIA

The intensive use of non-renewable groundwater resources in Saudi Arabia was unavoidable in the last 25 years, especially for agricultural development. This was an essential tool for social balance between urban and rural areas and for alleviating the low income of communities in villages and towns in rural areas. The average income *per capita* increased from less than US$ 1,000 prior to 1974 to about US$ 8,500 in 2000. The impacts on the development of public services were very pronounced between 1974 and 2000. For example, the numbers of health centres and hospitals increased from 200 to 720 centres and from 15 to 60 hospitals, respectively (Figs. 11, 12). The number of schools increased from 1,640 to 6,690, and the number of students increased from 273,000 to 1,250,000 (Figs. 13, 14). The lengths of paved and unpaved roads increased from about 4,000 to 13,200 km and from about 3,000 km to about 105,000 km (Figs. 15, 16). The number of employees covered by social insurance increased from about 70,000 to 750,000 (Fig. 17). These prosperous communities helped to supply the country with educated healthy generations of young men, in addition to food products, such as cereals, vegetables, fruits, poultry and dairy products. They also helped to inhabit deserted areas and to give support to security and defence authorities in remote areas. Other benefits were also gained, such as the minimisation of the movement of inhabitants from rural to urban areas. The present urban population reached about 15 million, or 75% of the total population of Saudi Arabia. Without the agricultural developments, the rural population could have decreased drastically. This has reduced the pressure on local authorities in urban areas to provide the required demands of water, power, education and transportation.

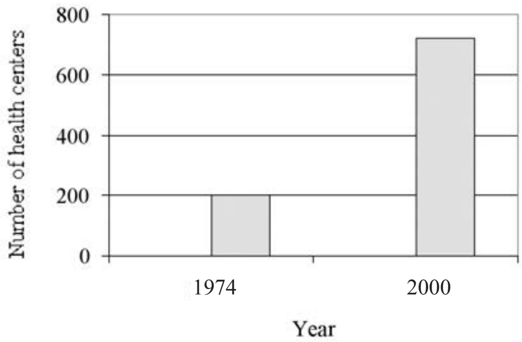

Figure 11. Growth in number of health centers in rural areas in 1974 and 2000.

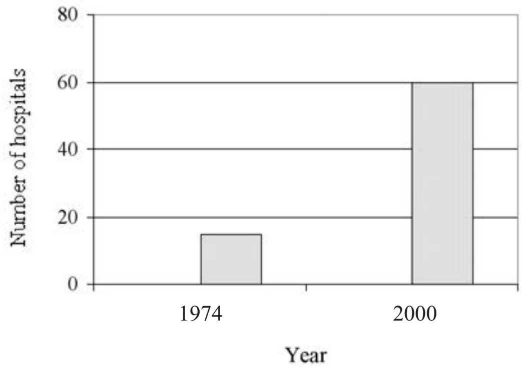

Figure 12. Growth in number of hospitals in rural areas in 1974 and 2000.

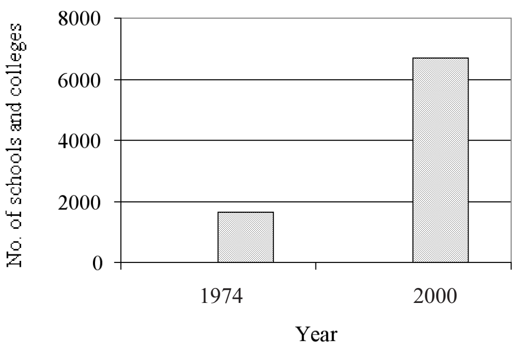

Figure 13. Growth in number of schools in rural areas in 1974 and 2000.

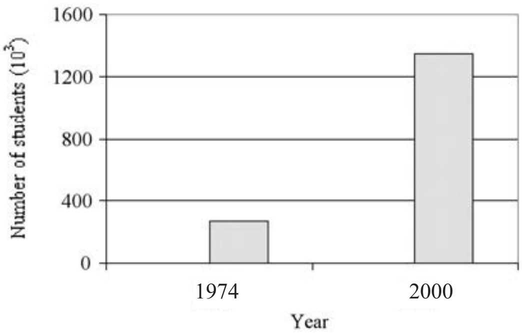

Figure 14. Growth in number of students in rural areas in 1974 and 2000.

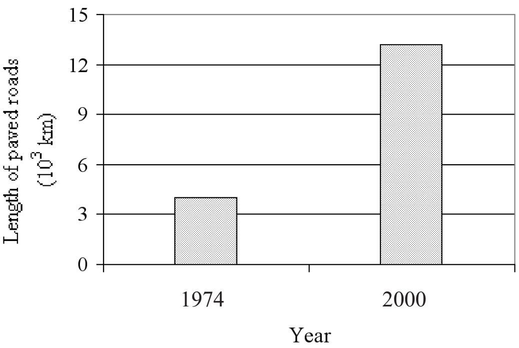

Figure 15. Growth in length of paved roads in rural areas in 1974 and 2000.

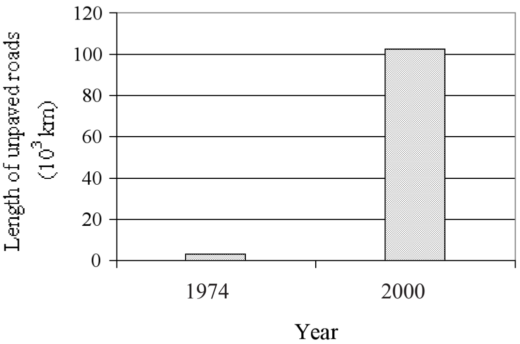

Figure 16. Growth in length of unpaved roads in rural areas in 1974 and 2000.

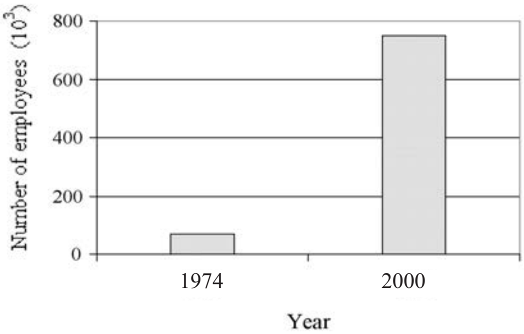

Figure 17. Growth in number of employees covered by social insurance in rural areas in 1974 and 2000.

There are additional positive impacts from the intensive use of non-renewable groundwater resources and agricultural development on the environment. The new green areas of about 800,000 ha helped to act as a sink for CO_2, which is produced from industrial activities in the Kingdom and in the region.

7 SUMMARY AND CONCLUSIONS

Non-renewable groundwater resources cannot be ignored as a major water supply source to meet increasing demands for different purposes, especially in arid regions where aquifer recharge is minimal and renewable resources are limited. The approach that confines the allowable quantities for use from non-renewable groundwater resources to the recharge values is not feasible and practical. This will result in limiting the use of valuable and sustainable water resources if properly managed. By understanding the geometry of aquifers and by adopting integrated groundwater management schemes, which consider all types of conventional and non-conventional resources in addition to demand management and socio-economic and environmental impacts, and by effective regulatory and legislation systems, it is possible and feasible to utilise part of non-renewable groundwater for a certain period of time to support socio-economic developments. A successful example is the Saudi experience in using part of its non-renewable groundwater resources in the last 25 years to achieve valuable socio-economic goals. The goals achieved were the development of advanced agricultural communities with effective health, education and commercial services, and the minimisation of urbanisation on rural communities against the strong attractions of cities. These new communities have made a significant contribution to the security and prosperity of the Kingdom. The government was dynamic in responding to arising negative impacts from excessive groundwater use on local aquifers by changing agricultural policies and groundwater pumping. The country has taken further actions to minimise water consumption for agriculture by increasing the dependence on non-conventional resources, such as treated wastewater effluents. The experience of Saudi Arabia can benefit other arid countries in developing sound groundwater management plans.

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SECTION 3

Socio-economic issues