9 Groundwater in Kuwait

Raafat Misak and Wafaa Hussain

Abstract

The fresh and brackish groundwater resources in the State of Kuwait are restricted to two main water-bearing formations (aquifers). These are the Dammam Formation and Kuwait Group. The Kuwait Group aquifer is generally unconfined, i.e., water table condition, whereas the Dammam fractured limestone Formation is a confined-semi confined aquifer. The quality of groundwater in Kuwait varies from brackish in the southwest to brine in the northeast of Kuwait. Fresh groundwater bodies of TDS less than 1000 mg/l occur on saline groundwater of TDS 100,000 mg/l in the north and the northeast, e.g. Raudhatain and Umm Al-Aish water fields. Generally, the water table varies from zero at the Arabian Gulf Coast to about 90 m below the surface in the southwest. Significant ongoing and future groundwater projects include monitoring groundwater level and water quality, establishing hydrological, geological and hydrochemical databases, reducing groundwater levels, long-term monitoring for groundwater quality e.g. Raudhtain and Um-Al Aish freshwater reservoirs and environment treatment of groundwater reservoirs. *The current study discusses the following parts: groundwater quality, groundwater geology, aquifer systems, Al-Raudhatain freshwater field, groundwater misuse and consequences (case of Wafra Agricultural Area), and* Monitoring *water ponds and saline soils, Al Wafra Agricultural Area (2008–2011).*

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9.1 Introduction

The rainfall in Kuwait is irregular and scanty, about 130 mm/yr in average. One of the natural hazards in Kuwait is Drought. In the last fifty years, several dry seasons that Kuwait experienced. For instance, during 2007–2008 and 2008–2009, the total rainfall was 35 and 65 mm, respectively. Some groundwater fields are seasonally recharged by rainfall and runoff water. These include Al-Raudhatain and Umm Al-Aish water fields.

In Kuwait, the water supplies include desalinized seawater (70% of water supplies), groundwater, and treated sewage water. Table 9.1 shows the installed capacity (MIG) and daily average of gross consumption (MIG) for desalinated water for 1980, 1990, 2000, 2020, and 2020. The installed capacity ranges from 100 Million Imperial Gallon in (1980) to 683.3 Million Imperial Gallon (2020).

Figures 9.1, 9.2 and 9.3 present information on the capacity distillation plants' and consumption of freshwater and brackish water production.

In Kuwait, there are five wastewater treatment plants operating, with a total capacity of 239 million m^3/y. The generation of wastewater in Kuwait is 154.6 m^3/capita/y, of which approximately 75% is treated (Aleisa & Al Shayji, 2019).

The usable groundwater in Kuwait is generally brackish to saline, except for some isolated freshwater lenses in Al-Raudhatain and Umm Al-Aish, north of Kuwait. Fresh and brackish groundwater resources are limited to the Kuwait Group and the Dammam Formation aquifers. The first aquifer is generally unconfined, whereas the second one is a confined-semi confined. The groundwater table range from zero at the Gulf coast to about 90 m below the surface in the southwest (Hussain, 2004). Detailed descriptions of the groundwater type and aquifers are given by many authors (Parsons Corporation, 1964; Al-Hamad, 1964; Bergstrom & Aten, 1964; Hantush, 1970; Senay, 1973; Omar et al., 1981; Al-Ruwaih, 1984, 1985, 2000;

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Table 9.1 Statistical indicators of distilled and freshwater (Ministry of Electricity and Water, 2021)

Year	Installed capacity (MIG)	Daily average of gross consumption (MIG)
1980	100	64.1
1990	252	130.3
2000	283.2	241.7
2010	423.1	367.5
2020	683.3	457.6

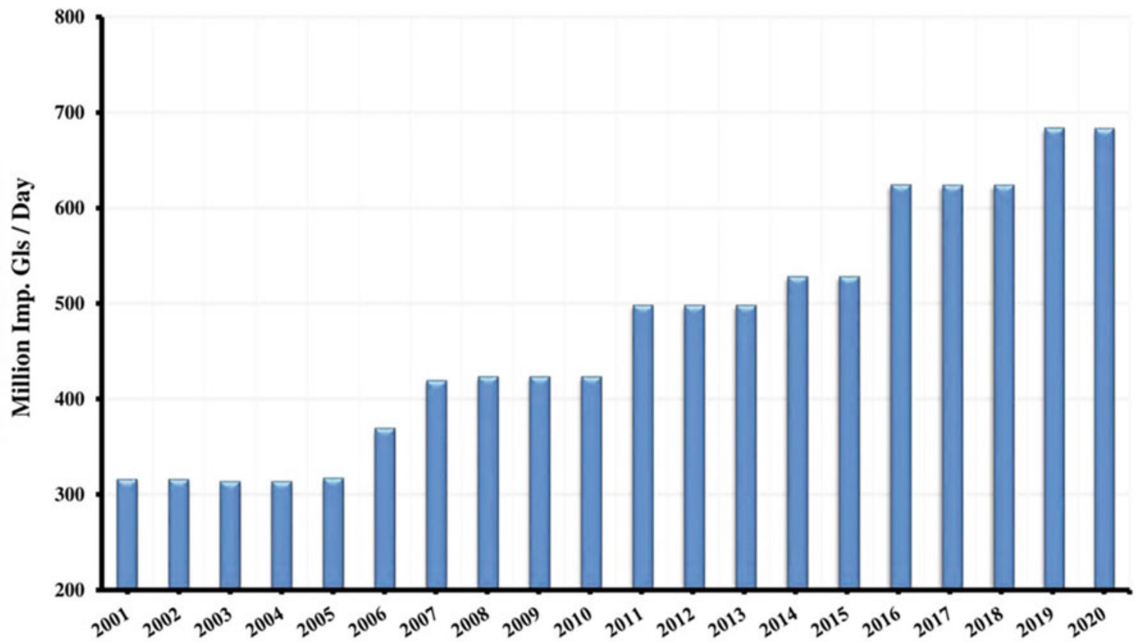


Fig. 9.1 Development of distillation plants' installed capacity

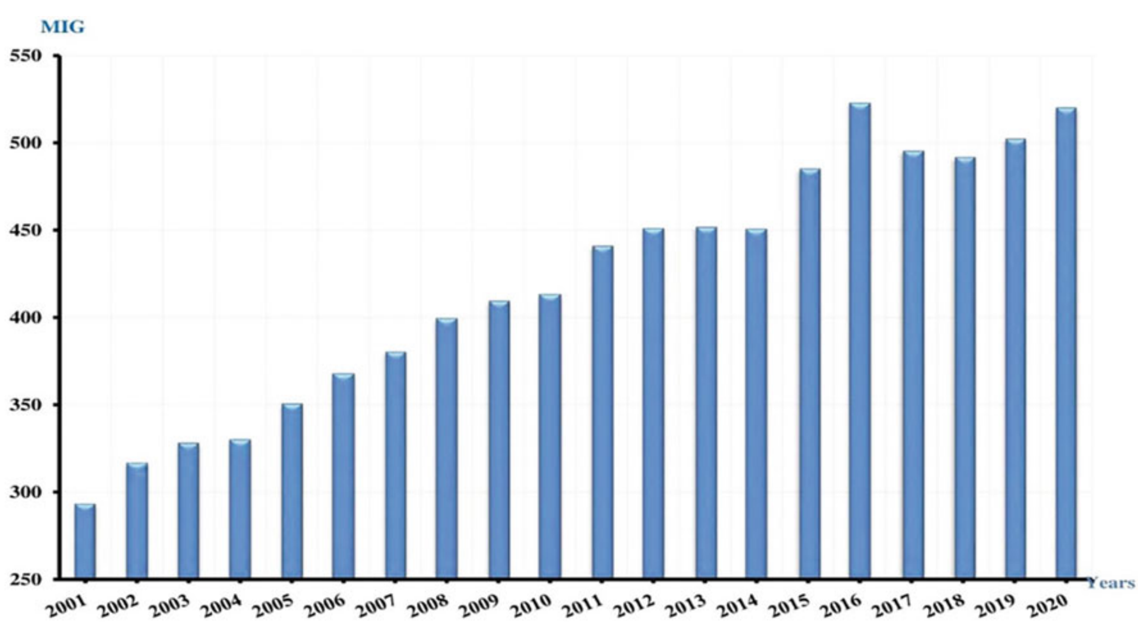


Fig. 9.2 Maximum daily gross consumption of freshwater

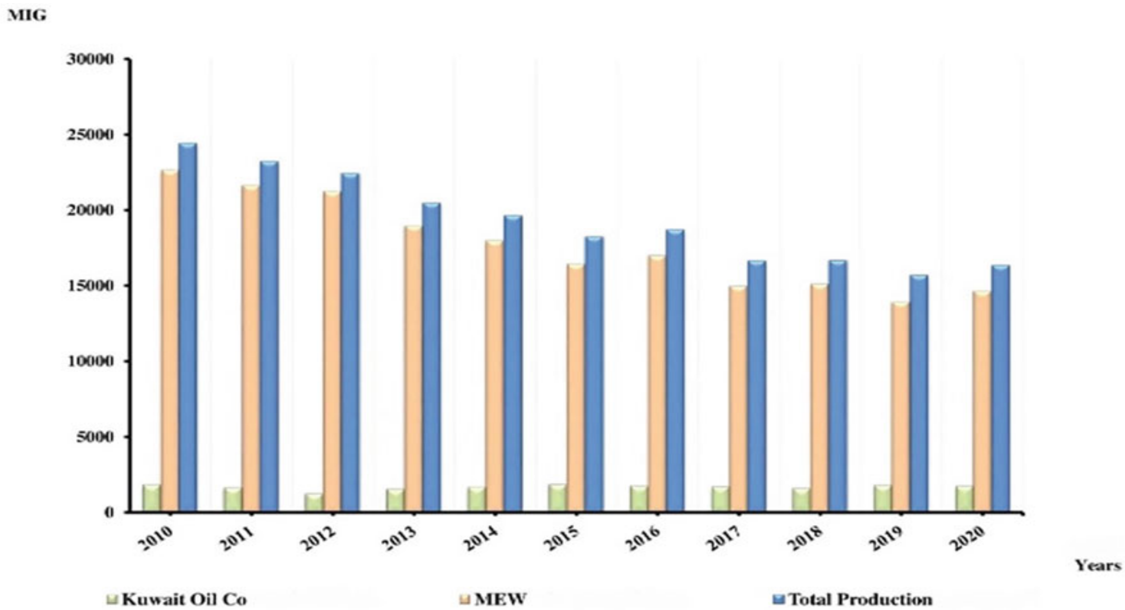


Fig. 9.3 Total production of groundwater

Al-Ruwaih, 1987; Abusada, 1988; Al-Murad, 1994; Mukhopadhyay et al., 1994; Al-Ruwaih et al., 1998; Al-Awadi et al., 1998; Al-Sulaimi et al., 2000; Al-Fahad & Al-Senafy, 2000; Viswanathan, et al., 2002; Al-Sulaimi & Al-Ruwaih, 2004; Khaled Hadi et al., 2018; Bhandary et al., 2018).

In Kuwait, the desalinated water meets almost 100% of the freshwater needs of Kuwait. It is provided to the local public consumers at the rate of almost \$0.67 per m^3 while for industrial consumers at the rate of \$0.21 per m^3 (Al-Rashed et al., 1998).

Significant ongoing and future groundwater projects include monitoring groundwater level and water quality, establishing hydrological, geological and hydrochemical databases, reducing groundwater levels, long-term monitoring for groundwater quality e.g. Raudhtain and Um-Al Aish freshwater reservoirs and environment treatment of groundwater reservoirs (UNCC, United Nations Compensation Committee) claim No. 5000256a.

This Chapter consists of the following parts: 1. Groundwater quality, 2. Groundwater geology, 3. Aquifer systems, 4. Al-Raudhatain freshwater field, 5. Groundwater misuse and consequences (case of Al Wafra Agricultural Area) and 6. Monitoring *water ponds and saline soils, Al Wafra Agricultural Area (2008–2011).*

9.2 Groundwater Quality

9.2.1 Al-Raudhtain Field (Freshwater)

Geographically, Al-Raudhtain freshwater field exists at the northeastern parts of Kuwait. The water of this field is considered as a mixture of predominantly fossil water recharged during Recent-Pleistocene, and replenished from infiltration of seasonal rainfall. The mixture of these waters gives an average salinity of 625 mg/l. The total potential of this field is 1057 m^3/d and the total volume of usable water in storage is approximately 739,762 m^3/d, half of it with salinity less than 1000 mg/l. The maximum saturated thickness of water containing less than 1000 mg/l of TDS is about 33 m, while water containing less than 2000 mg/l of TDS is about 10 to 20 m (Omer et al., 1981; Al-Ruwaih, 1987).

9.2.2 Dammam Formation Aquifer

The Dammam Formation aquifer constitutes a significant water source in Kuwait. Its quality reduces from southwestern to the central part of Kuwait. The TDS change from less than 3000 mg/l to 10,000 mg/l, respectively. The recharge source of the aquifer is from infrequent precipitation on the outcrop in Saudi Arabia and it flows from the north and the east. In the same direction, the mineralization of the water increases, and the chemical contents change from bicarbonate to sulfate to chloride.

9.3 Groundwater Geology

As mentioned in literature, the geologic sequence of Kuwait was mainly influenced by the stable shelf conditions of the Arabian Plate. The oldest exposed sedimentary rocks in Kuwait is Dammam Formation (Fig. 9.4).

The Tertiary–Quaternary sediments are divided into the Kuwait and the Hasa Groups. The first includes three formations, i.e., Dibdibba, Fars and Char. While the second group includes Dammam, Rus, and Radhuma Formations. The Mesozoic (Late Cretaceous) rocks are carbonate (Al-Ruwaih, 2001; Al-Sharhan & Naim, 1997). Holoce-Eocene lithostratigraphic column and groundwater conditions are shown in Fig. 9.5.

9.3.1 Kuwait Group

The Kuwait Group contains clastic sediments of the Miocene–Pleistocene age. Based on lithological bases, Kuwait Group can be divided into three units (Owen & Naser, 1958). These are from base to top are Ghar, Lower Fars, and Dibdibba Formations. The thickness of the Dibdibba Formation varies from a few meters to about 183 m in the northern part of Kuwait (Omar et al., 1981). The sediment content of Lower Fars Formation is shale, sandstone, conglomerate, and thin fossiliferous limestone. Its thickness varies from 60 m in the west of Kuwait to 180 m north of Kuwait. The Ghar Formation contains marine to terrestrial sand, silt, and gravel, with thickness reaches 183 m (Al-Ruwaih, 1999). Figure 9.6 shows sheets and sections of Kuwait Group.

9.3.2 Hasa Group

Hasa Group belongs to Middle Eocene–Paleocene and made of three formations (Al-Sulaimi et al., 1992). These are Dammam, Rus, and Radhuma. The Dammam Formation (Middle–upper Eocene) is the most significant aquifer in Kuwait.

The thickness of the Dammam Formation varies from 120 m in the southwest of Kuwait to 280 m in Sabriya in the north.

9.4 Aquifer Systems

The Tertiary–Quaternary sequence is the most significant aquifer system in Kuwait. Two separate water-bearing formations were identified, i.e., the upper Kuwait Group (clastic sediments) and the lower Dammam Formation (fractured limestone). Both aquifers are separated by a layer of cherts and/or clay (Al-Ruwaih & Hadi, 2005). Kuwait stretches over the discharge section of a hydrological system in which groundwater is recharged by infiltrating precipitation mostly through Hasa Group outcrops in the north-northeastern part of Saudi Arabia. Under the natural conditions of the

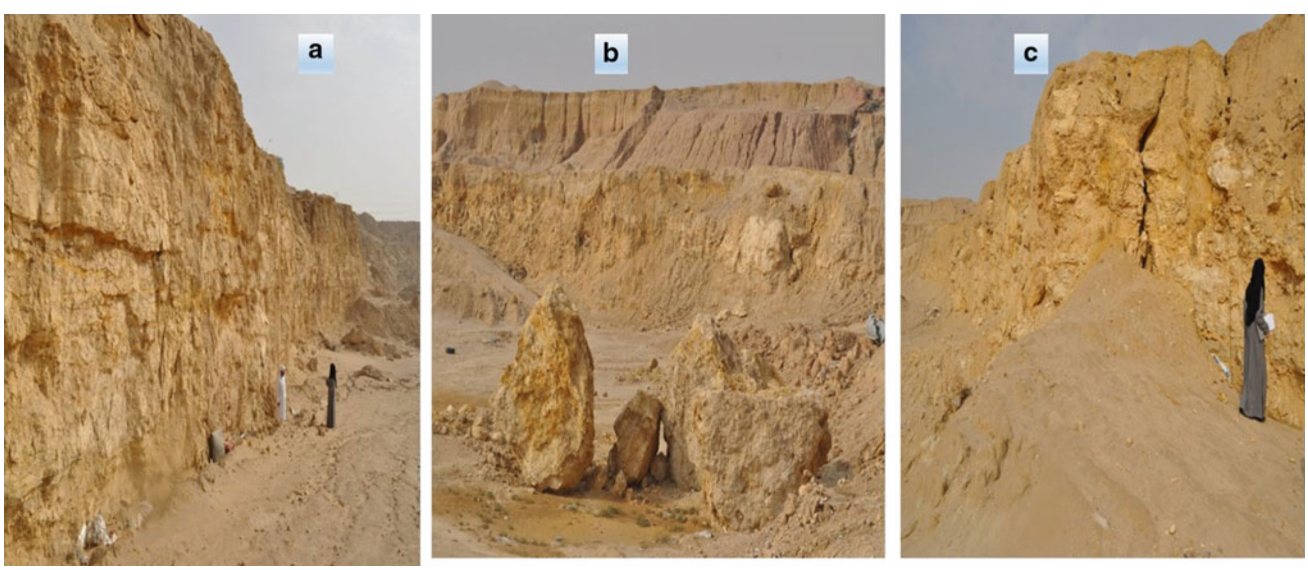


Fig. 9.4 Dammam Formation, Ahmadi Quarry, 2018, **a** surface section, **b** Cover of recent sediments, and **c** vertical fractures

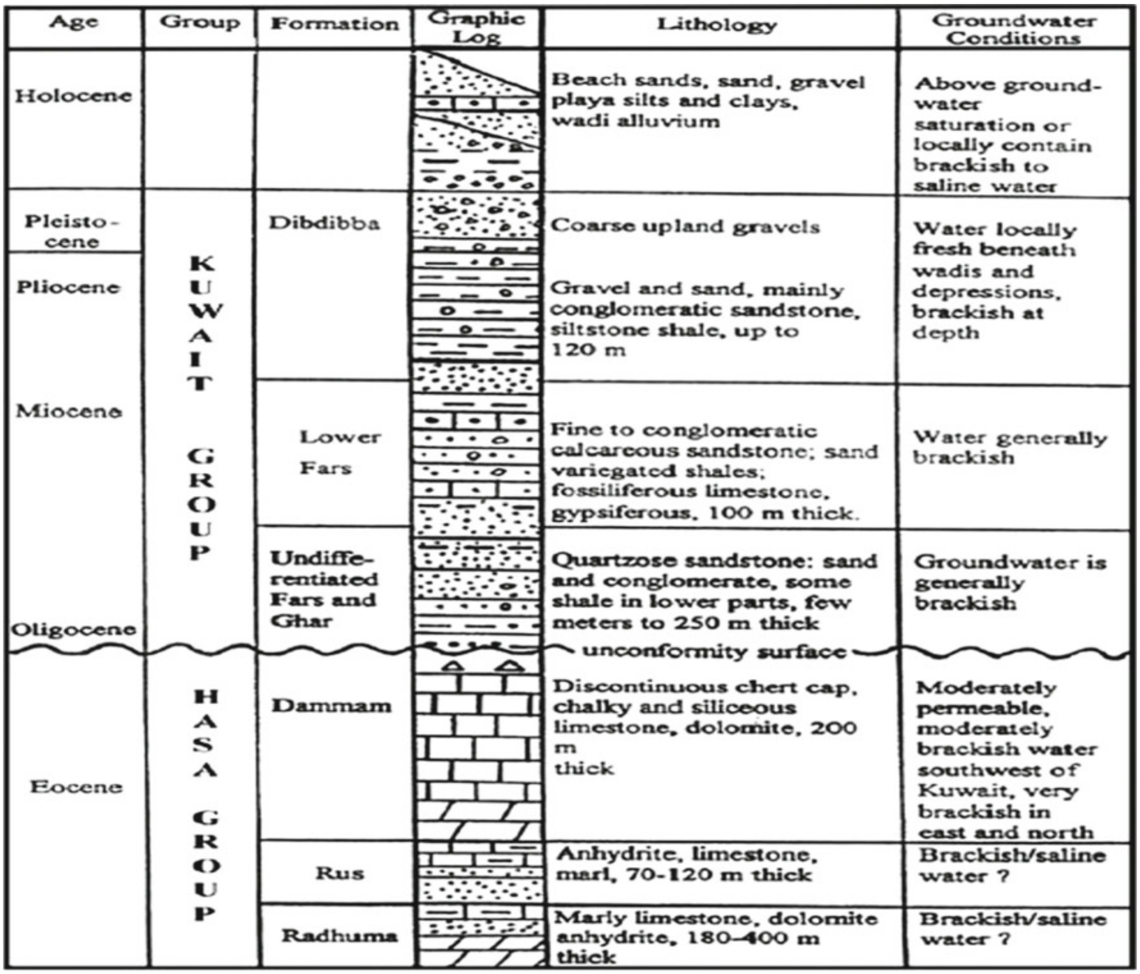


Fig. 9.5 Lithostratigraphic representation of the Tertiary–Quaternary sediments of Kuwait

hydrological events, the groundwater quality has composition that differs from southwest to northeast. It ranges from brackish to very saline, with some freshwater lenses within a saline groundwater in the north of Kuwait. In the southwest, the groundwater contains total dissolved salts equal to 3000 mg/l. This is increased toward northeast to about 100,000 mg/l.

Groundwater exploration and exploitation in Kuwait have been limited to the Neogene-Quarternary and the Eocene systems. Drilling data, geophysical logs, and groundwater analyses have made it possible to define the conditions, dimensions, and major characteristics of the aquifers and aquitards in most of Kuwait's territory. Figure 9.7 shows the surface geology of Kuwait.

The saturated part of the Kuwait Group and the underlying Dammam Formation form the regional aquifer system. This system is separated from the deeper units by mostly impervious, dense, anhydrite layers, and shaly limestone zone of the Rus Formation (Al-Sulaimi et al., 2000).

9.4.1 Kuwait Group Aquifer

As mentioned before, the Kuwait Group consists of an alternation of sands, gravels, sandstones, clays, silts, limestones, and marls. It covers the entire surface of Kuwait capping the Dammam Limestone Formation (Al-Ruwaih et al., 1998). The thickness of the Kuwait Group increases from about 150 m to 400 m from southwest of Kuwait to the northeast but is reduced to only a few meters over the Ahmadi Ridge and other domal structures. Generally, the Kuwait Group is completely dry in the extreme southwest of Kuwait and almost completely saturated with water along the Arabian Gulf coast. The TDS of the Kuwait Group aquifer is increased from about 2000 mg/l to 12,000 mg/l from southwest to northeast for 150 km. Figure 9.8 shows west–east hydrological section.

Two aquifers separated by an aquitard have been identified in the Kuwait Group, in areas southwest of the 12,000 mg/l concentration contour of the groundwater in the

Fig. 9.6 Kuwait Group (Dibdibba, Lower Fars, and Ghar Formations): **a** Sheet of sands and gravel, (Dibdibba Formation), Khabary Al Awazem 2019. **b** Cavernous calcareous sandstone, water-bearing formation, Al shaqiah 2019. **c** Dibdibba Formation over Fars Formation, Jal Az Zour, 2016. **d** Dibdibba Formation over Fars Formation, note the fractures and cavities at the base of the section, Jal Az Zour, 2016. **e** Dibdibba Formation (top) followed by calcareous sandstone and limestone (Fars Formation) Jal Az Zour, 2017. **f** White chalky limestone at the base of geologic section, Jal Az Zour, 2017

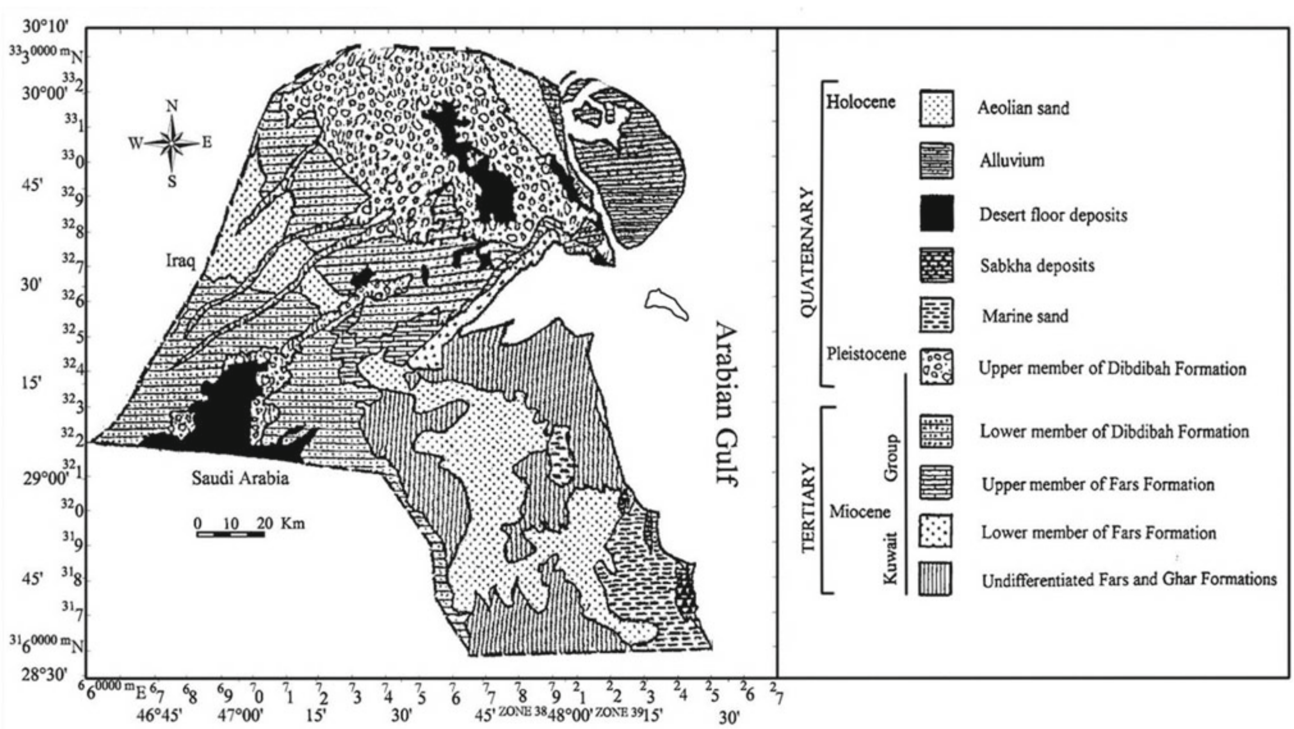


Fig. 9.7 Surface geological map of Kuwait

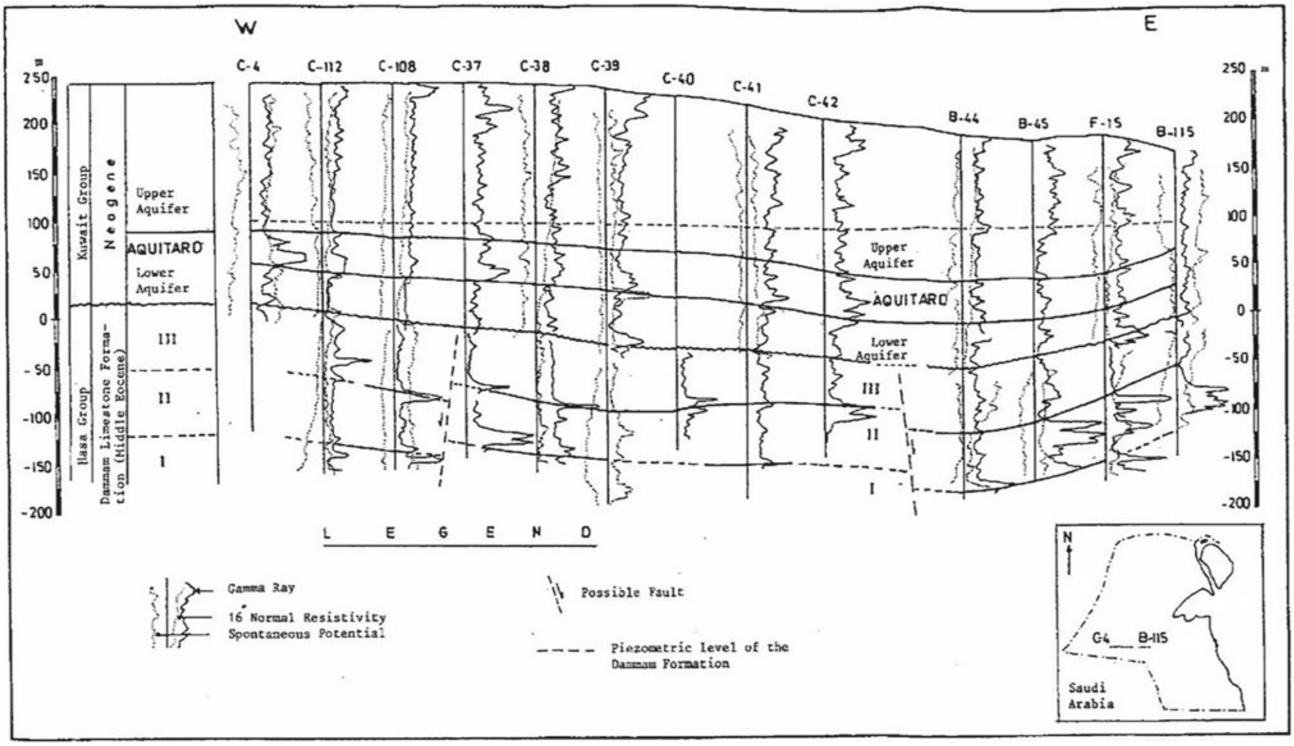


Fig. 9.8 Hydrological cross section (west–east) showing the hydrostratigraphic units of the Kuwait Group and Dammam Formation

underlying Dammam Limestone aquifer. These two aquifers of the Kuwait Group are believed to extend to the east and northeast of this contour line. The upper aquifer appears to be either a leaky water table aquifer or a leaky aquifer that is overlain by an aquitard containing a water table (Al-Sulaimi & El-Rabaa, 1994). The lower aquifer overlies the basal clays and/or the cherts capping the Dammam aquifer. Locally, however, the middle aquitard may grade into and dominate the lower aquifer forming together a relatively pervious aquitard. The two aquifers (and the underlying Dammam Formation, where semiconfined) form a system termed "couple leaky aquifers" or "mutually leaky aquifers" (Hantush, 1970). The water level in the Kuwait Group below the mean sea level (a.m.s.l) varies from zero along the coast to about 90 m in the southwest flowing generally towards the northeast (Al-Nasser, 1978).

9.4.2 Dammam Limestone Aquifer

The Dammam Formation underlies the entire state of Kuwait forming the main water-bearing formation in the country. It consists of chalky limestone, dolomitic limestone, limestone with zones of clay sand, and fossiliferous layers (Al-sharhan & Naim, 1997). The thickness of the Dammam Formation ranges from about 150 m to 280 m from southwest to northeast. The TDS content of the Dammam Formation groundwater ranges from 2500 mg/l up to 200,000 mg/l from extreme southwest to northeast (Fig. 9.9).

The initial piezometric heads of the Dammam aquifer (Fig. 9.10) indicate that water levels are about 140 m from mean sea level southwest of Kuwait (Abusada, 1988), and sloping in northeast direction. In comparison to Kuwait Group aquifer, the head in the Dammam aquifer is 3 to 20 m higher (Al-Ruwaih & Shehata, 1998). This resulted in expectation of upward vertical leakage between aquifers.

9.5 Al-Raudhtain Freshwater Field

As mentioned in literature, Al-Raudhtain water field is the oldest and biggest fresh groundwater field in Kuwait. Worth mentioning that this freshwater field was discovered accidently in the early 1960s (Parsons Corporation, 1963–1964). The TDS of the freshwater lenses range from less than 350 mg/l to 1000 mg/l. Al-Raudhtain topography, hydrogeology, and hydrochemistry were explored and studied by many researchers (Parson Corporation, 1964; Senay, 1973; Khalafalla, 1977; Al-Nasser, 1978; Al-Ruwaih, 1985, 1987; Al-Ruwaih & Ali, 1986; Al-Sulaimi, 1988; Al-Sulaimi et al., 1993; Hadi, 1993; Mukhopadhyay et al., 1996; Al-Sulaimi & Pitty, 1995; Al-Ruwaih & Shehata, 1998; Al-Sulaimi & Mukhopadhyay, 2000).

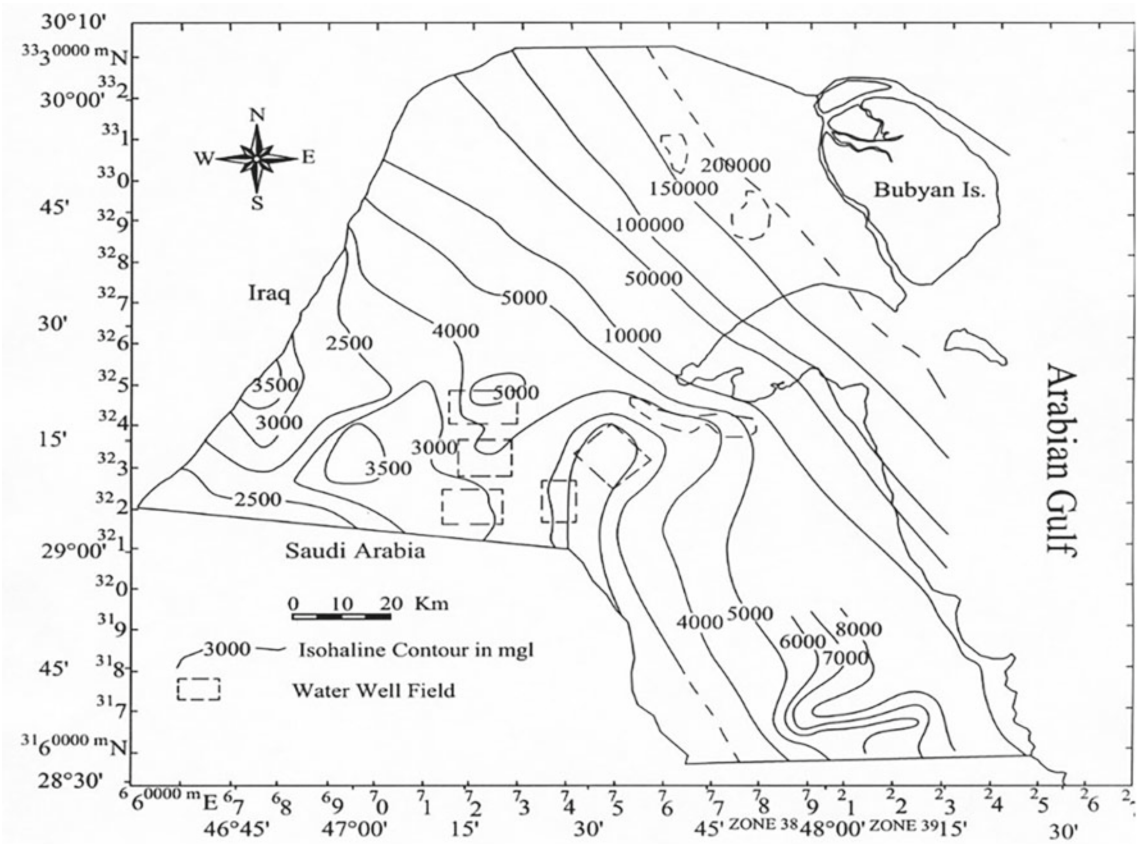


Fig. 9.9 Isosaline map showing the total dissolved solids in the groundwater of the Dammam Formation

Al-Raudhtain surface hydrologic unit is one of the major drainage basins in Kuwait. It exists in the northern part of the country, between latitudes 29° 40′N and 29° 59′N and longitudes 47° 20′E and 47° 44′E (Fig. 9.11). Generally Al-Raudhtain basin is a flat to slightly undulated area covered by sands and gravel. It is bounded by several dry wadis, which are flooded after heavy rain storms. Al-Raudhtain shallow hydrologic unit contains 12 wadis that drain into Al-Raudhtain playa from all directions (Fig. 9.12).

The total surface area of Al-Raudhtain drainage basin is about 670 km^2. The highest point in Al-Raudhtain drainage basin attains about 136 m above the sea level west of Kuwait, while the lowest point is close to 38 m above the sea level (Al-Sulaimi & Pitty, 1995). The lithology and stratigraphy of Al-Raudhtain hydrologic unit were studied by Senay (1973). The sediments of this hydrologic unit belong to the Holocene-Pleistocene period. They include drift sand, gravel, recent flood deposits silt, and clay besides the coarse sands and gravels of the Dibdibba Formation. The thickness of the Dibdibba Formation clastic attains approximately 107 m thick et al.-Raudhtain. The Dibdibba Formation is dominant with silts, cemented sands, gravels and with amount of minor clay. Shallow excavation in or near the middle of Al-Raudhtain basin has shown that below a depth of 1 to 2 m, the sand and gravel are firmly cemented by lime and gypsum lime which is known as gatch locally. The gatch zone extends up to a depth of 3.6 m, after which the cementation weakens and the sands and gravel become loose and friable.

According to Senay (1977), the system consists of only two main aquifers. The first one combines the upper and middle aquifers. The saturated thickness of this first aquifer ranges from 12 to 36 m and contains fresh groundwater occurring within depression. The second aquifer consists of the lower aquifer and underlying beds. The effective thickness may vary from 10 to 18 m and it contains saline water in the lower part and while in the upper part it contains brackish water. In general, its salinity varies from 205 to 975 mg/l, although the salinity of some wells may exceed 1300 mg/l. The mixture of these waters gives an average salinity of 625 mg/l. The best water quality appears at the upper limits of saturation (205–800 mg/l). The water salinity increases rapidly with depth, and there is the central part of the field represents the lowest water salinity; water quality tends to deteriorate towards the east and west.

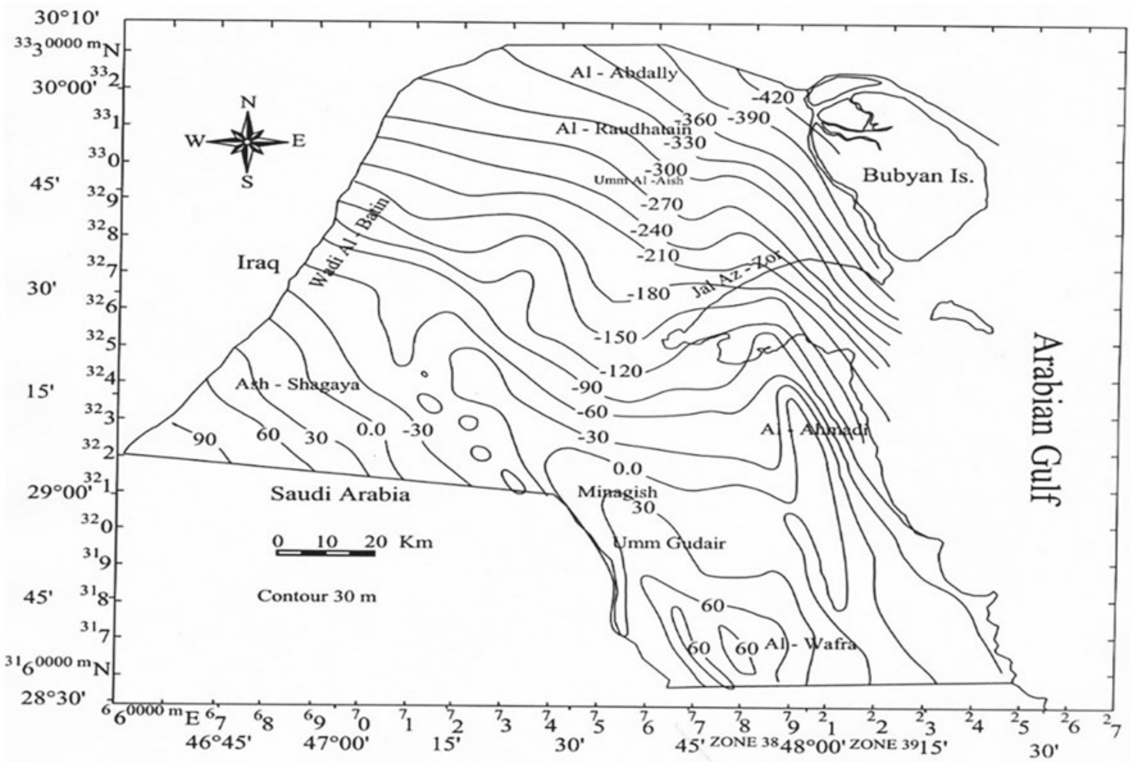


Fig. 9.10 Elevation contour map of the top of the Dammam Formation in Kuwait

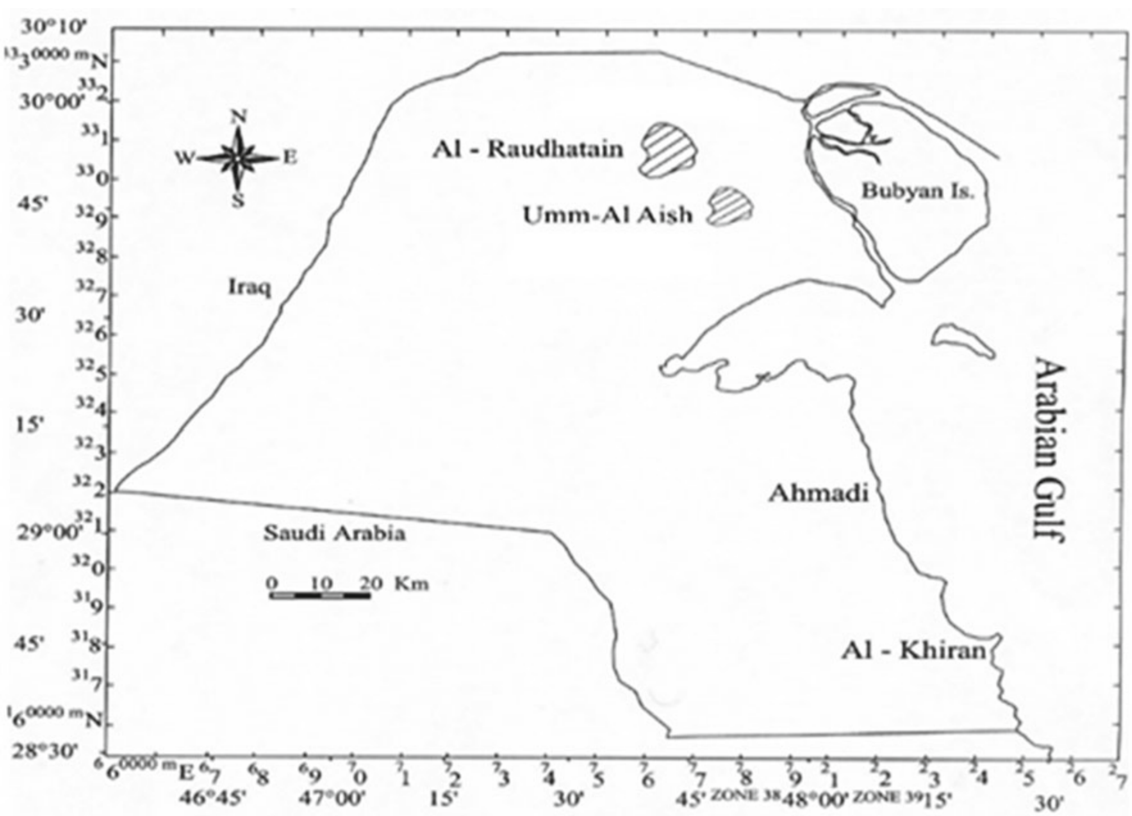


Fig. 9.11 Location map. Al-Raudhtain and Umm-Al-Aish

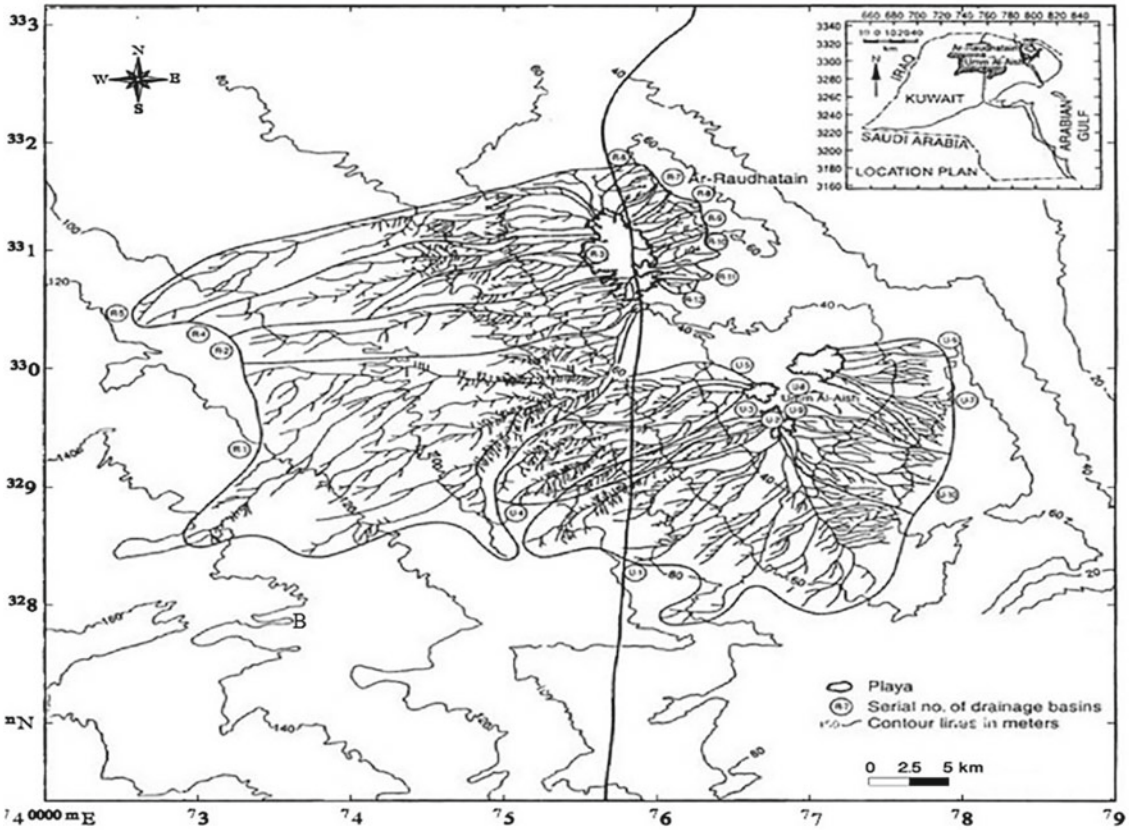


Fig. 9.12 Al-Raudhtain and Umm-Al-Aish drainage system

9.6 Groundwater Misuse and Consequences (the Case Al-Wafra Agricultural Area)

Misuse of irrigation water in Al-Wafra Agricultural Area is the main cause of soil salinization problem. During the period between 1995 and 2006, farmers were unofficially exploiting groundwater from Al Dammam Fractured Limestone aquifer (Salinity from 2500 mg/l to 10,000 mg/l). Some 600 flowing wells (Artesian) were developed. For at least ten years, there was no control over the flowing groundwater. Due to the lack of drainage systems at any level (farm or area levels), the irrigation water started to accumulate in low areas within the farms to form different depths, shapes, and sizes of water ponds. Due to high temperature (close to 45 °C in summer) and high evaporation in Kuwait (about 3000 mm/year), the soils started to be highly salinized. Consequently, the cultivations were deteriorated, and many farms were abandoned. While other farms were partially covered with water (depending on the farm elevation relative to the level of flowing wells in surrounding farms). Figures 9.13 and 9.14 show abandoned Al-Wafra Farms.

In general, the local geomorphology was one of the controlling factors for the salinity problem in Al-Wafra Agricultural Area (Hussain, 2016). Alternation of hollows (playas called locally khabrat) and ridges/cliffs accelerates the flow of water towards the farms in the low-lying areas (natural hollows). Soil salinization has negative economic, social, hydrologic and environmental impacts. In general, land degradation and depletion of crop yields are the most significant socioeconomic consequences of misuse of irrigation water. Figure 9.15 shows soil salinity, shallow groundwater level, abandoned farm, and deterioration of date palms in Al-Wafra Farms.

In 2009/2010, 434 flowing wells representing 72% of the total flowing wells were controlled by Ministry of Water and Electricity (MWE). As a result, water ponds disappeared and soils dried up. However, symptoms of soil salinization are remarkably observed.

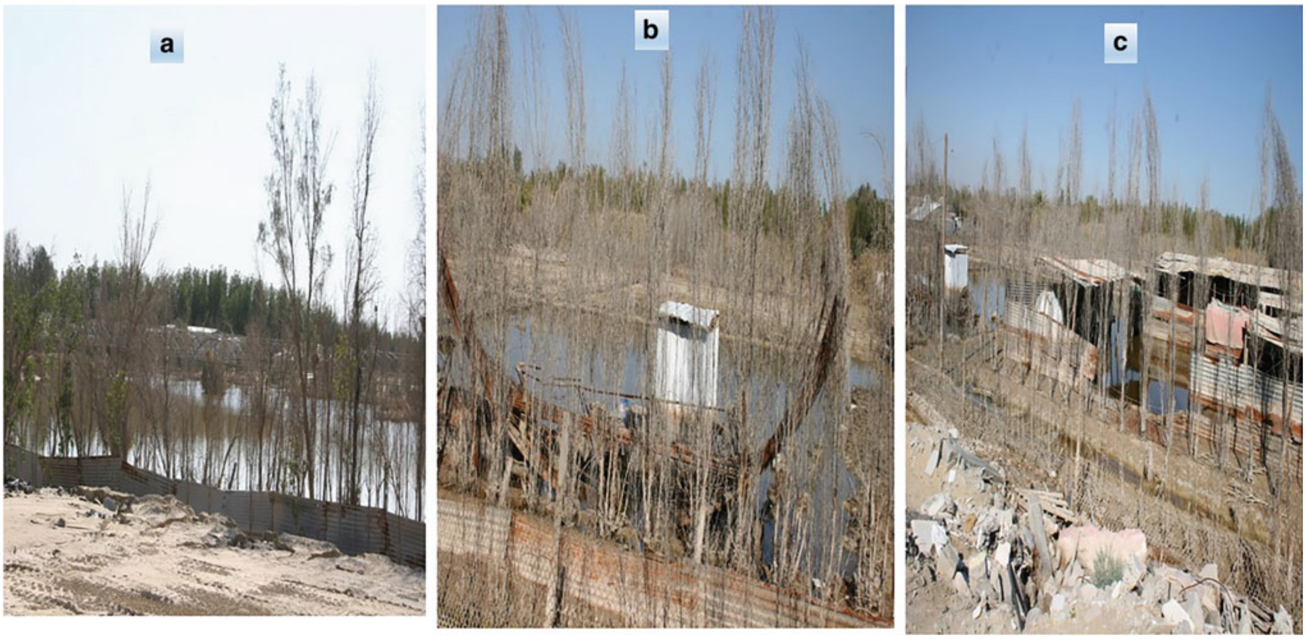


Fig. 9.13 Three abandoned Al-Wafra Farms, 2010 (before controlling flowing wells), **a** completely flooded **b**, **c** partly flooded

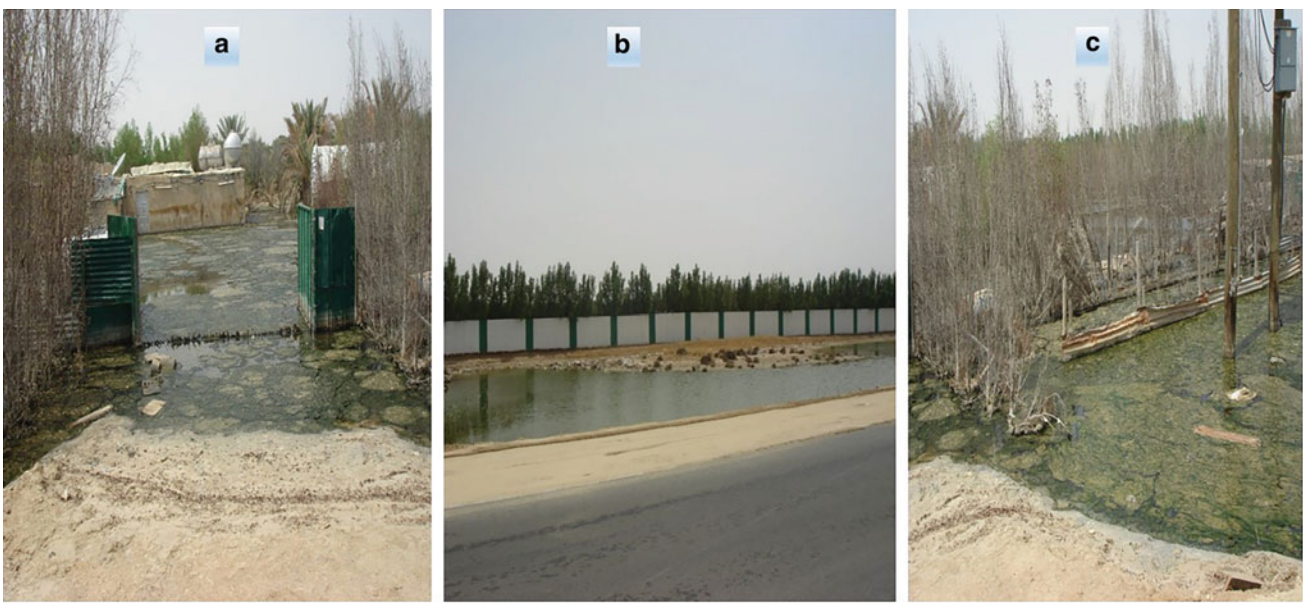


Fig. 9.14 Three abandoned Al-Wafra Farms, 2006 note the stagnant irrigation water in **a** and **c**

The level of salinity in some salt-affected farms in Al-Wafra Agricultural Area have reached a stage where the long-term productivity is deteriorated (EC more than 15 mS/cm), (Misak et al., 2014). Farmers invest in land improvement by covering the saline soils with a layer of fresh fine to medium sands of about 100 cm. thick they add manure to enhance soil fertility. Drip irrigation is applied. The cost of soil improvement is KD 0.65 ($ 2)/m^2. The cost includes materials and manpower. Figure 9.16 shows saline and cultivated soils.

Fig. 9.15 Soil salinization and water logging, Al-Wafra Farms (Misak, 2021). **a** Saline water pond (irrigation water drain). **b** Wet unproductive soil. **c** Salts (mainly sodium chloride) resulted from evaporation of irrigation water. **d** Shallow saline groundwater (about 100 cm from ground). **e** Killed date palm trees (saline soil). **f** Farm invaded by irrigation water (abandoned)

Fig. 9.16 Reclamation of saline soils after treatment (from saline nonproductive soil to non-saline and productive one)

9.7 Monitoring Water Ponds and Saline Soils, Al Wafra Agricultural Area (2008–2011)

In 2009/2010, some 434 flowing wells in Al Wafra Agricultural Area were controlled by the MEW in Kuwait. Consequently, the sizes of water ponds and saline wetlands were remarkably reduced. To monitor the water ponds and saline wetlands in Al Wafra Agricultural Area, five sites were selected. These sites were mapped using high-resolution satellite images of 2008 (before controlling flowing wells) and 2011 (after controlling flowing wells). Arc GIS 9.3 was used to accurately delineate the saline wetlands and water ponds (Table 9.2 and Figs. 9.17, 9.18 and 9.19).

9.8 Saline Wetlands

In 2008 (prior controlling the flowing wells which were the source of excessive irrigation water to Al Wafra Farms) the size of saline wetlands was 7,564,323 m^2. In 2011 (after controlling the flowing wells) the size was reduced to 151,292.2 m^2 (98%).

Site 1: In 2008 the size of the saline wetlands in site 1 was 601,983.2 m^2, while in 2011 it was decreased to 136,597.8 m^2 (77%)
Site 2: In 2008 the size of the saline wetlands in site 2 was 40,346 m^2, while in 2011 it was decreased to 3995.4 m^2 (90%)

Table 9.2 Comparing between 2008 and 2011 water ponds and saline soils

Site	Water ponds (m^2) 2008	Saline soils (wetlands), m^2 2008	Water ponds (m^2) 2011	Saline soils (wetlands) (m^2) 2011
1	67,368.6	601,983.2	18,120	136,597.8
2	8108.6	40,346	2941	3995.4
3	9464	908.2	3259.3	760.4
4	13,605.9	60,412.6	316.6	3921.9
5	12,947.9	52,782.3	613.5	6016.7
Total	111,495	756,4323	25,250.4	151,292.2
Average	**22,299**	**151,286.46**	**5050.08**	**30,258.44**

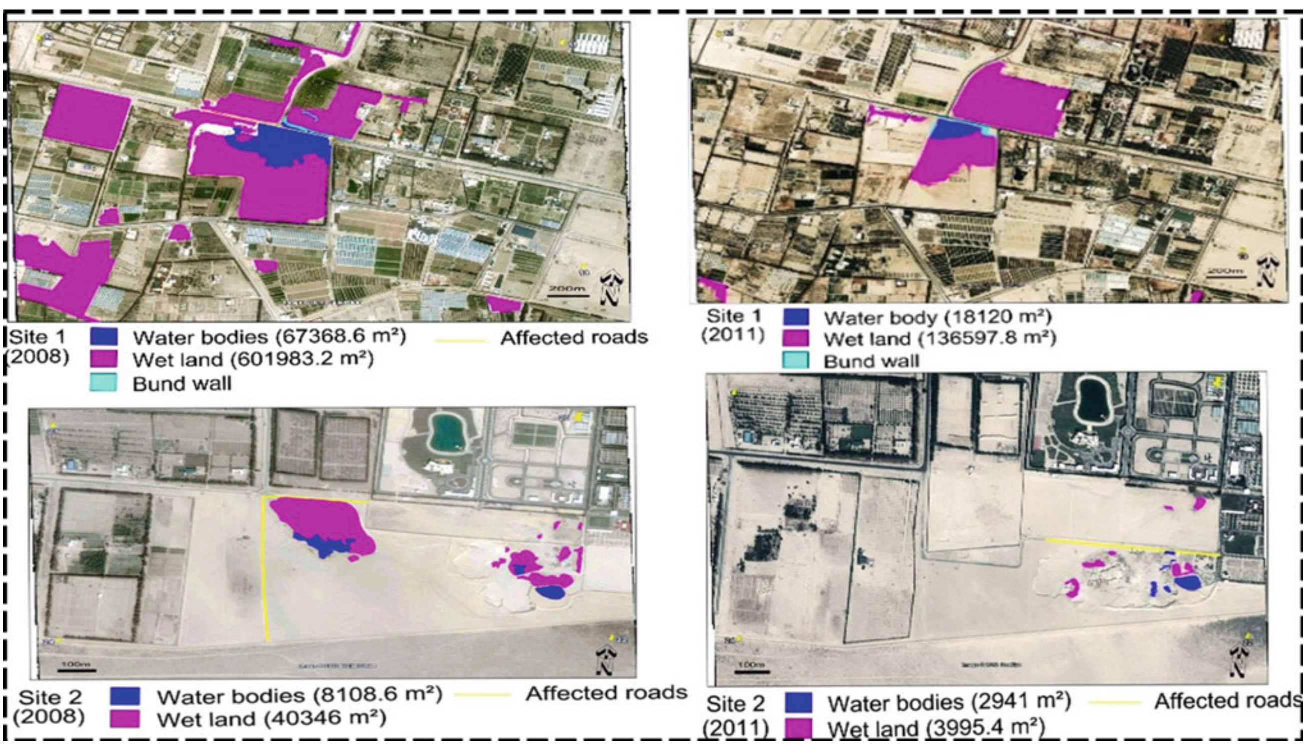


Fig. 9.17 Sites 1 and 2 (2008 and 2011)

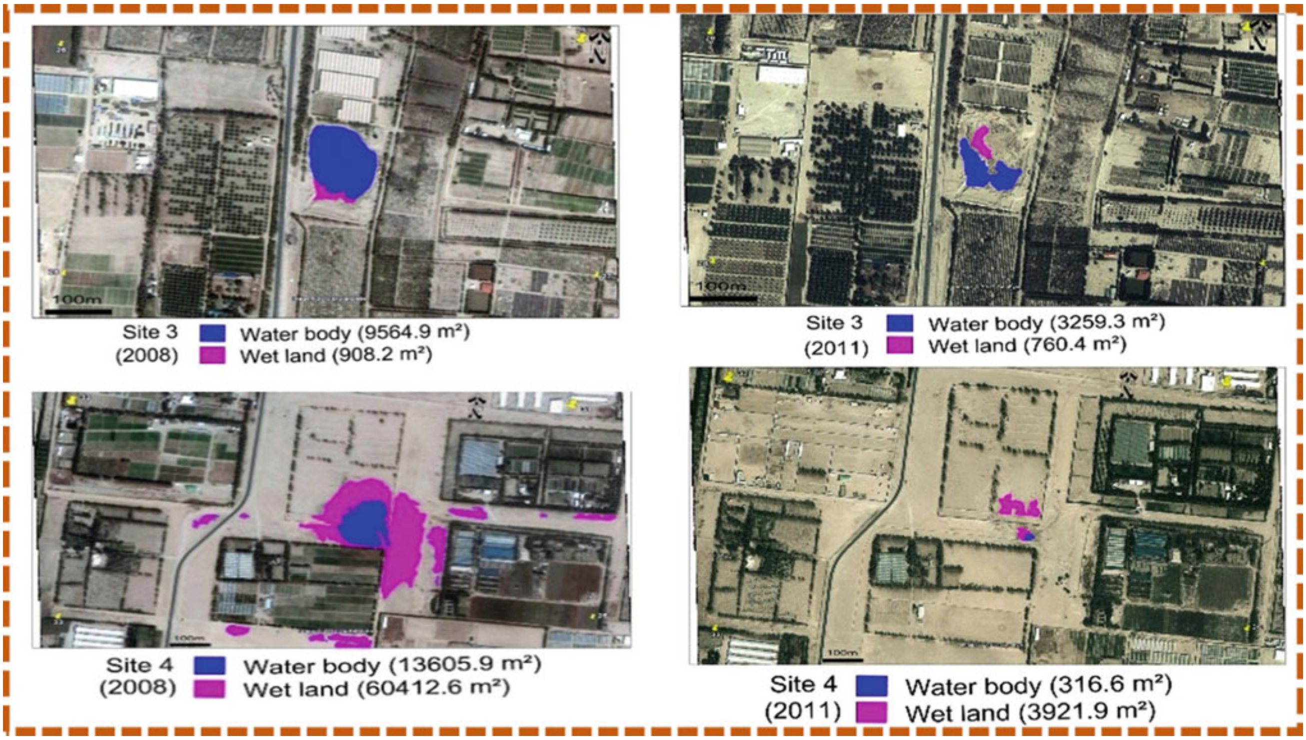
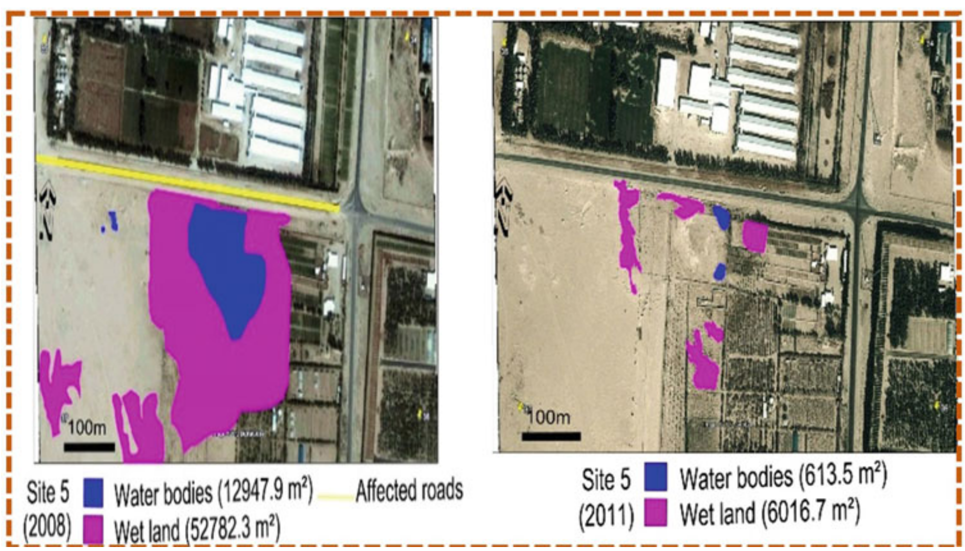


Fig. 9.18 Sites 3 and 4 (2008 and 2011)

Fig. 9.19 Site 5 (2008 and 2011)



Site 3: In 2008 the size of the saline wetlands in site 3 was 908.2 m^2 while in 2011 it was decreased to 760.4 m^2 (16%)
Site 4: In 2008 the size of the saline wetlands in site 4 was 60,412.6 m^2 while in 2011 it was decreased to 3921.9 m^2 (93%)
Site 5: In 2008 the size of the saline wetlands in site 5 was 52,782.3 m^2 while in 2011 it was decreased to 6016.7 m^2 (88.6%).

9.9 Water Ponds

In 2008 (prior controlling the flowing wells which were the source of excessive irrigation water to the farms) the size of the total water ponds was 111,495 m^2. In 2011 (after controlling the flowing wells) the size of the water ponds remarkably reduced to 25,250.4 m^2 (77%)

Site 1: In 2008 the size of the water ponds in site 1 was 67,368.6 m^2 while in 2011 was decreased to18120 (73%)
Site 2: In 2008 the size of the water ponds in site 2 was 8108.6 m^2 while in 2011 the size was decreased to 2941 m^2 (64%)
Site 3: In 2008 the size of the water ponds in site 3 was 9464 m^2 while in 2011 the size was decreased to 3259.3 m^2 (65.5%)
Site 4: In 2008 the size of the water ponds in site 4 was 13,605.9 m^2 while in 2011 the size was decreased to 316.6 m^2 (97%)
Site 5: In 2008 the size of the water ponds in site 5 was 12,947.9 m^2 while in 2011 the size was decreased to 613.6 m^2 (95%). Figures 9.17, 9.18 and 9.19.

9.10 Summary and Conclusion

In Kuwait, fresh and brackish groundwater resources form only two main aquifers. These are Dammam Formation and Kuwait Group. The Kuwait Group consists of an alternation of sands, gravels, sandstones, clays, silts, limestones, and marls. In Kuwait Group water, TDS increases in general from about 2500 mg/l to 100,000 mg/l from southwest to northeast. Fresh groundwater occurs in the depressions of Al-Raudhatain, Umm Al-Aish, and Umm Nigga north of Kuwait. The Dammam Formation is considered the main aquifer. It consists of chalky limestone, dolomitic limestone, and limestone with some clayey, sandy, and fossiliferous zones. TDS of the groundwater of the Dammam Formation ranges from 2500 mg/l to 200,000 mg/l in the direction from southwest to the northeast. The misuse of groundwater within Dammam Formation causes the soil salinization problems. These high salinity levels of soil cause deterioration of farm productivity. Farmers invest in land improvement by covering the saline soils with a layer of fresh sands. They add manure to enhance soil fertility. Drip irrigation is applied. The cost of soil improvement is KD 0.65 ($ 2)/m^2.

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