Chapter 16

Widyan-Salman

Umm er Radhuma-Dammam Aquifer System (North)

INVENTORY OF

SHARED WATER RESOURCES IN WESTERN ASIA (ONLINE VERSION)

How to cite

UN-ESCWA and BGR (United Nations Economic and Social Commission for Western Asia; Bundesanstalt für Geowissenschaften und Rohstoffe). 2013. Inventory of Shared Water Resources in Western Asia. Beirut.

Umm er Radhuma-Dammam Aquifer System (North)

Widyan-Salman

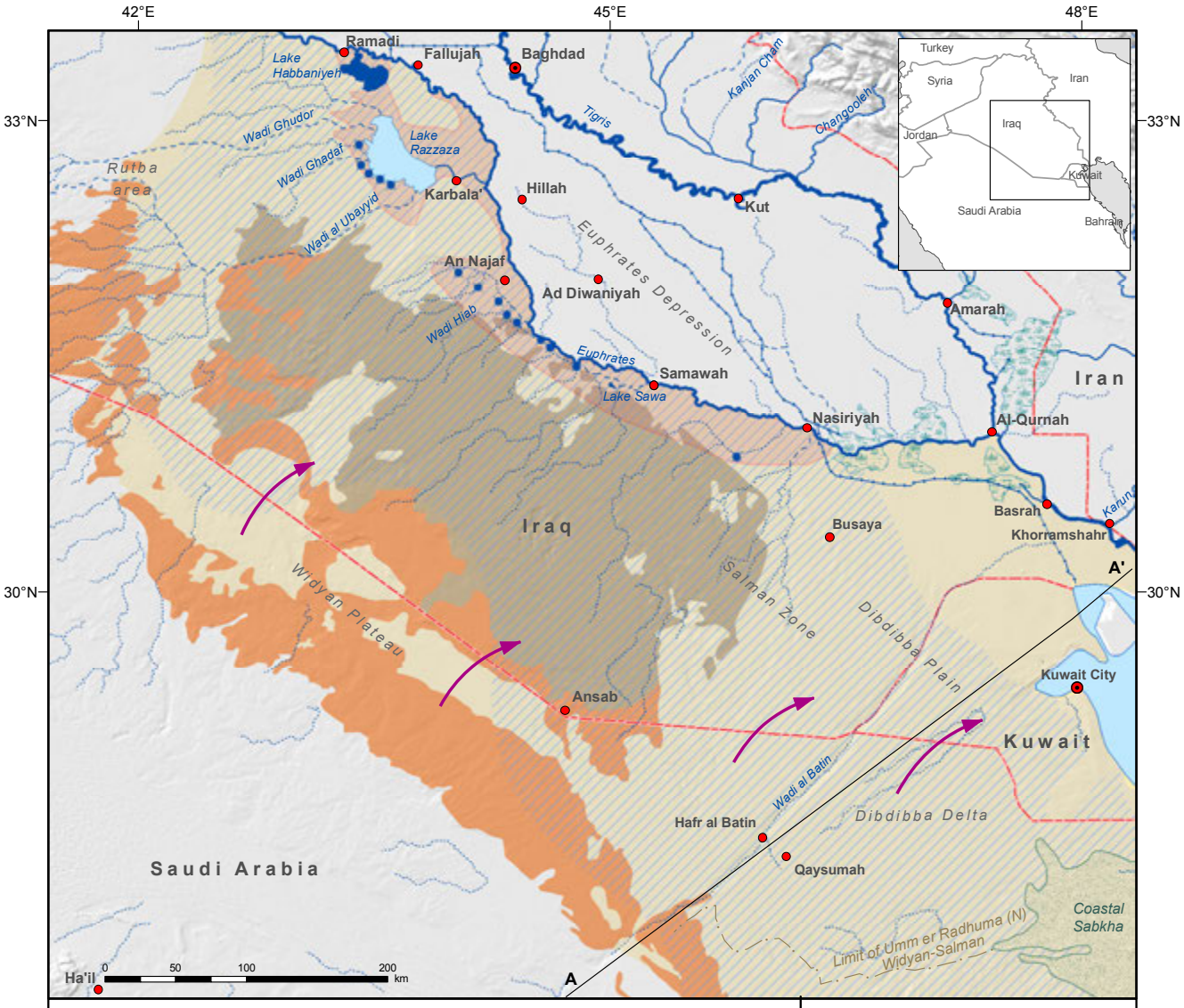
EXECUTIVE SUMMARY

The Umm er Radhuma and Dammam Formations constitute the main aquifers in this system, which stretches from the Rutba-Widyan area eastward through the Salman Zone to the Dibdibba Delta, forming a shared aquifer system between Iraq, Kuwait and Saudi Arabia. The two main aquifer formations are composed mainly of limestone and exhibit a shallow water table (0 - <250 m bgl). Limited recharge occurs mainly through the Umm er Radhuma outcrops. The general groundwater flow direction is from the outcrops in the south-west towards the Euphrates Depression and the Gulf coast in the north-east. Good quality water is found around the Salman Zone in Iraq, while springs along the Euphrates River naturally discharge slightly more saline groundwater. Available information indicates that the three riparian countries currently exploit the aquifer system, primarily in the Dammam and the upper part of the Umm er Radhuma Formations, resulting in a water-level decline of up to 60 m in both formations. Nevertheless, the aquifer system remains exploitable in most of this section, except in the Widyan Plateau that straddles the Saudi-Iraqi border and coastal areas where it is either dry or contains saline water.

BASIN FACTS

RIPARIAN COUNTRIES	Iraq, Kuwait, Saudi Arabia
ALTERNATIVE NAMES	Euphrates-Northern Gulf Basin, Euphrates-Dibdibba
RENEWABILITY	Very low to low (0-20 mm/yr)
HYDRAULIC LINKAGE WITH SURFACE WATER	Weak
ROCK TYPE	Fissured/karstic
AQUIFER TYPE	Unconfined to semi-confined or confined
EXTENT	~246,000 km^2
AGE	Cenozoic (Paleogene)
LITHOLOGY	Mainly limestone and dolomite, with some evaporates
THICKNESS	Dammam: 30-80 m Umm er Radhuma: 240-600 m
AVERAGE ANNUAL ABSTRACTION	Iraq: ~45 MCM (early 1990s) Kuwait: ~90 MCM (1993) Saudi Arabia: ..
STORAGE	..
WATER QUALITY	Fresh to hypersaline
WATER USE	Agricultural, industrial and domestic use except for drinking
AGREEMENTS	-
SUSTAINABILITY	Over-abstraction resulting in lowering of the water table and salinity increase due to upconing of saline water and seawater intrusions

OVERVIEW MAP



Umm er Radhuma-Dammam Aquifer System (North): Widyan-Salman

- Capital
- Selected city, town
- International boundary
- River
- Intermittent river, wadi
- Freshwater lake
- Saltwater lake
- Spring
- Canal, irrigation tunnel
- Umm er Radhuma Formation outcrop
- Dammam and Rus Formations outcrop
- Approximate subsurface extent of the aquifer formations
- Approximate extent of exploitable area
- A__A' Hydrogeological cross-section
- Direction of groundwater flow
- Sabkha
- Artesian zone
- Wetland

ESCWA

BGR Bundesanstalt für Geowissenschaften und Rohstoffe

Inventory of Shared Water Resources in Western Asia

Disclaimer
The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

CONTENTS

INTRODUCTION 410

Location 410
Area 410
Climate 410
Population 410
Other aquifers in the area 410
Information sources 410

HYDROGEOLOGY - AQUIFER CHARACTERISTICS 411

Aquifer configuration 411
Stratigraphy 411
Aquifer thickness 412
Aquifer type 412
Aquifer parameters 412

HYDROGEOLOGY - GROUNDWATER 413

Recharge 413
Flow regime 413
Storage 413
Discharge 413
Water quality 414
Exploitability 414

GROUNDWATER USE 415

Groundwater abstraction and use 415
Groundwater quality issues 415
Sustainability issues 415

AGREEMENTS, COOPERATION & OUTLOOK 416

Agreements 416
Cooperation 416
Outlook 416

NOTES 417

BIBLIOGRAPHY 418

FIGURES

FIGURE 1.	Hydrogeological cross-section of the Umm er Radhuma-Dammam Aquifer System (North) across the Kuwait-Saudi border	411
FIGURE 2.	Recharge estimates for the Umm er Radhuma-Dammam Aquifer System (North) north-west of Wadi al Batin	413
FIGURE 3.	Groundwater salinity map - Umm er Radhuma-Dammam Aquifer System (North)	414
FIGURE 4.	Annual groundwater abstraction from well fields in Kuwait	415

TABLES

TABLE 1.	Lithostratigraphy and water-bearing characteristics of the Umm er Radhuma-Dammam Aquifer System (North) Paleogene Formations	411
TABLE 2.	Hydraulic parameters of the Umm er Radhuma-Dammam Aquifer System (North)	412

Introduction

The Umm er Radhuma-Dammam Aquifer System in this Inventory

The Umm er Radhuma-Dammam Aquifer System extends from northern Iraq to the southern coast of the Arabian Peninsula over a distance of 2,200 km. Overall, it covers an area of more than 1,220,000 km^2, of which 363,000 km^2 is covered by outcrops. The total area of this aquifer system in Saudi Arabia, which shares the northern, central and southern sections with neighbouring countries, is 662,000 km^2 (see 'Overview and Methodology: Groundwater' chapter, Map 2).

This system generally comprises three Paleogene (Paleocene-Eocene) Formations: the Dammam, the Rus and the Umm er Radhuma. These formations stretch across Iraq, Yemen and the six Gulf Cooperation Council countries.[1] However, the water contained within these formations cannot be considered shared between all countries. For example, a well pumping from the Dammam Formation in Iraq cannot affect the productivity of this formation in Yemen and vice versa. Furthermore, there is significant variation in the lithostratigraphy of these three formations, particularly the Rus, which is water-bearing in some areas, while acting as an aquitard in others.

Because of the large geographical extent and the lithostratigraphic variations within the formations, the aquifer system has for the purpose of this Inventory been divided into three sections: a northern section (see current chapter), a central section (see Chap. 15) and a southern section (see Chap. 14).[2] This division, which is primarily based on the geographical extent of the formations, also takes relevant geological information into consideration to define the section boundaries.

LOCATION

The northern section of the Umm er Radhuma-Dammam Aquifer System extends south-eastwards from the Rutba area in Iraq to the Dibdibba Delta in Saudi Arabia, covering two wide plateaus – the Widyan Plateau and the Salman Zone (see Overview Map) – from which it derives its name. This section is delimited by the Euphrates River in the north and constitutes a shared aquifer system between Iraq, Kuwait and Saudi Arabia.

AREA

The northern section of the aquifer as covered in this chapter only represents about 20% of the aquifer system's total area. Within the boundary of the suggested delineation, the northern section of the aquifer system covers a total area of 246,000 km^2, of which around 150,000 km^2 is located in Iraq, 16,000 km^2 in Kuwait and 80,000 km^2 in Saudi Arabia.

CLIMATE

Most of this section of the aquifer system falls within the Summan Plateau agro-climatic zone, except for the coastal areas, which constitute the Southern Gulf Coast agro-climatic zone.[3] Average temperatures range from lows of 14°C in winter to highs of 34°C in summer, except in the coastal areas where temperatures can reach up to 60°C in July. Mean annual precipitation is around 90 mm,[4] with rainfall concentrated in winter and spring.

POPULATION

The entire state of Kuwait, which has an estimated population of 3.3 million,[5] falls within the Umm er Radhuma-Dammam Aquifer System (North) section. This population partly relies on the aquifer system for irrigation, industrial and domestic uses other than drinking. In Iraq, the governorates of Basrah, Muthanna and An Najaf[6] fall within this region, with a total population of approximately 4.5 million inhabitants. In Saudi Arabia, the area is sparsely populated with a total of 240,000 inhabitants, or 2-5 inhab./km^2,[7] in the Ar'ar and Rafha Governorates.[8]

OTHER AQUIFERS IN THE AREA

The overlying (Neogene) Kuwait Group Aquifer is heavily used in Kuwait and to a lesser extent in Iraq, where it is known as the Dibdibba Aquifer (see Chap. 26). The northern section of the Umm er Radhuma Aquifer System is underlain by the Cretaceous Aquifers of the Aruma in Saudi Arabia and Hartha-Tayarat-Digma in Iraq (see Chap. 13).

INFORMATION SOURCES

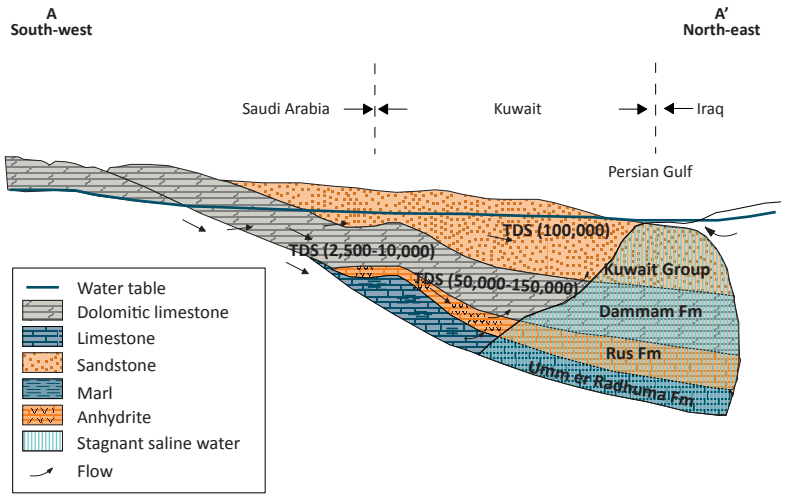
While hydrogeological data on the Umm er Radhuma-Dammam Aquifer System (North) is available, data on abstraction is limited and mostly outdated. Data included in this chapter was mainly collected from Iraq and Kuwait. Delineation of the Overview Map was based on various local and regional references.[9]

Hydrogeology - Aquifer Characteristics

AQUIFER CONFIGURATION

The Umm er Radhuma and the Dammam Formations constitute the main aquifers in the system, while the Rus (or Jil)[10] Formation separating them acts mainly as an aquitard and may retain poor-quality water in specific locations.[11] The top of the Umm er Radhuma is generally situated 100-400 m asl, but drops rapidly in the centre of the Wadi al Batin area and its eastern extension to the Dibdibba Plain, where it can reach 800 m bsl. The top of the Dammam lies about 200 m higher than the Umm er Radhuma and crops out over larger areas north-west of the Salman Zone in Iraq. In the late 1990s, the water table in the Umm er Radhuma was 100-200 m asl in the central part of this section of the aquifer system.[12] Further east, where the Dammam and younger sediments cover the Umm er Radhuma, the water table was 50-200 m asl.

Figure 1. Hydrogeological cross-section of the Umm er Radhuma-Dammam Aquifer System (North) across the Kuwait-Saudi border



Source: Modified by ESCWA-BGR based on UN-ESCWA and BGR, 1999.

STRATIGRAPHY

The lithology of the two major units that form the aquifer system displays some variation both vertically (within a country) and laterally (across countries), as indicated in Figure 1 and Table 1.

The lower aquifer, the Umm er Radhuma, crops out extensively along the Widyan Plateau and intensive karstification of these outcrops has been reported, particularly in the border

Table 1. Lithostratigraphy and water-bearing characteristics of the Umm er Radhuma-Dammam Aquifer System (North) Paleogene Formations

COUNTRY	UMM ER RADHUMA		DAMMAM	
	LITHOLOGY	WATER-BEARING CHARACTERISTICS	LITHOLOGY	WATER-BEARING CHARACTERISTICS
Iraq (Salman Zone)	Upper: limestone, dolomite. Lower: marly limestone, dolomite, marl, evaporites.	Upper: aquifer with moderate productivity; generally confined. Lower: aquitard; locally poor aquifer.	Limestone, dolomite.	Major, extensive and productive aquifer; confined or semi-confined.
Kuwait	Marly limestone, dolomite, some anhydrite.	Brackish to saline water.	Upper and middle: chalky and karstified limestone. Lower: dolomitic limestone, anhydrite, shale.	Upper and middle: major aquifer. Lower: aquitard; locally poor aquifer.
Saudi Arabia	Chalky and dolomitic limestone, dolomite, with significant layers of anhydrite and chert in the upper part.[13]	Brackish to saline water.	Limestone and marl.	Moderate aquifer.

Source: Compiled by ESCWA-BGR based on United Nations, 1999; Jassim and Buday, 2006b; Ministry of Agriculture and Water in Saudi Arabia, 1984.

area of Ansab between Iraq and Saudi Arabia. Accordingly, yield and water quality vary laterally and vertically. The Damman Aquifer is generally more extensive and productive in the Salman Zone and often has better water-bearing characteristics than the Umm er Radhuma Aquifer. The Rus (Jil) crops out mainly in the central to north-eastern areas and consists predominantly of anhydrite with some limestone, shale and marl.

AQUIFER THICKNESS

The Umm er Radhuma has a thickness of 240 m at the type section in the Wadi al Batin area in Saudi Arabia[14] and in the Nukhaib area in Iraq.[15] Thickness generally increases towards the east where it can reach 600 m.[16] The Dammam is generally thinner, with a saturated thickness decreasing towards the northern parts of the Salman Zone (30-80 m). In some areas of the Umm er Radhuma-Dammam Aquifer System (North), perched groundwater occurs above low permeability layers at shallow depths within the Dammam.

AQUIFER TYPE

In most of the western areas of this section where the Umm er Radhuma crops out, the formation is either unsaturated, contains discontinuous groundwater occurrences, or comprises discontinuous perched or shallow aquifers.[17] In the central part, where the Umm er Radhuma is confined by the Rus at shallow depths, it constitutes an aquifer with moderate productivity. The Dammam is of unconfined or semi-confined nature in the Salman Zone in Iraq and neighbouring areas of south-western Kuwait. By contrast, it is confined in the Wadi al Batin area in Saudi Arabia. In the lowland areas to the east and south of the outcrops (i.e. the Euphrates Valley, Wadi al Batin area and Dibdibba-Kuwait Plain), the Dammam is also confined below an aquitard layer composed of Neogene marls.

AQUIFER PARAMETERS

Groundwater in this aquifer system is produced mainly from the Dammam Formation and the upper part of the Umm er Radhuma Formation, which are usually hydraulically connected through the Rus Formation. The transmissivity of this aquifer system is largely controlled by karstification, lineaments and facies changes within the carbonate rocks. In general, transmissivity is high in karstified areas and low where marl occurs more frequently. Therefore, the aquifer system has a wide range of transmissivity values (Table 2).[18] Strong karstification occurs where the upper part of the Umm er Radhuma and Rus (Jil) Formations crop out, causing dissolution of the underlying gypsum and producing sinkholes and depressions in the overlying carbonates.[19]

Table 2. Hydraulic parameters of the Umm er Radhuma-Dammam Aquifer System (North)

COUNTRY	UMM ER RADHUMA		DAMMAM	
	TRANSMISSIVITY (m^2/s)	STORATIVITY	TRANSMISSIVITY (m^2/s)	STORATIVITY
Iraq (Salman Zone)	$1.2x10^{-4}$-$2.0x10^{-2}$	..	$3.5x10^{-5}$-$1.7x10^{-2}$	$1.0x10^{-2}$-$2.8x10^{-1}$
Kuwait	..	..	$1.5x10^{-4}$-$5.4x10^{-2}$ AVG:[a] $5.6x10^{-3}$	$6.0x10^{-7}$-$3.9x10^{-1}$
Saudi Arabia	$4.0x10^{-5}$-$1.1x10^{-2}$	..	$2.7x10^{-3}$ (Wadi al Batin)	..

Source: Compiled by ESCWA-BGR based on Ministry of Agriculture and Water in Saudi Arabia, 1984; UN-ESCWA and BGR, 1999.
(a) AVG refers to average values.

Hydrogeology - Groundwater

RECHARGE

Only 4-8 mm/yr (7-13%) of the estimated 60 mm/yr of rain that falls on the Umm er Radhuma outcrop infiltrates into the aquifer.[20] This area lies mainly within Saudi Arabia and probably has the highest rate of replenishment to the aquifer system, since the upper part of this formation is the most karstified. In the Salman Zone, where outcrops of the Dammam Formation are most common, the average recharge rate is estimated at 6-7.5 mm/yr.[21]

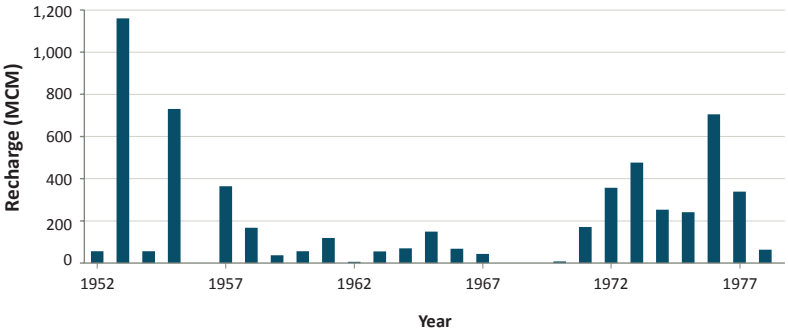
North-west of Wadi al Batin, total annual recharge to the Umm er Radhuma outcrops over an area of 82,400 km^2 ranged between nil and 1,160 MCM (0-14.1 mm/yr) for the period 1952-1978 (Figure 2) with an average annual recharge of 213 MCM (2.6 mm/yr).[22] The relatively significant but highly variable observed recharge can be attributed to three characteristic factors in this zone:

- The prevalence of high-intensity rainfall in desert-type storms which creates overland flow.
- The widespread occurrence of elevated gravel ridges, which are a remnant of old paleo-river drainage systems that still act as drainage paths in times of heavy rainfall, resulting in the formation of ponds.
- The exposed karst features in Paleogene and younger sediment outcrops, particularly in solution collapse areas allowing for fast infiltration.[23]

FLOW REGIME

The general groundwater flow direction is from the recharge areas in the south-west to the discharge areas in the north-east. In northern areas, the flow is towards the Euphrates Depression that was created by a major regional fault. In the Wadi al Batin area and Dibdibba Delta areas further south, groundwater flows towards the Gulf coast and Shatt al Arab with the formation of a large sabkha at the surface.

Figure 2. Recharge estimates for the Umm er Radhuma-Dammam Aquifer System (North) north-west of Wadi al Batin



Source: Compiled by ESCWA-BGR based on Faulkner, 1994.

STORAGE

The Umm er Radhuma probably has significantly higher storage than the Dammam for the following reasons:

- The Dammam is thinner and has over the years been tapped by thousands of wells due to the shallow depth to water.
- Most of the aquifer system replenishment area is covered by Umm er Radhuma outcrops.[24]

However, no data was available on the volume of storage in both formations.

DISCHARGE

In places where the Paleogene outcrops are covered by Neogene-Quaternary sediments in Iraq, natural discharge occurs from springs along the western bank of the Euphrates River and Lake Razzaza,[25] as well as in the small natural, groundwater-fed Lake Sawa. Total annual discharge in this area has been estimated at 50 MCM, with a discharge of 33 MCM from large springs in the artesian zone around the Euphrates Depression, 3 MCM from small springs on the plateau area west of the valley, and 14 MCM through evaporation from Lake Sawa.[26]

From the early 1950s to late 1970s, annual discharge from the Umm er Radhuma in Saudi Arabia was virtually identical to recharge, indicating that abstraction was within the sustainable yield[27] before development started and water levels began to drop.

WATER QUALITY

While groundwater is relatively fresh in the western (Widyan-Nukhaib) area (<1,000 mg/L TDS), it becomes brackish (TDS up to 5,000 mg/L) in the central (Salman-Hafr al Batin) area and changes drastically to hypersaline brines (TDS 50-150 g/L) over a short distance along the coastal Dibdibba Plain (Figure 3; see also Figure 1). Hence, the groundwater salinity generally increases along the flow path from the recharge areas (Umm er Radhuma outcrop) to the discharge areas along the Euphrates Depression and Gulf coast. This is also reflected in the major ion composition of groundwater, which changes from HCO_3-type in the Widyan-Nukhaib area to SO_4-Cl-type in the Salman-Hafr al Batin area to Cl-type in the Dibdibba Plain.

EXPLOITABILITY

The following criteria were used to delineate the exploitable areas of this aquifer system:

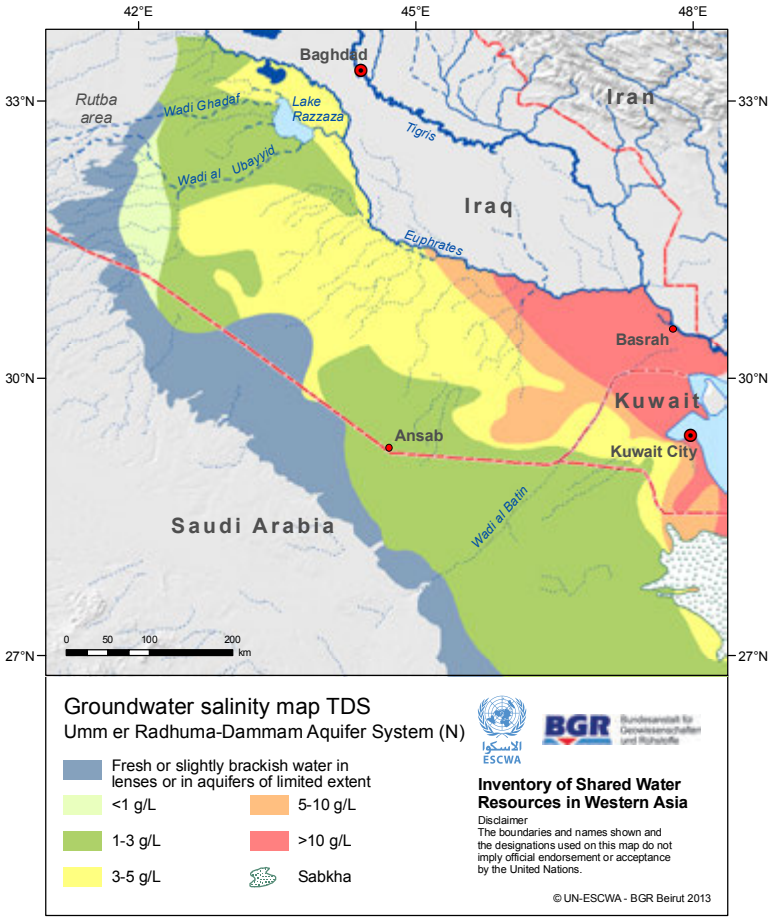
- **Depth to top of aquifer:** the average depth to the top of the Dammam in Saudi Arabia was reported at 80-120 m bgl.[28] In the Salman Zone and the western part of Wadi al Batin, the top of the Umm er Radhuma is at 50-100 m bgl[29] and the depth of exploitation bore-holes is 50-150 m bgl.[30] Hence drilling depth is not a limiting factor to exploitability in this section of the Aquifer System.

- **Depth to water level:** depth to groundwater in the Salman Zone was found to be around 50 m bgl rising to 5-20 m bgl[31] along the Euphrates River where groundwater is also discharged on the surface. This indicates that groundwater is shallow enough for exploitation.

- **Water quality:** salinity is a limiting factor in the coastal areas in the Dibdibba Plain (Figure 3).

Based on the above, most of the Umm er Radhuma-Dammam Aquifer System (North) appears to be exploitable (see Overview Map), with the exception of the Widyan Plateau and the coastal areas where the aquifer is either of limited extent or contains saline water as shown in Figure 3. The total exploitable area within the delineated basin is 179,000 km^2 of which around 123,000 km^2 lies in Iraq, 9,000 km^2 in Kuwait and 47,000 km^2 in Saudi Arabia.

Figure 3. Groundwater salinity map - Umm er Radhuma-Dammam Aquifer System (North)



Source: Modified by ESCWA-BGR based on UN-ESCWA and BGR, 1999.

Groundwater Use

GROUNDWATER ABSTRACTION AND USE

Available data indicates that the three riparian countries currently exploit the aquifer system.

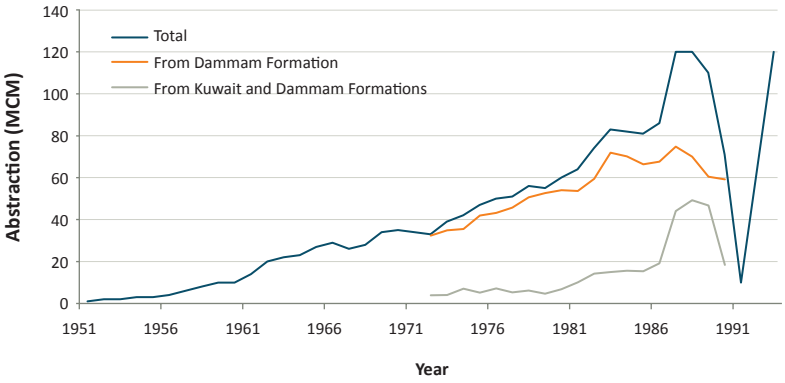
In Kuwait, pumping of about 1 MCM/yr, mainly from the Dammam, started in 1951, slowly increasing to 10 MCM/yr by 1960. Over the next three decades abstraction rates rose significantly to reach 120 MCM/yr in 1988 (Figure 4). The sharp drop in production during the period 1990-92 can be ascribed to the reduction in operations and destruction of well fields during the Second Gulf War. However, even during the war, the growing demand could not be satisfied from the Dammam Aquifer alone and exploitation of the overlying Kuwait Group Aquifer supplemented supply through the expansion of the Umm Gudair well fields.[32] By 1993, groundwater abstraction had returned to pre-war levels (120 MCM/yr) through the use of dual wells in the Dammam and overlying Kuwait Aquifers (Figure 4). About 75% of the abstracted water (excluding private wells) came from the Dammam.[33] More dual completion well fields with an operation capacity of 66 MCM/yr were planned in the late 1990s.[34] Data about their implementation was not available.

In Saudi Arabia, abstraction from the Umm er Radhuma-Dammam Aquifer System takes place mainly in the central section of the aquifer system in the Gulf area. By 2004, around 720 MCM had been extracted from the Umm er Radhuma, and 350 MCM from the Dammam Formation (see Chap. 15). Abstraction from the much less heavily populated Umm er Radhuma-Dammam Aquifer System (North) is thought to be significantly less, though no data is available.

In Iraq, abstraction through pumping in the early 1990s was concentrated in the Salman Zone where 50 bore-holes withdrew around 3.5 MCM/yr.[35] Most of the abstraction in Iraq (approx. 40 MCM/yr) takes place from springs in the Euphrates Depression.

Declining water levels indicate that stored groundwater is being depleted in the Umm er Radhuma and Dammam Aquifers. In Kuwait, a comparison of the potentiometric surface for the Dammam Aquifer in 1960 (pre-development phase) and 1990 registered a drop of 40-60 m.[36] The drop in water level was accompanied by a salinity increase from 5,000 to 10,000 mg/L TDS.[37] Official data indicates that the water level is still declining at a rate of $3.2x10^{-1}$-$9.1x10^{-1}$ m/yr.[38]

Figure 4. Annual groundwater abstraction from well fields in Kuwait



Source: Compiled by ESCWA-BGR based on UN-ESCWA and BGR, 1999.

In Kuwait, groundwater is abstracted mostly for agricultural, industrial and domestic purposes other than drinking water. Groundwater is also occasionally blended with desalinated water for drinking purposes.[39] In Iraq, groundwater in the Salman Zone is mainly suitable for irrigation and watering livestock, except in wells near recharge karst depressions where the groundwater is suitable for domestic purposes.[40] While the saline to hypersaline groundwater is not suitable for human use, its discharge at the surface and the formation of natural reservoirs such as Lake Sawa contributes significantly to local ecosystems.

GROUNDWATER QUALITY ISSUES

In the areas of highest abstraction (i.e. Kuwait), groundwater levels are close to sea level and hence the aquifer system has been subject to and is at great risk from further seawater intrusion. Furthermore, a significant increase in groundwater salinity between 1980 and 1990 was attributed to upward leakage from the deeper zones through a deep fault system that hydraulically connects the Dammam with the underlying saline Umm er Radhuma.[41]

SUSTAINABILITY ISSUES

As indicated above, the aquifer system is at risk from salinization, and deteriorating groundwater quality may become an increasingly limiting factor to groundwater use.

Agreements, Cooperation & Outlook

AGREEMENTS

There are no water agreements in place for the Umm er Radhuma-Dammam Aquifer System (North) which is shared between Iraq, Kuwait and Saudi Arabia.

COOPERATION

Kuwait and Saudi Arabia are reportedly preparing a joint study of the shared aquifer.[42]

OUTLOOK

Monitoring of groundwater quality in general and the groundwater-seawater interface in particular would allow for the detection of increasing salt concentrations. Effective joint management decisions could decrease the risk of salinization and make the aquifer system more sustainable.

Desert near Basrah, Iraq, 2012. Source: Earth & Marine Environmental Consultants (EAME).

Notes

1. Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, United Arab Emirates.
2. This division was based on UN-ESCWA and BGR, 1999.
3. Ministry of Agriculture and Water in Saudi Arabia, 1995 as cited in Vincent, 2008.
4. Al-Jerash, 1985 as cited in Vincent, 2008.
5. Kuwait Government Online, 2012.
6. Central Organization for Statistics in Iraq, 2010.
7. CIESIN, 2010.
8. Central Department of Statistics and Information in Saudi Arabia, 2004.
9. UN-ESCWA and BGR, 1999; Jassim and Buday, 2006b.
10. The Rus Formation contains some evaporates like anhydrite, which dissolves completely in some localities. Jassim et al., 1984 (cited in Jassim and Goff, 2006) introduced the name Jil in Iraq for the Rus equivalent at outcrop areas where the anhydrite has been dissolved.
11. UN-ESCWA and BGR, 1999; Jassim and Buday, 2006b.
12. UN-ESCWA and BGR, 1999.
13. Ministry of Agriculture and Water in Saudi Arabia, 1984.
14. Ibid.
15. Jassim and Buday, 2006a.
16. Ministry of Agriculture and Water in Saudi Arabia, 1984.
17. UN-ESCWA and BGR, 1999.
18. Ministry of Agriculture and Water in Saudi Arabia, 1984.
19. Jassim and Buday, 2006a.
20. Ministry of Agriculture and Water in Saudi Arabia, 1984.
21. Al Mashadani, 1995, cited in UN-ESCWA and BGR, 1999.
22. Faulkner, 1994.
23. Ibid.
24. Ministry of Agriculture and Water in Saudi Arabia, 1984.
25. A manmade lake created by surface water diversion from the Euphrates River in Iraq.
26. Al Mashadani, 1995, cited in UN-ESCWA and BGR, 1999.
27. Faulkner, 1994.
28. Ministry of Agriculture and Water in Saudi Arabia, 1984.
29. UN-ESCWA and BGR, 1999.
30. Krasny et al., 2006.
31. Ibid.
32. UN-ESCWA and BGR, 1999.
33. Ibid.
34. Ibid.
35. Al Mashadani, 1995 cited in UN-ESCWA and BGR, 1999.
36. UN-ESCWA and BGR, 1999.
37. Ibid.
38. Ministry of Electricity and Water in Kuwait, 2011.
39. UN-ESCWA and BGR, 1999.
40. Krasny et al., 2006.
41. UN-ESCWA and BGR, 1999 (see also Figures 18 and 19 in this reference).
42. Ministry of Electricity and Water in Kuwait, 2011.

Bibliography

Central Department of Statistics and Information in Saudi Arabia. 2004. Census by Governorate and City. Available at: http://www.cdsi.gov.sa/english/index.php?option=com_docman&task=cat_view&gid=45&Itemid=113. Accessed on June 6, 2011.

Central Organization for Statistics in Iraq. 2010. Annual Abstract for Statistics 2008-2009. Available at: http://www.iraqcosit.org/english/section_2.php. Accessed on July 14, 2011.

CIESIN (Center for International Earth Science Information Network). 2010. Population Density Future Estimates 2010. Available at: http://sedac.ciesin.columbia.edu/gpw/. Accessed on June 6, 2011.

Faulkner, R. D. 1994. Fossil Water or Renewable Resource; The Case for One Arabian Aquifer. **Proceedings of Institution of Civil Engineers, Water Maritime and Energy**, 106: p. 325-331.

Jassim, S. Z. and Buday, T. 2006a. Middle Paleocene-Eocene Megasequence AP10. In **Geology of Iraq.** 1st ed. Published by Dolin, Prague and Moravian Museum. Prague.

Jassim, S. Z. and Buday, T. 2006b. Units of the Stable Shelf. In **Geology of Iraq.** 1st ed. Published by Dolin, Prague and Moravian Museum. Prague.

Jassim, S. Z. and Goff, J. C. 2006. Geology of Iraq. 1st ed. Published by Dolin, Prague and Moravian Museum. Prague.

Krasny, J., Alsam, S. and Jassim, S. Z. 2006. Hydrogeology. In **Geology of Iraq.** 1st ed. Published by Dolin, Prague and Moravian Museum. Prague.

Kuwait Government Online. 2012. Population of Kuwait according to the Central Statistical Office 2008. Available at: http://www.e.gov.kw/sites/kgoenglish/portal/Pages/Visitors/AboutKuwait/KuwaitAtaGlane_Population.aspx#. Accessed on January 30, 2012.

Ministry of Agriculture and Water in Saudi Arabia. 1984. Water Atlas of Saudi Arabia. Riyadh.

Ministry of Electricity and Water in Kuwait. 2011. Country Consultation with the State of Kuwait. In **Country Consultations for the Inventory of Shared Water Resources in Western Asia 2011-2012**. Beirut.

UN-ESCWA and BGR (United Nations Economic and Social Commission for Western Asia; Bundesanstalt für Geowissenschaften und Rohstoffe). 1999. Groundwater Resources in Paleogene Carbonate Aquifers in the ESCWA Region: Preliminary Evaluation. New York.

United Nations. 1999. Groundwater Resources in Paleogene Carbonate Aquifers in the ESCWA Region: Preliminary Evaluation. Published by United Nations. New York.

Vincent, P. 2008. Saudi Arabia: An Environmental Overview. Published by Taylor & Francis. London/New York.