Chapter 12

Tawila-Mahra/Cretaceous Sands

Wasia-Biyadh-Aruma Aquifer System (South)

INVENTORY OF
SHARED WATER RESOURCES IN WESTERN ASIA (ONLINE VERSION)

german cooperation
DEUTSCHE ZUSAMMENARBEIT

BGR Bundesanstalt für Geowissenschaften und Rohstoffe

ESCWA
United Nations Economic and Social Commission for Western Asia

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.

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Tawila-Mahra/Cretaceous Sands

EXECUTIVE SUMMARY

The Wasia-Biyadh Sandstones merge with the Aruma in the southern areas of Saudi Arabia to constitute the so-called Cretaceous Sands. These sandstones extend across the Rub' al Khali Depression into Yemen where stratigraphically correlatable sandstones exist (the so-called Tawila-Mahra Group), thus forming a transboundary aquifer system denoted here as the Wasia-Biyadh-Aruma Aquifer System (South).

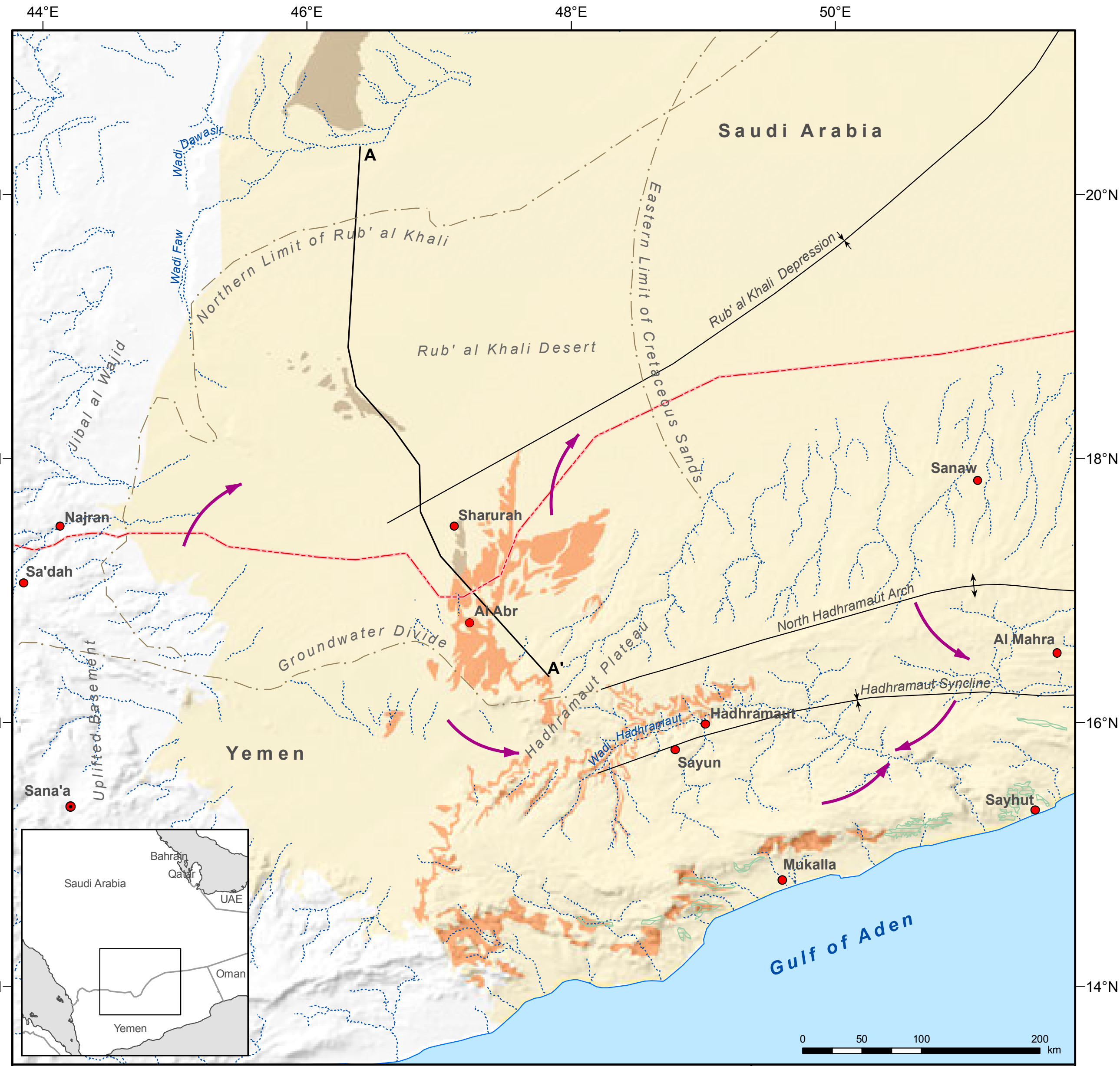
The maximum extraction potential from this aquifer system is estimated at around 500 BCM, making this one of the most promising groundwater reservoirs in the Arabian Peninsula. The aquifer system is hardly used at present due to the remote and harsh nature of the sparsely populated desert environment. Extraction only takes place in the area around the Sharurah/Al Abr border posts, where the sandstones appear at or near the surface, and nomadic populations use freshwater from shallow wells for drinking water supply. The presence of exploratory wells in the sandstones south of the delineated area indicates that freshwater is also found at depth.

This large reservoir of fresh groundwater is an important resource for the economic development of the Sharurah/Al Abr area in the future. It may also prove to be a source of water for more distant but rapidly developing urban areas that face growing water shortage such as Najran in Saudi Arabia and Sa'dah in Yemen.

BASIN FACTS

RIPARIAN COUNTRIES	Saudi Arabia, Yemen
ALTERNATIVE NAMES	Cretaceous Sands, Mahra Group, Tawila Group
RENEWABILITY	Very low (0-2 mm/yr)
HYDRAULIC LINKAGE WITH SURFACE WATER	Weak to medium
ROCK TYPE	Mixed
AQUIFER TYPE	West: Confined East: Unconfined
EXTENT	~157,000 km^2
AGE	Mesozoic (Cretaceous)
LITHOLOGY	Predominantly sandstones with some marls and siltstones
THICKNESS	100-200 m
AVERAGE ANNUAL ABSTRACTION	Unknown, but very limited
STORAGE	~500 BCM
WATER QUALITY	Fresh (400-800 mg/L TDS)
WATER USE	Water supply for desert nomads and the Sharurah/Al Abr border posts
AGREEMENTS	-
SUSTAINABILITY	-

OVERVIEW MAP



Wasia-Biyadh-Aruma Aquifer System (South): Tawila-Mahra/Cretaceous Sands

- Capital
- Selected city, town
- International boundary
- Intermittent river, wadi
- Anticline
- Syncline
- Tawila-Mahra Sandstone outcrop (Mukalla Formation)
- Wasia-Biyadh Sandstones outcrop
- Approximate subsurface extent of the aquifer formations
- A A' Approximate location of cross-section
- Direction of groundwater flow
- Zone of agricultural development (selection)

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Inventory of Shared Water Resources in Western Asia

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CONTENTS

FIGURES

The Wasia-Biyadh-Aruma Aquifer System in this Inventory

The Wasia, Biyadh and Aruma Formations extend across the Arabian Peninsula over a distance of about 2,400 km from north-eastern Iraq to the southern coast of the peninsula, with a width that varies between 350 km and 1,450 km and covering a total area of about 1,923,000 km^2 (see 'Overview and Methodology: Groundwater' chapter, Map 1).

The large geographical extent and the lithostratigraphic variations within the formations suggest that they can be divided into three sections, as described below:

- **In the northern section**, the Biyadh Formation disappears completely, while the Wasia (known in this area as the Sakaka)[1] forms an aquifer system with the overlying Aruma Formation that continues across the border into the Rutba area in Iraq. This section is presented in Wasia-Biyadh-Aruma Aquifer System (North) Sakaka-Rutba (see Chap. 13).[2]

- **In the southern section** near Wadi Dawasir, the sandstones of the Biyadh and Wasia grade together with the Aruma to form a thick sandstone unit, known as the Cretaceous Sands,[3] which extends to the Yemeni border. The stratigraphically correlatable sandstones across the border are known as the Tawila Group in Yemen (see current chapter).[4]

- **In the central section**, both the Wasia and Biyadh Formations are present and constitute one aquifer system inside Saudi Arabia, which may extend as far east as the western boundary of the Shu'aiba Formation. Beyond that, the two aquifers are separated by the well-developed dolomitic limestone of the Shu'aiba.[5] The Wasia Aquifer extends to Bahrain where it is currently not used due to high salinity and excessive depth. Hence, while the central section of the Wasia-Biyadh is a major aquifer system inside Saudi Arabia, it is not considered a shared aquifer.

The Bir Ali Crater with the Gulf of Aden in the background, Yemen, 2009. Source: Email4Mobile.

Introduction

LOCATION

The Wasia-Biyadh-Aruma Aquifer System (South) is located in the south-western part of the Rub' al Khali Depression, which has been described as the largest area of sand dune fields in the world, with some dunes reaching hundreds of metres in height.[5] The aquifer system extends across the Saudi-Yemeni border.

AREA

This chapter focuses only on the small area in the southern section of the aquifer system that is considered to be shared. The aquifer system was delineated on the basis of available information, resulting in an area of around 157,000 km^2, of which 52,000 km^2 lies in Yemen, and 105,000 km^2 in Saudi Arabia.

The Tawila-Mahra/Cretaceous Sands Formations occur in a largely inaccessible, arid and hyper-arid region, where the only sign of human settlement is in the Sharurah/Al Abr area. On the Yemeni side, the aquifer system is located in the north-eastern plateau zone, which descends gradually from the north of Wadi Hadhramaut to the southern reaches of the Rub' al Khali Desert.[6] The elevation is approximately 900 m on the edge of this desert, which also extends into Saudi Arabia.[7] In Saudi Arabia, the sandstones lie in extensive dune areas.

CLIMATE

The aquifer system lies within the Hadhramaut Plateau in Yemen, which is generally hot and dry with average annual rainfall below 100 mm and an annual Penman evapotranspiration of 2,000-3,500 mm.[8] There is a slight decrease in rainfall towards the northern Rub' al Khali areas, where the annual average may range between 40 and 80 mm.[9] Temperatures may rise to 50°C during the day, but decrease immediately after sunset.[10]

POPULATION

The area of the Wasia-Biyadh-Aruma Aquifer System is sparsely populated, with a population density of 0.1-1 inhab./km^2. No significant human settlements exist apart from the border post towns of Sharurah and Al Abr.[11]

OTHER AQUIFERS IN THE AREA

In the Sharurah/Al Abr area, the Wasia-Biyadh-Aruma Aquifer System (South) is overlain by Quaternary deposits. Further east, it is overlain by the Hadhramaut Group (Paleogene) Aquifer System (see Chap. 14). It is separated from the underlying Wajid Aquifer System (Cambro-Ordovician to Devonian-Permian, see Chap. 11), by a number of pre-Cretaceous Formations (Figure 1) of which the Middle to Lower Jurassic Formations (e.g. Kohlan Sandstones in Yemen) constitute local aquifers.

INFORMATION SOURCES

In the absence of specific data on the Cretaceous Sands in Saudi Arabia, this chapter draws on information from the Wasia-Biyadh (Central) area where relevant. For the area in Yemen, information is mainly drawn from a number of studies on the Mukalla Sandstone that were undertaken in the eastern part of the country, towards the border with Saudi Arabia and Oman. The Overview Map was delineated based on various local and regional references from both riparian countries.[12]

Hydrogeology - Aquifer Characteristics

AQUIFER CONFIGURATION

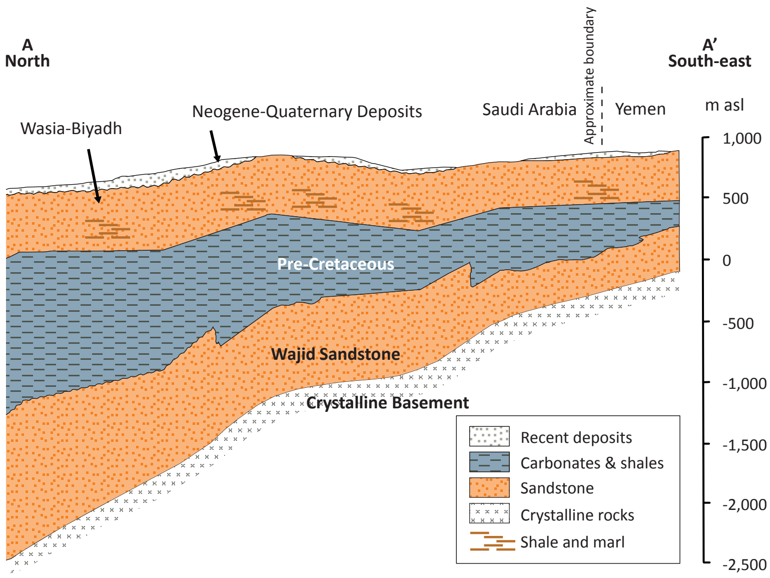
The aquifer system is bounded on four sides:

- In the east by the limit of the Cretaceous Sands.[13]
- In the west by the uplifted basement and Jibal Wajid (see Chap. 11).
- In the south by the North Hadhramaut Arch, which forms a groundwater divide.[14]
- In the north by the limit of the Rub' al Khali Depression.[15]

The Wasia-Biyadh-Aruma Aquifer System (South) is part of the Rub' al Khali structural depression that formed a depositional basin for Paleozoic and Mesozoic Formations. The basin stretches into north-eastern Yemen and is bounded by the Paleozoic North Hadhramaut Arch to the south. All Paleozoic and Mesozoic sedimentary sequences pinch out onto the North Hadhramaut Arch, which prevents the advance of Paleozoic transgressions further south.[16] In the northern part of the basin, the flank slopes gently but in a step-like manner and the sedimentary column thickness increases from about 2 km near the crest of the Hadhramaut Arch to over 4 km on the Saudi-Yemeni border. Accordingly, the formations dip in an east to north-easterly direction. A reactivation of the North Hadhramaut Arch probably occurred in the Paleocene. Both the Arch and the Rub' al Khali Depression reached their present form by the end of Eocene.[17] As a result, the Paleogene Hadhramaut Group (Umm er Radhuma-Dammam Aquifer System) forms an extensive and almost continuous cover overlying the Cretaceous Formations in the eastern part of Yemen.[18]

The main outcrops of the sandstones are found in Yemen, where they extend into Saudi Arabia along a fault. The sandstones also occur on the surface at the foot of Jibal al Wajid near the western margin of the Rub' al Khali Depression, in the form of isolated outcrops that are separated from the central Wasia-Biyadh outcrops. In the south-west, the sandstones may overlie the Precambrian Basement,[19] whereas further east they lie on top of the Paleozoic-Mesozoic Sequence (Figure 1).

Figure 1. Geological cross-section of the eastern Rub' al Khali showing the stratigraphic position of the Wasia-Biyadh Sandstones



Source: Modified by ESCWA-BGR based on Edgell, 1997.

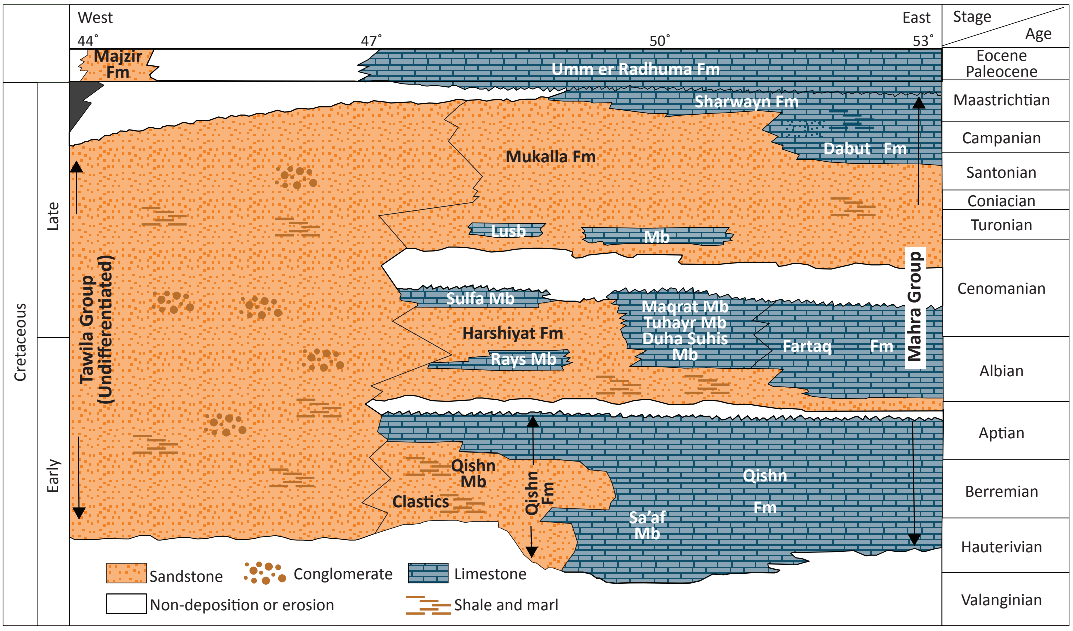
In the northern part of the study area, the sandstones are overlain by superficial deposits of Quaternary age.

STRATIGRAPHY

During the Cretaceous period, the marine advance into the region was from the east with a series of short transgressions followed by regressions, but marine conditions never covered the western areas where terrestrial, fluvial and fluvio-deltaic conditions prevailed.[20] Figure 1 highlights the lithostratigraphic similarity of the early to middle Cretaceous Formations in the eastern areas of Saudi Arabia and Yemen.

Figure 2 shows that in Yemen the zone of the main lateral interdigitation of the individual formations occurs roughly between longitudes 49°30' and 50°30'. West of longitude 47°, the Tawila Group is entirely made up of undifferentiated clastics,[21] which constitute the major aquifer in north-western Yemen. East of this longitude, the Mukalla Formation constitutes the main aquifer within the Mahra Group.

Figure 2. Lithostratigraphy of the Wasia-Biyadh-Aruma Aquifer System (South) in Yemen



Source: Modified by ESCWA-BGR based on Beydoun et al., 1998.

Similarly, only the lowest unit of the Wasia-Biyadh Formations (Khafji-Safaniyah) is water-bearing in the eastern areas of Saudi Arabia, compared with the central part where the sandstone deposition was much thicker (Figure 2) and continued until the Late Cretaceous epoch (sandstone unit of the Aruma Formation not shown in Figure 3).

AQUIFER THICKNESS

In Saudi Arabia, the Wasia Sandstone reaches a maximum thickness of 600 m in the Rub' al Khali[22] where a thickness of 1,000 m is not uncommon for the Cretaceous Sands east of Wadi Dawasir.[23] The Mukalla Sandstone also reaches a thickness of 1,000 m in Yemen, south of the North Hadhramaut Arch. In the North Hadhramaut Arch and its Rub' al Khali Depression flank, however, the thickness of the sandstone in the subsurface varies between 100 and 200 m.[24] This would suggest that the Cretaceous Sands are less thick in the border area than they are further to the north in Saudi Arabia, or to the south in Yemen.

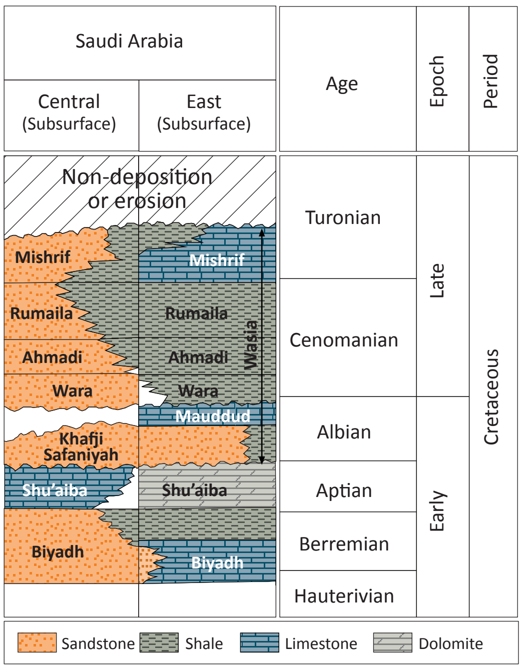
AQUIFER TYPE

Water table conditions are common, whereas some perched water is localized in areas where it is held above the clay layers.[25] In the eastern part of the basin, the sandstone is overlain by a thick sequence of Paleogene carbonate rocks, and the aquifer may be mostly confined in these areas.

AQUIFER PARAMETERS

A transmissivity range of 6.9×10^{-3} to 1.1×10^{-3} m^2/s has been recorded for five wells in the Mukalla Sandstone.[26] These values are within the range estimated by FAO for only a part of the Hadhramaut Valley (2.0×10^{-2} – 3.9×10^{-3} m^2/s).[27] No values could be found for storativity.

Figure 3. Lithostratigraphy of the Wasia-Biyadh-Aruma Aquifer System (South) in Saudi Arabia



Source: Modified by ESCWA-BGR based on Alsharhan and Nairn, 1997.

Hydrogeology - Groundwater

RECHARGE

Despite the very low rainfall, recharge to the Mukalla Sandstone reportedly occurs across the area.[28] Modern recharge could occur in the following manner:

- The areas along the Saudi border are covered by aeolian and alluvial sands which would quickly absorb the infrequent but intense rainfall and allow it to percolate into the sandstones, particularly near the outcrop areas where the alluvial cover is thin.
- A strong potential for structurally facilitated recharge occurs in the western and central areas, where the Mukalla Sandstone and the Umm er Radhuma Formation are exposed, because of the intensive structural dislocation and faulting within these rocks.
- The eastern part of the plateau that is covered by the practically impervious Jeza Formation[29] generates considerable runoff. This in turn infiltrates into the permeable Umm er Radhuma and Mukalla Formations, which are exposed in the deeply incised valleys, and into the Quaternary alluvial valley fill further north.[30]

The age of deep water in the Mukalla Sandstone was determined through carbon-14 dating at 8,000 years, which is relatively young compared to the deep water in the Umm er Radhuma Aquifer System (20,000 years). This young age together with the stable isotopic composition (^{18}O: -2.0 to -3.5‰) suggest that recent recharge water must be reaching the sandstones.[31] Similarly, the water in the Wasia-Biyadh Aquifer System was found to be 8,000 years old at the main outcrop near Al Kharj and 16,000 years down-dip in the Khurais area[32] (see 'Overview and Methodology: Groundwater' chapter, Map 1) for the central part of the aquifer system.

A summary[33] of several studies[34] undertaken in Saudi Arabia estimated recharge to the Wasia-Biyadh and Aruma System at 419 MCM/yr over an area of 47,500 km² (29,000 km² of Wasia-Biyadh outcrops and 18,500 km² of Aruma outcrops), which would be equivalent to 8.8 mm/yr for the outcrop areas.

A far lower rate for direct recharge through the Mukalla Sandstone outcrops (1.5 mm/yr) was found in the Hadhramaut Plateau south of the study area (see Overview Map).[35] These estimates (1.5 and 8.8 mm/yr) and the outcrop areas of the sandstones of the aquifer system as delineated here (8,660 km²) would translate into a direct recharge volume of between 13 and 76 MCM. Indirect recharge is also likely to occur through runoff, particularly through the wadis descending from the uplifted basement areas where precipitation is higher. However, no estimates of this additional recharge were available.

FLOW REGIME

The Mukalla Sandstone dips in an easterly to north-easterly direction[36] and hence groundwater flows towards the Rub' al Khali and south-eastern Saudi Arabia.[37] Further north, groundwater in the Wasia-Biyadh Formations flows towards the Persian Gulf under the influence of a small but consistent hydraulic head.[38]

STORAGE

A 1986 study compiled data from previous studies and estimated the quantity of water in storage in the Wasia-Biyadh Aquifer System in Saudi Arabia between 120 and 290 BCM.[39] Since then, other studies have given a wide range of values for the same aquifer system.[40] Perhaps the most comprehensive study is that prepared by the British Arabian Advisory Company for the Ministry of Agriculture and Water in Saudi Arabia in 1980, in which both depth and water quality limitations were taken into consideration.[41] This study estimated that the total volume of water with acceptable quality (TDS = 2,000 ppm) that could be extracted from a depth of 300 m in this aquifer system was in the order of 500 BCM (the maximum depth currently possible with pumping technology existing at the time).[42]

The storage calculation of the Mukalla Sandstone,[43] which extends to the Gulf of Aden and covers around 200,000 km², was based on an assumed porosity of about 25%. However, such a high porosity is most likely not sustained

Between Mukalla and Bir Ali, Yemen, 2000. Source: Kebnekaise.

throughout this huge area. Even if such high values were sustained, they would not represent effective (drainable) porosity. Effective porosities of sandstones vary between 0.5% and 10%; in this case a value of 5% was used for the Mukalla Sandstone.[44] Assuming a regional drawdown of 200 m below the groundwater table and an effective porosity of 5%, total storage would be 2,000 BCM. If it is then assumed that at least 25% of this water lies within the boundaries of the Wasia-Biyadh-Aruma (South) Aquifer System – a very conservative figure – then the maximum extraction potential from the aquifer system in this basin would be roughly 500 BCM. This figure is identical to that estimated for the Wasia-Biyadh Aquifer System in Saudi Arabia as shown above.

DISCHARGE

There are no visible signs of discharge on the surface. Downward flow discharge into the Upper Wajid Sandstone could occur on the Yemeni side of the border where the Khuff Formation, which separates the two aquifer systems in Saudi Arabia, seems to disappear. However, there is no data to confirm or negate this.

WATER QUALITY

Groundwater from seven bore-holes drilled into the Mukalla Sandstone in the plateau area south of the North Hadhramaut Arch was found to be of excellent quality, with TDS values in the range of 406-833 mg/L and ionic compositions as follows:
$Ca > Mg > Na$ and $HCO_3 > SO_4 > Cl$.[45]

No information is available on groundwater quality north of the North Hadhramaut Arch, but TDS values are possibly similar.

EXPLOITABILITY

The top of the Cretaceous has an approximate maximum depth of 600 m bgl across the whole area shown in the Overview Map.[46] Information on observed depth to groundwater (100-200 m bgl) and water quality (TDS of ≤1,000 mg/L) was only available for the Yemeni part of the study area. As both parameters are within the limits of the criteria selected for exploitation (see 'Overview and Methodology: Groundwater' chapter), the entire delineated area can be considered exploitable, subject to accessibility and drilling/well stability in areas of thick sand dunes.

However, groundwater exploitation would probably present logistical and access issues at these depths, thus significantly increasing unit cost per volume of groundwater extracted. The area of exploitation could even extend beyond the mapped area if depth to water and TDS were not considered limiting factors. Recent data however suggests that one or both parameters may be limiting factors, since practically no exploitable area is shown beyond the eastern limit of the Cretaceous Sands.[47]

Groundwater Use

GROUNDWATER ABSTRACTION AND USE

The water table in the sandstones is in the range of 100-200 m bgl, with the possible exception of wadi bed areas, where relatively shallow groundwater occurs.[48] The use of groundwater from the aquifer system is at present limited to insignificant quantities for the needs of small groups of nomadic populations.

GROUNDWATER QUALITY ISSUES

There are no quality issues related to use since there is very limited abstraction. However, water quality may be affected by natural elements in the future if water is abstracted on a larger scale. Sandstone formations may contain substantial amounts of disperse uranium (U) derived originally from granitic or related metamorphic host rocks.[49] This would suggest that the Tawila-Mahra/Cretaceous Sands, which lie in the vicinity of the Basement, may contain radionuclides that are potentially hazardous to human health. Groundwater quality in the aquifer system is further threatened by the infiltration of saline water from wadi beds. Possible future threats could also include pollution from the oil industry, as a growing number of exploratory oil wells are drilled in the Rub' al Khali.

SUSTAINABILITY ISSUES

The aquifer system is in a very remote and sparsely populated area where no sustainability issues are foreseen in the near future.

Wadi Doan, Yemen, 2000. Source: Kebnekaise.

Agreements, Cooperation & Outlook

AGREEMENTS

There are no water agreements in place for the Wasia-Biyadh-Aruma Aquifer System (South) which is shared between Saudi Arabia and Yemen.

COOPERATION

No information was available regarding cooperation between the riparian countries on the aquifer system.

OUTLOOK

This is a 'virgin' aquifer system that has a potential for producing groundwater for many, perhaps hundreds, of years, if protected from pollution by the oil industry.

Mukalla, Yemen, 2000. Source: Kebnekaise.

Notes

1. Christian, 2000.
2. Ministry of Agriculture and Water in Saudi Arabia, 1984.
3. Van der Gun and Ahmed, 1995.
4. Othman et al., 1986.
5. Sultan et al., 2008.
6. DLIFLC, 2010 and OWNO, 2012.
7. Van der Gun and Ahmed, 1995.
8. Ibid.
9. PSRCE, 2007.
10. Hestler and Spilling, 2010.
11. CIESIN, 2010.
12. FAO Near East Cooperative Program, 1979; Van der Gun and Ahmed, 1995; Rybakov et al., 1995.
13. Ministry of Agriculture and Water in Saudi Arabia, 1984.
14. FAO Near East Cooperative Program, 1979.
15. Vincent, 2008.
16. Beydoun et al., 1998, p. 8.
17. Alsharhan, 2001, p. 62.
18. Van der Gun and Ahmed, 1995.
19. Ibid.
20. Beydoun, 1964, 1966, 1970, 1997, Beydoun and Greenwood, 1968 in Beydoun et al., 1998; Alsharhan et al., 2001.
21. Beydoun et al., 1998.
22. Othman et al., 1986.
23. Ministry of Agriculture and Water in Saudi Arabia, 1984; Othman et al., 1986.
24. Beydoun et al., 1998.
25. Rybakov et al., 1995, p. V-38.
26. Komex International Inc., 1997.
27. FAO Near East Cooperative Program, 1979.
28. Komex International Inc., 1997; FAO Near East Cooperative Program, 1979; Van der Gun and Ahmed, 1995.
29. Van der Gun and Ahmed, 1995. The Jeza Formation is a Paleogene Formation between the Umm er Radhuma and Rus, consisting mainly of shales and fine-grained limestone.
30. FAO Near East Cooperative Program, 1979.
31. Komex International Inc., 1997, p. 154, 163.
32. Ministry of Agriculture and Water in Saudi Arabia, 1984.
33. Othman et al., 1986.
34. SOGREAH, 1967; Sir M. Macdonald Partners, 1975.
35. Komex International Inc., 1997, p. 154, 163. Recharge calculated on the basis of outcrop areas within the Tawila-Mahra Basin north of the groundwater divide.
36. Van der Gun and Ahmed, 1995.
37. FAO Near East Cooperative Program, 1979; Rybakov et al., 1995.
38. United Nations, 1982.
39. Othman et al., 1986.
40. See Al Alawi and Abdulrazzak, 1993; Al Sheikh, 2000.
41. BAAC, 1980.
42. Al Alawi and Abdulrazzak, 1993.
43. Van der Gun and Ahmed, 1995, p. 57.
44. Komex International Inc., 1997, p. 154, 163; Domenico and Schwartz, 1990.
45. Komex International Inc., 1997.
46. Christian, 2000.
47. Schubert et al., 2011.
48. Van der Gun and Ahmed, 1995, p. 80.
49. Al-Saud et al., 2011.

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