Chapter 22

Azraq-Dhuleil Basin

Basalt 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.

Basalt Aquifer System (South)

Azraq-Dhuleil Basin

EXECUTIVE SUMMARY

The Azraq-Dhuleil Basin extends over the south-eastern part of the Jebel al Arab basalt field in south-western Syria and north-eastern Jordan, comprising the catchment of the Azraq groundwater discharge area between the Jebel al Arab Mountain range in the north, the north-eastern desert in Jordan and the Azraq Plain.

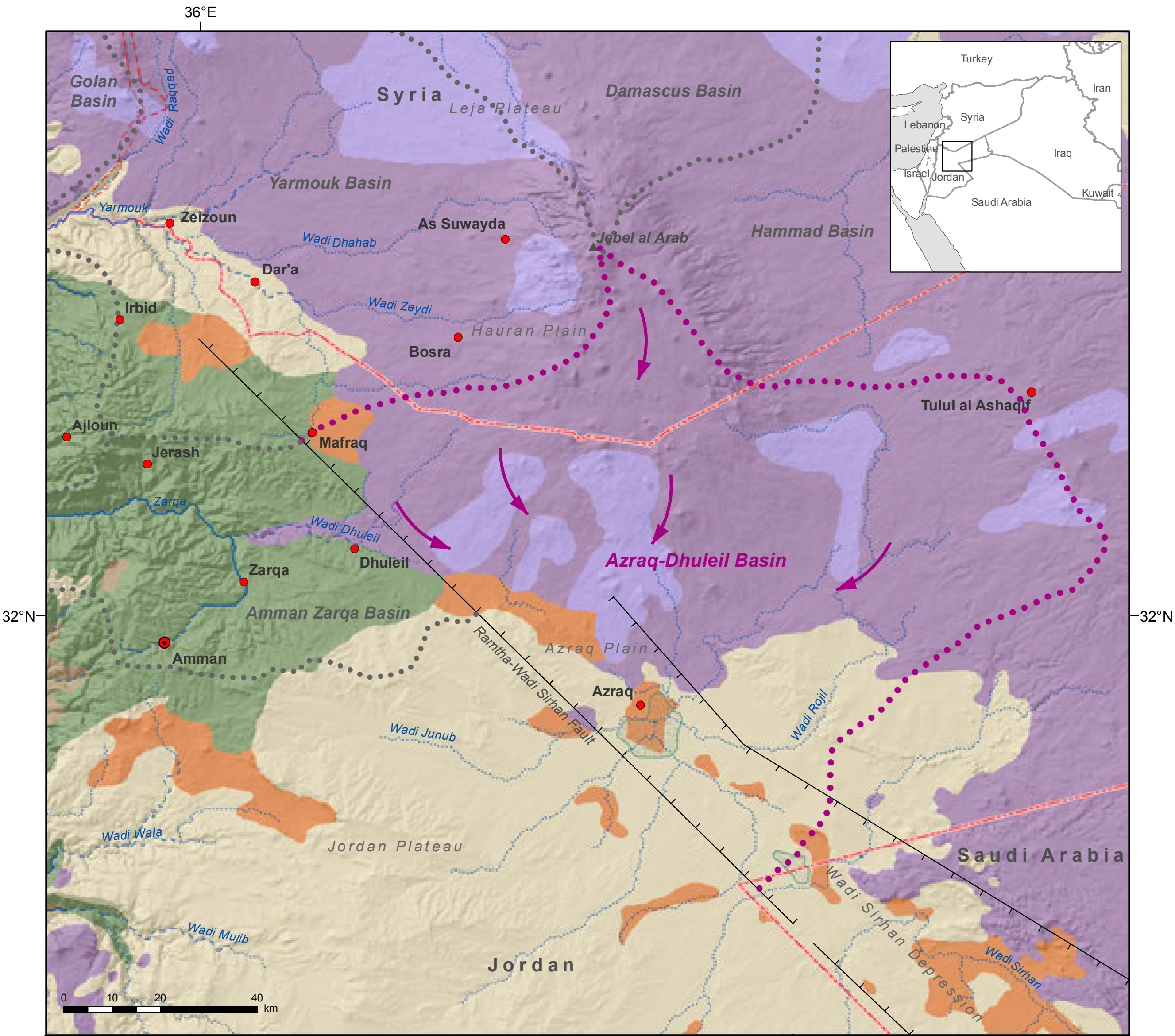
Groundwater in the Basalt Aquifer System of the Azraq-Dhuleil Basin flows from topographically higher parts of the catchment to the major discharge zone in the Azraq area in the south. The groundwater flow regime extends over a combined aquifer system constituted mainly of permeable layers in Neogene-Quaternary basalts and underlying Paleogene chalky limestones. In the Dhuleil area in the west of the Azraq-Dhuleil Basin, the aquifer system also includes Upper Cretaceous limestones and dolomites.

Groundwater discharge appears to be maintained largely by present-day recharge over wide catchment areas with travel periods of more than 20,000 years. Discharge from springs in the Azraq area ceased completely after the creation of a large well field in the area in 1980. Groundwater quality has deteriorated as a result of the infiltration of irrigation return flows in downstream areas where intensive irrigation takes place.

BASIN FACTS

RIPARIAN COUNTRIES	Jordan, Syria
ALTERNATIVE NAMES	-
RENEWABILITY	South: medium North: high
HYDRAULIC LINKAGE WITH SURFACE WATER	Medium to low (2-100 mm/yr)
ROCK TYPE	Fractured to mixed
AQUIFER TYPE	Unconfined
EXTENT	8,500 km^2
AGE	Neogene-Quaternary, Paleogene, Upper Cretaceous
LITHOLOGY	Basalt, limestone
THICKNESS	<100m - >500m
AVERAGE ANNUAL ABSTRACTION	Northern part: 15-20 MCM
STORAGE	-
WATER QUALITY	Mainly fresh, brackish in some areas
WATER USE	Agricultural and domestic
AGREEMENTS	..
SUSTAINABILITY	Groundwater level decline and salinization due to over-abstraction

OVERVIEW MAP



Basalt Aquifer System (South): Azraq-Dhuleil Basin

- Capital
- Selected city, town
- International boundary
- Armistice Demarcation Line
- River
- Intermittent river, wadi
- Freshwater lake
- Sabkha
- Mountain
- Graben
- Quaternary volcanics
- Neogene volcanics
- Quaternary-Neogene undifferentiated
- Paleogene (Wadi Shallala and Umm Rijam Formations)
- Cretaceous (Amman and Wadi as Sir Formations)
- Pre-Cambrian outcrops
- Direction of groundwater flow in Azraq-Dhuleil Basin
- Boundary of Azraq-Dhuleil Basin
- Basin boundary

الاسكوا
ESCWA

BGR Bundesanstalt für Geowissenschaften und Rohstoffe

Inventory of Shared Water Resources in Western Asia

CONTENTS

FIGURES

TABLES

The Basalt Aquifer System in this Inventory

The Quaternary-Neogene basalts of the North Arabian Volcanic Province extend from south-western Syria through eastern Jordan into Saudi Arabia over a total length of around 460 km and with a width of 50-150 km.

They cover an area of approximately 48,000 km^2, of which 11,000 km^2 is located in Jordan, 23,000 km^2 in Saudi Arabia and 14,000 km^2 in Syria. The basalts generally overlie sedimentary formations of Paleogene and Cretaceous ages (see Figure 1, Chap. 21) and are hydraulically connected with them to form a complex aquifer system that is denoted as the Basalt Aquifer Complex in this Inventory.[1] This volcano-sedimentary complex extends across the boundaries of Jordan, Saudi Arabia and Syria (see 'Overview and Methodology: Groundwater' chapter) to constitute shared aquifer systems in the following basins:

Yarmouk Basin

The basin extends across the border of Syria and Jordan and the aquifer system within the basin is denoted as the Basalt Aquifer System (West) (see Chap. 21). In the basin, the basalts generally overlie the Paleogene (Shallala-Rijam) formations, except in certain structurally high locations where the Paleogene is missing and the basalts come in direct contact with the Cretaceous (Amman-Wadi as Sir) formations.

Azraq-Dhuleil Basin

The basin[2] also extends across the border of Syria and Jordan, and the aquifer system within the basin is referred to as the Basalt Aquifer System (South-East) (see current chapter). In the basin, the basalts are hydraulically connected with the Paleogene (Shallala-Rijam) formations in the eastern areas and the Cretaceous (Amman-Wadi as Sir) formations in the western areas to form one aquifer system with both formations.

Wadi Sirhan Basin

The basin extends across the border of Jordan and Saudi Arabia and the aquifer system within the basin is denoted as the Tawil-Quaternary Aquifer System (see Chap. 17). In the basin, the Quaternary-Neogene basalts and alluvium form the upper part of a thick aquifer system that comprises both the Paleogene and Cretaceous (Tawil-Sharawra) formations.

The Basalt Aquifer Complex, which was originally delineated on the basis of surface drainage and morphology, comprises three other basins that are of less relevance as shared aquifers. They are therefore not covered in separate chapters in this Inventory. The **Golan Basin**[3] and **Damascus Basin** lie entirely in Syria, the **Amman-Zarqa Basin** lies entirely in Jordan while the basalts in the **Hammad Basin** are practically dewatered.[4]

The basalt rock formations in the area of Al Lajat, north of Suweida, Syria, 2009. Source: Adel Samara.

Introduction

LOCATION

The Basalt Aquifer System (South-East), hereafter referred to as Azraq-Dhuleil Basin, extends from the southern border of the Jebel al Arab basalt field in Jordan and Syria to the Azraq Depression along the main Ramtha-Wadi Sirhan Fault System (see Overview Map).

AREA

The morphology of the basin is dominated by the 1,800 m peaks of the Jebel al Arab Mountain range in the north, with altitudes dropping below 500 m in the Azraq Plain (Qaa al Azraq) in the south. Prominent volcanic peaks are scattered throughout the Jebel al Arab Mountain range and the plateaus to the south. In the east, the area around Tulul al Ashaqif constitutes a major mountainous zone in north-eastern Jordan (900 m).

Surface water divides have been used to define the boundary of the Azraq-Dhuleil Basin with neighbouring basins (Yarmouk Basin in the north-west; Amman-Zarqa Basin in the west; and Hammad Basin in the east). In the south-west, the Ramtha-Wadi Sirhan Fault System separates it from the eastern Jordanian limestone plateau, which comprises Mesozoic to Paleogene sedimentary sequences.[5]
Based on this delineation, the Azraq-Dhuleil Basin covers an overall area of 8,500 km^2, of which 7,610 km^2 is in Jordan and 890 km^2 in Syria. About 6,450 km^2 is covered in outcrops of basaltic rocks. The area of basalt outcrop is about 6,500 km^2. The basalts are covered by Quaternary sabkha or alluvial deposits in local morphologic depressions, such as the Azraq Plain. Basalts are not present in the southern part of the Azraq-Dhuleil Basin, which drains from the eastern Jordanian Limestone Plateau.

CLIMATE

The Azraq sub-basin is predominantly arid with an average precipitation of 87 mm/yr during the period 1967-1995, most of which occured as storms between January and March.[6] The basalt plateau on the northern tip of the sub-basin forms an exception: precipitation can reach 500 mm on the slopes of Jebel al Arab.[7]

POPULATION

The Azraq-Dhuleil Basin has an estimated total population of 126,900 inhabitants with a low population density. In Syria, the basin falls within a small part of As Suwayda Governorate, with around 43,600 inhabitants in the area.[8] The Jordanian part of the topographic Azraq-Dhuleil Basin has a population of around 83,300 inhabitants, comprising parts of the governorates of Mafraq and Zarqa.[9]

OTHER AQUIFERS IN THE AREA

The Azraq-Dhuleil Basin is underlain by the sandstones of the Kurnub-Ram Formations, which form a deeper aquifer system. Across the basin, the Ajlun aquitard seperates the sandstones from the Basalt Aquifer Complex.[10]

INFORMATION SOURCES

Information for this chapter was mainly derived from a 1996 study,[11] in addition to more recent regional and local publications as listed in the bibliography.

Hydrogeology - Aquifer Characteristics

AQUIFER CONFIGURATION

The Basalt Aquifer is underlain by aquiferous Paleogene carbonates, which appear to form a combined aquifer system with the basalts in most parts of the basin. In the north-western part of the basin, the basalts directly overlie Upper Cretaceous carbonates to form a joint aquifer.

The Wadi Sirhan Graben system extends to the north-western border of Jordan, across the centre of the Azraq-Dhuleil Basin, where it is known locally as the Azraq Graben or Azraq Depression (see Overview Map). The Ramtha-Wadi Sirhan Fault limited the extrusion of the basalts towards the west, except in the Wadi Dhuleil area. The combined effect of the two major structures has resulted in the creation of a complex groundwater divide. As a result, the flow from the Jebel al Arab area into the eastern areas of the Amman-Zarqa Basin is directed towards the Azraq Plain (see Overview Map).

In the northern part of the basin, the basalts are intercalated with the Wadi Shallala and Umm Rijam Formations, and separated from the Wadi as Sir and Amman Formations by the marls and marly limestones of the Muwaqqar Formation.[12] In the southern areas, the Azraq-Dhuleil Basin is largely covered by the Wadi Shallala and Umm Rijam Formations.

STRATIGRAPHY

The geologic sequence of the basalt complex in the Azraq-Dhuleil Basin is composed of Neogene plateau basalts and Quaternary (Pleistocene to recent) basaltic lava flows and shield volcanoes (see Chap. 21, Table 1). The total thickness of the Neogene to Quaternary basalts increases from less than 100 m on the southern fringes of the basalt field to more than 700 m on the slopes of the Jebel al Arab Mountain range.

Neogene basalts are exposed in the Jebel al Arab area on the northern tip of the Azraq sub-basin and to the east and south-east of this area. Neogene, mainly Pliocene, plateau basalts are made up of numerous lava sheets. Individual lava sheets are generally several metres thick, and may be separated by soil and sedimentary layers. Basaltic dykes cross the sequence of Neogene basalts. The Neogene basalts probably reach a maximum thickness of about 1,500 m beneath the Jebel al Arab Mountain range.[13]

The Quaternary volcanics are more common in the western areas, mainly within the Azraq Graben. They are composed mainly of lava flows and shield basalts. Quaternary lava flows have a total thickness of a few metres to 150 m and fill valleys in a pre-existing morphologic relief. While the Quaternary lava flows are generally narrow and relatively thin, Quaternary shield basalts may cover considerable areas with a thickness of up to 100 m. Occurrences of basaltic cinder, scoria and tuff are scattered over the Quaternary basalt field.

In most areas of the Azraq-Dhuleil Basin, the basalts rest on Paleogene sedimentary rocks. They form the main outcrops in the areas adjoining the basalt field to the west, where the Wadi as Sir and Amman Formations are exposed. To the south, the formations are in the subsurface, separated from the outcropping Wadi Shallala and Umm Rijam Formations by the Ajlun Group. In the Dhuleil area in the south-west of the Azraq-Dhuleil Basin, the Paleogene chalks and Upper Cretaceous-Paleogene marls are missing over a structural high and the basalts lie directly above Upper Cretaceous limestones and dolomites.

AQUIFER THICKNESS

The saturated thickness of the basalt decreases from more than 300 m on the slopes of the Jebel al Arab Mountain range to less than 100 m on the southern fringes of the basalt field. The combined thickness of the Wadi Shallala and Umm Rijam Formations ranges between a few metres in erosional areas to about 500 m in the Azraq Depression.[14] The thickness of the Wadi as Sir and Amman Formation also decreases progressively from about 300 m near the Fuluk Fault to around 100 m in the areas to the west.

AQUIFER TYPE

The Jebel al Arab basalts constitute a generally unconfined main aquifer; semi-confined conditions occur locally within individual volcanic flows. The Wadi as Sir and Amman

Aquifer is unconfined in the Dhuleil area[15] but confining conditions arise towards the east where the main part of the basin is covered by the Muwaqqar Formation. The Wadi Shallala and Umm Rijam Aquifer is mainly unconfined.

AQUIFER PARAMETERS

Up to 50% of the rock sequence in the Jebel al Arab Basalt Complex consists of porous basalts. Horizontal groundwater flow is, however, generally restricted to permeable layers on the boundaries of individual lava flows. Fractures created by cooling of the basalt or by tectonic movements allow for vertical interconnections between the permeable layers. Layers with interconnected porosity may be assumed to comprise 10%-20% of the total saturated thickness of the basalt complex.

Transmissivity values of the Basalt Aquifer System in the Azraq-Dhuleil Basin in Jordan are estimated to range between $5.6x10^{-4}$ and $0.51m^2/s$. Mean discharge rate values in different areas of the Basalt Aquifer System (South-East) are 1-40 m^2/h corresponding with transmissivity values of between $3.47x10^{-4}$ and $1.50x10^{-2}$ m^2/s.[16] The basalt sequence has a thickness of 100-300 m. If a distribution of 20% permeable layers is assumed, transmissivity values can be calculated at around $1.0x10^{-2}$ m^2/s with corresponding permeabilities of $2x10^{-4}$ to $6x10^{-4}$ m/s.

In areas where the basalts form a hydraulically connected aquifer with underlying carbonate rocks, relatively high well capacities are found.[17] In the Azraq and Wadi Dhuleil areas and in the northern desert of Jordan east of Mafraq, relatively high well yields (above $3.5x10^{-1}$ MCM/yr and median discharge rate values of 32 to 39 m^2/h) may be related to an elevated transmissivity of Cretaceous limestones and dolomites underlying the Basalt Aquifer. However, in the Mafraq area itself, no interaction between the basalt and the Upper Cretaceous limestone aquifer exists.[18]

Agriculture in the area of Azraq, Jordan, 2009. Source: David L. Kennedy, Aerial Photographic Archive for Archaeology in the Middle East.

Hydrogeology - Groundwater

RECHARGE

Favourable recharge conditions exist on the southern slopes of the Jebel al Arab Mountain range, where mean annual precipitation reaches up to 500 mm. Relatively high recharge may also occur in sections of wadi systems where runoff is collected from extensive catchments, and on outcrops of Neogene and Quaternary shield basalts which have very limited soil cover. Recharge volumes in some areas appear to be restricted mainly to local indirect recharge in wadi systems, in particular in the arid eastern and south-eastern parts of the Azraq-Dhuleil Basin.

In general, direct and indirect recharge in the Azraq-Dhuleil Basin amounts to around 3% of precipitation, increasing to 6% in the semi-arid northern parts.[19] Total recharge in the Azraq-Dhuleil Basin is estimated at 37.3 MCM/yr. Annual groundwater recharge has been estimated as follows for different parts of the Azraq-Dhuleil Basin:

- 13.5 MCM in the semi-arid northern catchment of the Azraq sub-basin (6% of 150-250 mm over 1,260 km^2).
- 10.8 MCM in the arid eastern catchment of the Azraq sub-basin (2.4 mm over 4,500 km^2).
- 13 MCM in the Wadi Dhuleil catchment (1,320 km^2).

Most samples from bore-holes in northern Jordan (the Mafraq area, the north-eastern desert in Jordan and the basalt area north of Azraq) have an isotopic signature indicating recharge on the slopes of Jebel al Arab and groundwater movement over long distances with retention periods of 6,000 to 16,000 years. In the arid north-eastern parts of the basalt region, bore-hole tests revealed fossil groundwater with groundwater ages of more than 20,000 years and stable isotope composition characteristic of recharge during previous pluvial periods.[20]

FLOW REGIME

Under natural conditions, groundwater in the Azraq-Dhuleil Basin flows southward from the Jebel al Arab Mountain range in Syria to the Azraq discharge zone in Jordan (see Overview Map). Depth to groundwater in the main Basalt Aquifer ranges from more than 400 m bgl in the topographically higher areas to less than 50 m on the southern fringes of the basalt field (see Chap. 21, Fig. 2). Most of the water in the Azraq area originates from the Basalt Aquifer.[21]

In some parts of the Dhuleil area west of the Azraq-Dhuleil Basin, groundwater flow in the basalt and the underlying Upper Cretaceous aquifer may be directed toward the Zarqa River in the west. The groundwater regime is, however, highly disturbed by groundwater extraction.

STORAGE

Information on groundwater storage was not available.

DISCHARGE

The major groundwater discharge area in the Azraq-Dhuleil Basin is situated at Azraq on the southern margin of the basin. Previously, groundwater in the Azraq area in Jordan discharged from four major springs: the freshwater Aura and Mustadhema and the brackish Souda and Qaysiyeh Springs (Table 1). Prior to the development of groundwater resources in the region, spring discharge and evapotranspiration in the Qaa al Azraq, a plain with swamps and salt flats,[22] was 16 MCM/yr. It appears to have been largely sustained by present-day recharge, which occurs chiefly in the mountainous northern parts of the catchment. Spring discharge decreased significantly after 1980 with the establishment of a new well field, which tapped the Basalt Aquifer and Paleogene chalk aquifer upstream of the spring discharge area.[23] The springs are reported to have run dry between 1991 and 1993.[24]

WATER QUALITY

Groundwater salinity in the Basalt Aquifer in the western part of the Azraq-Dhuleil Basin is generally low to moderate (see Chap. 21, Figure 2). TDS values range between 200 and 400 mg/L, while most of the groundwater is Na-HCO_3 or Na-Cl type.

The hydrochemical composition may be related to the low chemical reactivity of the basaltic silicate rocks; solution processes of carbonate and silicate minerals probably contribute to dissolved solids.

Higher TDS concentrations up to several thousand mg/L are found on the south-western fringes of the basalt field, where the basalts form a joint aquifer with underlying sedimentary formations.[25] In the Azraq Plain, high groundwater salinity rates can probably be attributed to the infiltration of irrigation return flow and evaporative salt enrichment.
In the arid south-eastern parts of the Azraq-Dhuleil Basin, groundwater salinity is generally 1,000-1,500 mg/L TDS.

In the Azraq Plain area, groundwater in the shallow aquifer has high salinity levels originating from several sources, including infiltration from the underlying saline Umm Rijam Aquifer[26] and infiltration of shallow groundwater in the plain, which is affected by evaporative enrichment of dissolved substances.[27] The sabkha area of the Azraq Plain contains saline groundwater.

Groundwater salinity in the south-eastern part of the Azraq-Dhuleil Basin is generally more than 1,000 mg/L TDS. In general, the elevated groundwater salinity can be attributed to the arid climate with very low recharge rates, high evaporative enrichment of the limited quantities of infiltrating water, and low rates of groundwater circulation and flushing of aquifers. Freshwater occurrences appear to be restricted mainly to lenses along major wadi courses.

Mean carbon-14 ages of groundwater indicate contemporary recharge on the slopes of the Jebel al Arab Mountain range as compared to the Azraq area, where an increase to between 8,000 and 15,000 years is observed.[28] Delta-O-18 values of groundwater in the Azraq-Dhuleil Basin generally range from -5.5‰ to -6.5‰ and are consistent with a groundwater movement over long distances from the slopes of the Jebel al Arab Mountains towards the Jordanian part of the basalt field. In the areas where intensive irrigation is practised near Azraq and in Wadi Dhuleil, the stable isotope values of the groundwater show a dominant influence of irrigation return flow.[29]

Table 1. Mean annual discharge of major springs in the Azraq area in 1982

NAME	MEAN ANNUAL DISCHARGE (MCM)
Aura	1.5
Mustadhema	0.7
Souda	2.4
Qaysiyeh	5.4

Source: Compiled by ESCWA-BGR based on UN-ESCWA et al., 1996.

EXPLOITABILITY

According to the standardized exclusion criteria used to assess exploitability in this Inventory,[30] the aquifer basin is characterized by limited exploitability in the northern and eastern areas as follows:

- **Depth to top of aquifer** is not a limiting factor in this shallow aquifer basin.

- **Depth to water level** exceeds 300 m in most or all of the main recharging areas in the northern part of the basin (see Chap. 21, Figure 2). Accordingly, exploitability of the aquifer in the Azraq-Dhuleil Basin is limited in Syria and in areas close to the Jordanian border.

- **Water quality:** Salinity varies within the basin, with values of less than 250 mg/L in the Jebel al Arab Mountain range in the north, increasing to over 1,500 mg/L on the eastern fringes of the basin (see Chap. 21, Figure 2). Salinity may limit exploitability, especially in the arid eastern part of the basin.

Groundwater Use

GROUNDWATER ABSTRACTION AND USE

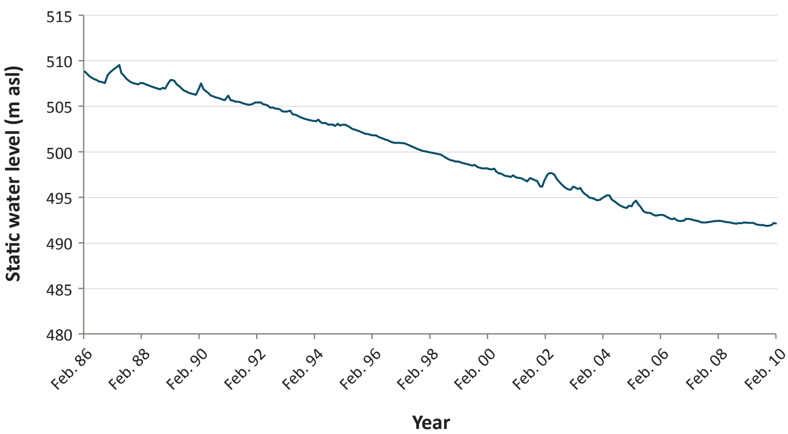
In Jordan, groundwater from the Azraq-Dhuleil Basin is used for domestic and agricultural purposes. The aquifer in the basin is exploited through a large number of drilled wells. The Azraq-Dhuleil Basin currently provides 25% of Amman's potable water.[31] Agricultural wells, which are mainly used to irrigate olive trees, are concentrated in the north-eastern desert east of Mafraq, and in the Dhuleil and Azraq areas in Jordan.[32] Most of the abstraction in the Azraq-Dhuleil Basin in Jordan is not from the Basalt Aquifer, but from the Eocene (B4) aquifer, especially in the Azraq Plain and the southern part of the basin. In Wadi Dhuleil in the south-west of the Azraq-Dhuleil Basin, wells mainly tap the Upper Cretaceous carbonate aquifer (A7/B2 aquifer), which is partly covered by Pleistocene basalt. Disaggregated abstraction figures for the individual aquifers and locations were not available.

While the first wells in Azraq were drilled in the 1930s, irrigated agriculture only took off in the 1960s with the introduction of diesel motor pumps. The introduction of modern irrigation techniques that were already in use in the Jordan Valley led to an agricultural boom in the highlands in the late 1970s and 1980s. In 1980, agricultural water in the Azraq-Dhuleil Basin originated entirely from the springs, which naturally discharged on the surface. However, over the past three decades, the absence of regulations to limit agricultural expansion has led to a sharp rise in groundwater use.[33] In the Azraq region in particular, total agricultural land area has risen from 756.6 ha in 1980 to around 8,803 ha in 2010.[34] In addition, groundwater from the Amman Water Sewerage Authority (AWSA) well field north of Azraq supplies domestic water to Amman, Irbid and Zarqa since the early 1980s.[35]

Total abstraction in the basin nearly tripled after 1980, increasing from 21.6 MCM/yr in 1983 to 58.5 MCM/yr in 2004. As a result, the water table has dropped at a rate of $3x10^{-1}$-$8x10^{-1}$ m/yr[36] (Figure 1), creating serious water quantity and quality problems. Since 2004, some farms have been abandoned as a result of the steep decline in groundwater levels, reduced well productivity and rising salinity – especially around the town of Azraq. However, groundwater over-abstraction continues to be a problem in the basin, with abstractions reaching 215% of the safe yield.[37] In 2009, total annual abstraction from 960 wells in the basin reached 51.16 MCM, of which 27.5 MCM were used for agricultural purposes, 22.9 MCM for drinking water and $7.6x10^{-1}$ MCM for other purposes.[38]

Satellite images of the Syrian part of the Azraq-Dhuleil Basin also show agricultural development, but no information was available regarding wells or abstraction figures.

Figure 1. Groundwater level in observation well F1043 near the AWSA well field in the Azraq Plain



Source: Modified by ESCWA-BGR based on Alraggad and Jasem, 2010.

Azraq Oasis, Jordan, 1997. Source: David L. Kennedy, Aerial Photographic Archive for Archaeology in the Middle East.

GROUNDWATER QUALITY ISSUES

Groundwater quality and sustainability are obviously affected by the high rates of abstraction from the Basalt Aquifer System. In the Dhuleil and Azraq areas in Jordan, heavy groundwater abstraction for irrigation has resulted in soil salinization, deterioration of groundwater quality and depletion of water resources (Figure 1). The drying up of major springs in the Azraq Plain has destroyed a unique desert oasis environment.

In 1994/95 the Jordanian Government decided to pump $5x10^{-1}$ MCM/yr to keep the oasis alive. However, feeding the former oasis with pumped groundwater led to an increase in groundwater salinity in the area, as the hydraulic system of the oasis was reversed from a point of discharge to a point of groundwater recharge. Salts are now actively washed down into the shallow aquifer (Figure 2).[39]

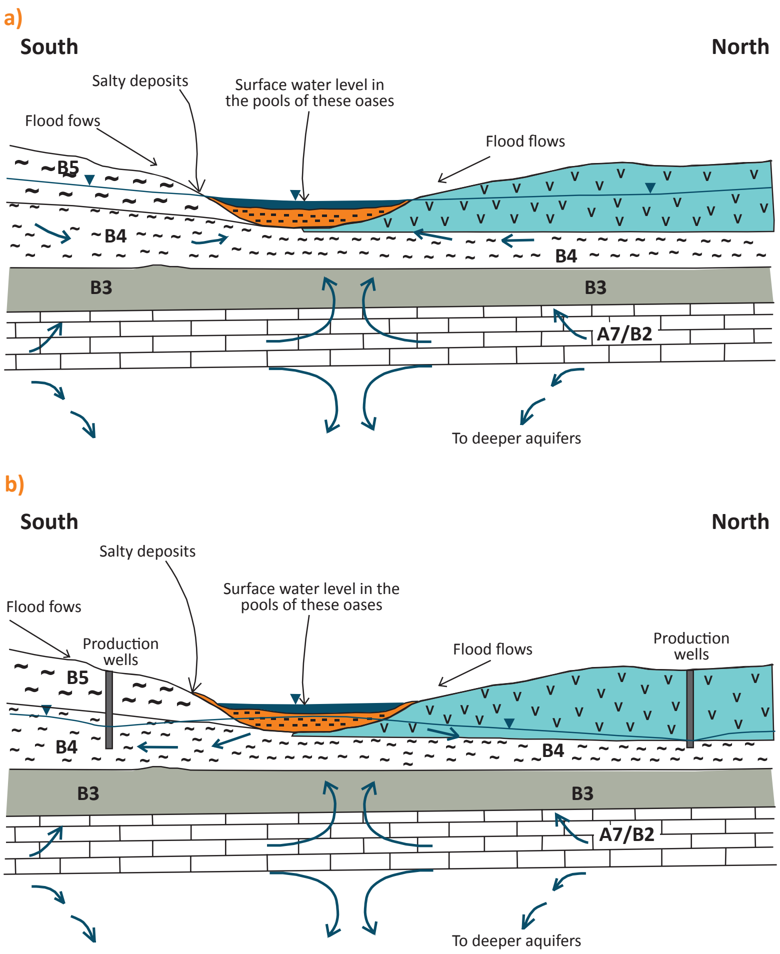
Groundwater exploitation at moderate rates is not expected to significantly affect the resources in distant downstream areas. Operation of well fields with high discharge may, however, have a strong impact on the aquifer in a relatively wide radius.

In Wadi Dhuleil in the south-west of the Azraq-Dhuleil Basin, about 80 production wells are in operation for irrigation and domestic supply. The wells mainly tap the Upper Cretaceous carbonate aquifer (A7/B2 aquifer), which is covered by Pleistocene basalt in part of the area. Groundwater salinity in samples here ranges from 400 to 6,000 mg/L TDS. Mean concentrations of all major ions, except for HCO_3^-, are higher than in other areas of the western part of the Basalt Aquifer System. High groundwater salinity and groundwater quality deterioration is reportedly mainly caused by the rapid recycling of irrigation water. Part of the water applied for irrigation seeps directly into the subsurface without longer retention in the soil zone.

SUSTAINABILITY ISSUES

The over-exploitation of groundwater resources in the Azraq-Dhuleil Basin since 1980 is partly due to uncontrolled agricultural growth and has resulted in a significant drop in water levels, as well as the deterioration of soil and groundwater quality. This has also severely affected the wetlands in the Azraq area, which formed an important environmental site with rich fauna and flora.

Figure 2. Schematic geological cross-sections through the Azraq Oasis: (a) before groundwater abstraction, (b) after major groundwater abstraction



Source: Modified by ESCWA-BGR based on Salameh, 1996.

Agreements, Cooperation & Outlook

AGREEMENTS

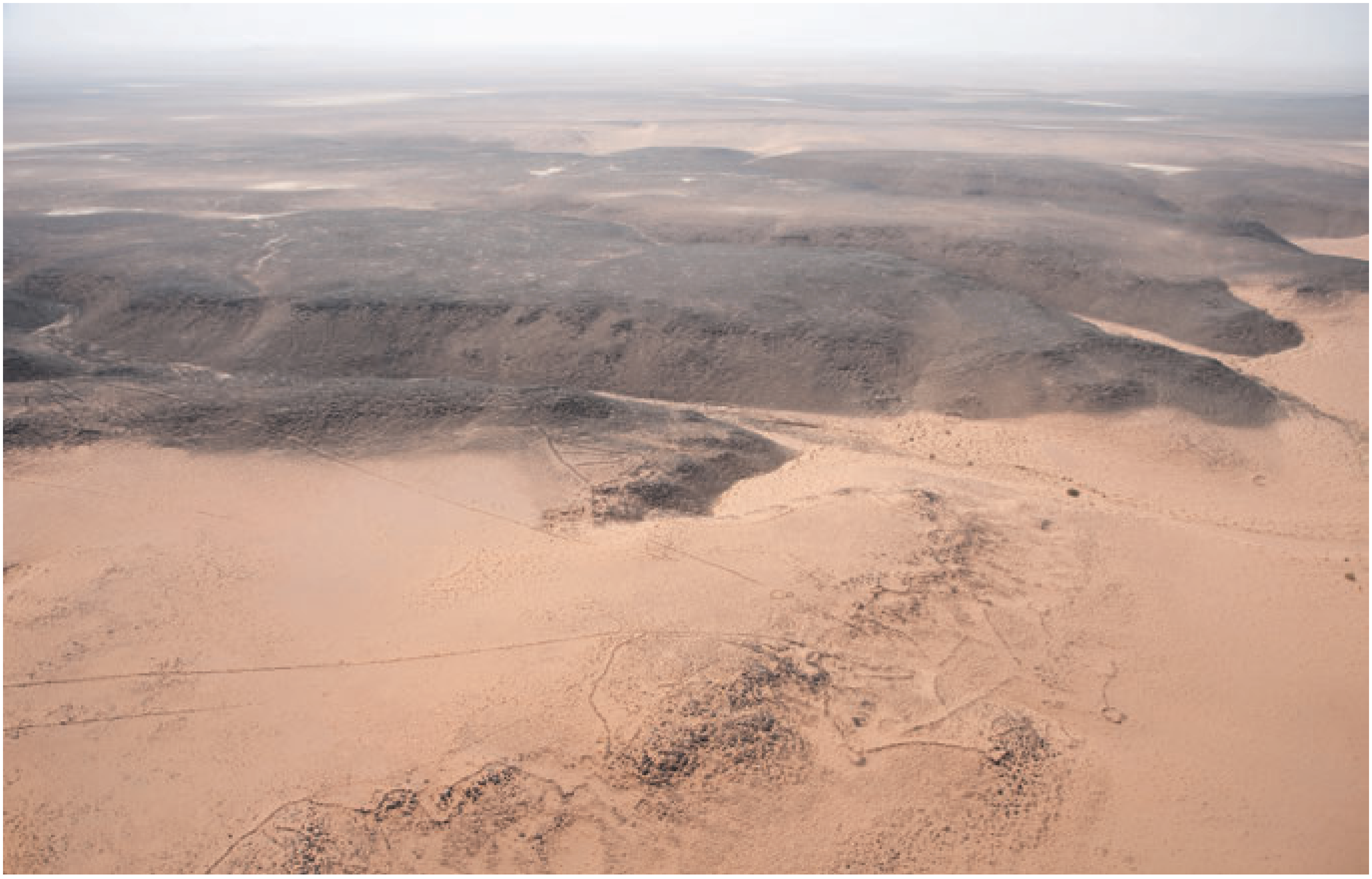
There are no formal water agreements in place for the Azraq-Dhuleil Basin, which is shared between Jordan and Syria.

COOPERATION

In the early 1990s, ESCWA and BGR facilitated cooperation between the Ministry of Water and Irrigation in Jordan and the Ministry of Irrigation in Syria to investigate and monitor groundwater resources in the Basalt Aquifer System.[40] This process was, however, discontinued shortly afterwards.

OUTLOOK

No information was available regarding current or potential transboundary impacts of groundwater use in the Azraq-Dhuleil Basin. It appears that groundwater in the basin is mainly developed in Jordan, where the decline in water levels and rising salinization are important factors that could restrict groundwater exploitation. Farming in the Jordanian Highlands is still quite profitable for some investors, however. Moreover, compared to the Jordan Valley, water quality in the area remains high and it is difficult to reduce support for irrigation due to the strong political ties between farmers and the Jordanian Government. Nevertheless, the government is stepping up its efforts to tackle the over-exploitation of the aquifer. In December 2010, the Jordanian Ministry of Water and Irrigation issued an Amendment to the Groundwater Control Regulation, which outlines an increase in water tariffs for drinking and agricultural water.[41] Other initiatives in Jordan, such as the Highland Water Forum aim to encourage sustainable groundwater management practices in the basin.[42]



Area of Mafraq, Jordan, 2009. Source: Robert Bewley, Aerial Photographic Archive for Archaeology in the Middle East.

Notes

1. The aquifer system has also been referred to as Jebel al Arab Aquifer based on the name of the mountain range (altitude: ≤1,800 m asl).
2. In the original study of the regional basalt aquifer system (UN-ESCWA, 1996), the Azraq and Dhuleil were considered to be separate basins on the basis of surface drainage and morphology. From a hydrogeological perspective, however, the two basins can be merged into one, since part of the groundwater in the Dhuleil Basin flows into the Azraq Basin in the area of the main discharge zone.
3. While the Golan Basin is not considered a shared aquifer, most of its basin area has been occupied by Israel since 1967 and the aquifer here discharges into the transboundary Jordan River Basin. See Chap. 21, Box 1 for an overview of the Golan Basin.
4. UN-ESCWA et al., 1996.
5. The southern part of the Azraq-Dhuleil Basin below the Ramtha-Wadi Sirhan Fault System is excluded from the delineation because groundwater in this part of the Limestone Plateau is not related to the Jebel al Arab Basalt area. Moreover, this groundwater does not constitute a shared resource since it originates and discharges in Jordan.
6. El-Naqa, 2010.
7. Ibid.
8. Based on a 2004 population census (Central Bureau of Statistics in the Syrian Arab Republic, 2005) and 2010 estimates (Central Bureau of Statistics in the Syrian Arab Republic, 2011).
9. Based on 2011 estimates by Department of Statistics in Jordan, 2012. A very small part of Maan Governorate is also included, but this area is very sparsely populated.
10. Figure 4, Margane et al., 2002; El-Naqa and Al-Shayeb, 2009; Al-Mahamid, 2005.
11. UN-ESCWA et al., 1996.
12. Ibid.
13. Krasnov et al., 1966.
14. Margane et al., 2002; El-Naqa, 2010.
15. Al-Mahamid, 2005.
16. UN-ESCWA et al., 1996.
17. Ibid.; Schelkes, 1997.
18. Abu-Jaber et al., 1998; Eraifej and Abu-Jaber, 1999.
19. All recharge figures and calculations in the text based on Schelkes, 1997; Wagner, 2011.
20. Geyh et al., 1985.
21. Abu-Jaber et al., 1998.
22. Also known as the Azraq Oasis and Azraq Plain.
23. In the early 1970s, 54 private wells were dug in the wetland area and abstracted 2 MCM/yr for irrigation purposes (despite the prohibition of unlicensed digging in 1971). By 1984, 327 wells abstracted 8 MCM/yr (GIZ, 2010).
24. UN-ESCWA et al., 1996.
25. Ibid.
26. Abu-Jaber et al., 1998.
27. Salameh, 1996.
28. UN-ESCWA et al., 1996.
29. Ibid.
30. The following criteria are used to assess exploitability in this Inventory: drilling depth/depth to top of aquifer; groundwater level; and water quality/salinity. For more information on the approach, see 'Overview & Methodology: Groundwater' chapter.
31. GIZ, 2010.
32. According to GIZ, 2010, olive trees constitute 51% of agriculture in the highlands, followed by vegetables and stone fruits (respectively 20% and 17%).
33. Al-Adamat et al., 2003.
34. Ministry of Agriculture in GIZ, 2010.
35. El-Naqa et al., 2007. The Amman Water Sewerage Authority (AWSA) began pumping water from the Azraq wetland to Amman in 1981 at a rate of 1.5 MCM/yr. One year later, 15 wells were drilled in the northern part of the oasis to meet domestic water demand in Amman and Zarqa, with an average abstraction of 17 MCM/yr (GIZ, 2010).
36. Water levels in some wells are reported to have dropped by 20 m between 1983-2004 (GIZ, 2010).
37. The safe yield is 24 MCM/yr (GIZ, 2010).
38. GIZ, 2010. Of these, 909 were situated in the Azraq area (865 of these were used for agricultural purposes) and 51 were situated in the northern Badia region in Jordan. Illegal abstraction from the Azraq-Dhuleil Basin amounts to 13 MCM/yr.
39. Salameh, 1996.
40. UN-ESCWA et al., 1996.
41. GIZ, 2010 states that the amendment is awaiting approval by the Prime Minister's Cabinet.
42. The Highland Water Forum is a multi-stakeholder dialogue that aims to build consensus among water users, especially the agricultural community and the authorities, regarding the cause of the decline in groundwater resources and appropriate response measures. It is supported by international donors.

Bibliography

Abu-Jaber, N. S., Ali, A. J. and Al-Qudah, K. 1998. Use of Solute and Isotopic Composition of Ground Water to Constrain the Ground Water Flow System of the Azraq Area, Jordan. **Ground Water**, 36(2): p. 361-365.

Al-Adamat, R. A. N., Foster, I. D. L. and Baban, S. M. J. 2003. Groundwater Vulnerability and Risk Mapping for the Basaltic Aquifer of the Azraq Basin of Jordan Using GIS, Remote Sensing and DRASTIC. **Applied Geography**, 23(303-324).

Al-Mahamid, J. 2005. Integration of Water Resources of the Upper Aquifer in Amman-Zarqa Basin Based on Mathematical Modeling and GIS, Jordan. **Freiberg Online Geology**, 12.

Alraggad, M. and Jasem, H. 2010. Managed Aquifer Recharge (MAR) through Surface Infiltration in the Azraq Basin/Jordan. **Journal of Water Resource and Protection**, 2: p. 1057-1070.

Central Bureau of Statistics in the Syrian Arab Republic. 2005. General Census, Population in the Areas and Suburbs 2004. Available at: http://cbssyr.org/General%20census/census%202004/pop-man.pdf. Accessed on October 15, 2010.

Central Bureau of Statistics in the Syrian Arab Republic. 2011. Statistical Abstract 2011. Available at: http://www.cbssyr.org/yearbook/2010/chapter2-EN.htm. Accessed on March 5, 2012.

Department of Statistics in Jordan. 2012. Population Estimates for 2011. Available at: http://www.dos.gov.jo/dos_home_a/main/2004/. Accessed on March 5, 2012.

El-Naqa, A. 2010. Study of Salt Water Intrusion in the Upper Aquifer in Azraq Basin. Published by IUCN. Available at: http://cmsdata.iucn.org/downloads/final_report_azraq_2011.pdf. Accessed on December 15, 2012.

El-Naqa, A., Al-Momani, M., Kilani, S. and Hammouri, N. 2007. Groundwater Deterioration of Shallow Groundwater Aquifers Due to Overexploitation in Northeast Jordan. **Clean: Soil, Air, Water**, 35(2): p. 156-166.

El-Naqa, A. and Al-Shayeb, A. 2009. Groundwater Protection and Management Strategy in Jordan. **Water Resources Management**, 23: p. 2379-2394.

Eraifej, N. and Abu-Jaber, N. 1999. Geochemistry and Pollution of Shallow Aquifers in the Mafraq Area, North Jordan. **Environmental Geology**, 37(1-2): p. 162-170.

Geyh, M., Khouri, J., Rajab, R. and Wagner, W. 1985. Environmental Isotope Study in the Hamad Region. **Das Geologische Jahrbuche**, C(38): p. 3-15.

GIZ (Gesellschaft für Internationale Zusammenarbeit). 2010. Farming in the Desert: Analysis of the Agricultural Situation in Azraq Basin. Published by German-Jordanian Programme Management of Water Resources. Amman. Available at: http://highlandwaterforum.files.wordpress.com/2012/08/agro-economic-study-chantal-demilecamps.pdf. Accessed on November 4, 2012.

Krasnov, A. A., Kazmin, V. G. and Kulakov, V. V. 1966. The Geological Map of Syria 1:200000 Explanatory Notes. Sheets I-36-VI, I-37-I, II. Moscow.

Margane, A., Hobler, M., Almomani, M. and Subah, A. 2002. Contributions to the Hydrogeology of Northern and Central Jordan. **Geologisches Jahrbuch**, 68(52).

Salameh, E. 1996. Water Quality Degradation in Jordan (Impacts on Environment, Economy and Future Generations Resources Base). Published by Friedrich Ebert Stiftung and Royal Society for the Conservation of Nature. Amman.

Schelkes, K. 1997. Groundwater Balance of the Jordan-Syrian Basalt Aquifer. Published by BGR (Bundesanstalt für Geowissenschaften und Rohstoffe). Hannover.

UN-ESCWA, BGR, Ministry of Water and Irrigation in Jordan and Ministry of Irrigation in the Syrian Arab Republic (United Nations Economic and Social Commission for Western Asia; Bundesanstalt für Geowissenschaften und Rohstoffe). 1996. Investigation of the Regional Basalt Aquifer System in Jordan and Syria. Amman.

Wagner, W. 2011. Groundwater in the Arab Middle East. Published by Springer-Verlag. Berlin, Heidelberg.