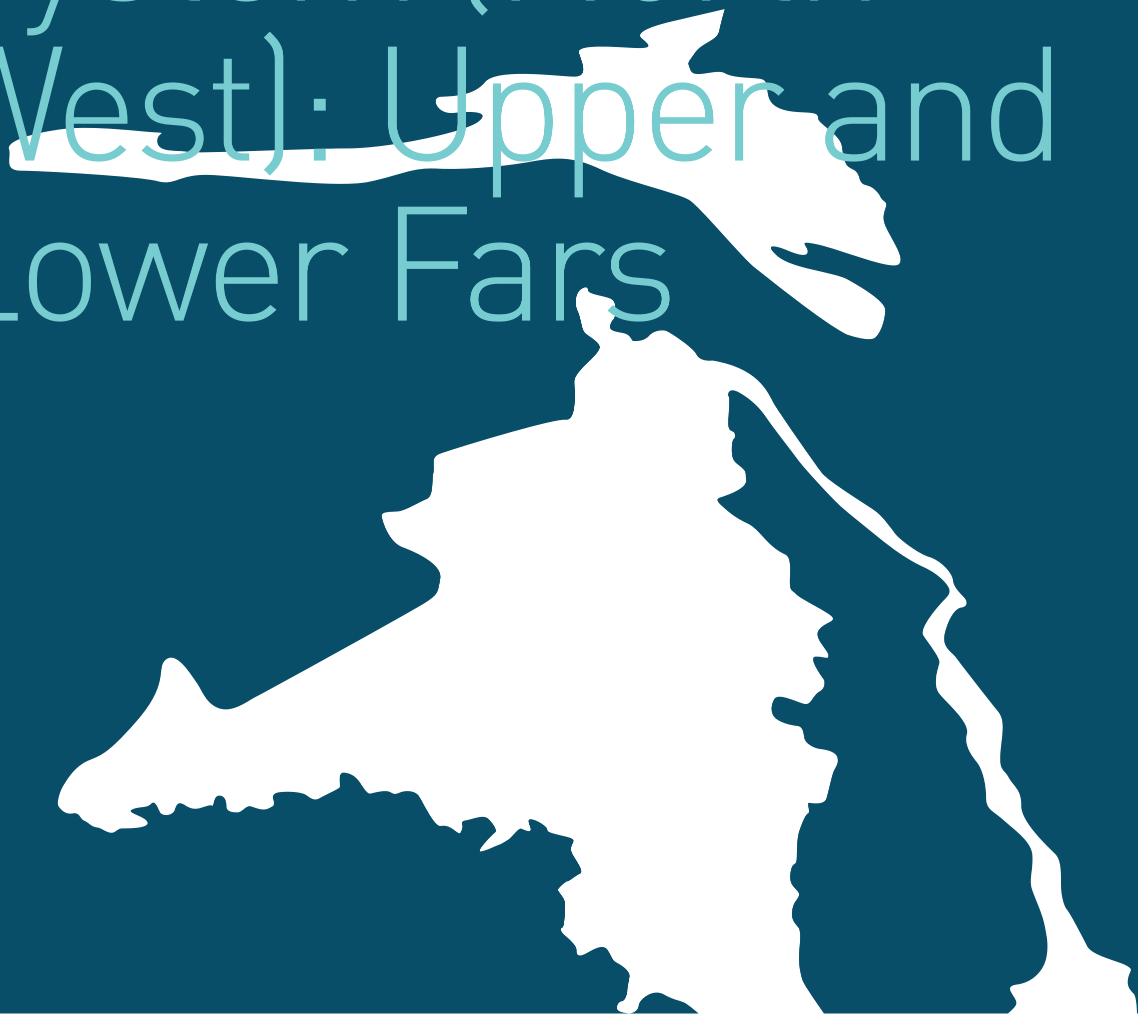
Chapter 25

Jezira Basin

Neogene Aquifer System (North-West): Upper and Lower Fars



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

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Neogene Aquifer System (North-West): Upper and Lower Fars

Jezira Basin

EXECUTIVE SUMMARY

The eastern part of the Upper and Middle Neogene Formations beneath the Mesopotamian Plain constitutes a shared aquifer system between Iraq and Syria. This aquifer system is referred to as the Neogene Aquifer System (North-West), and comprises the Upper and Lower Fars Formations of Miocene age (presently known in Iraq as Injana and Fatha). It consists of a lower part composed mainly of gypsum, and an upper part made up mostly of sandstones and clay.

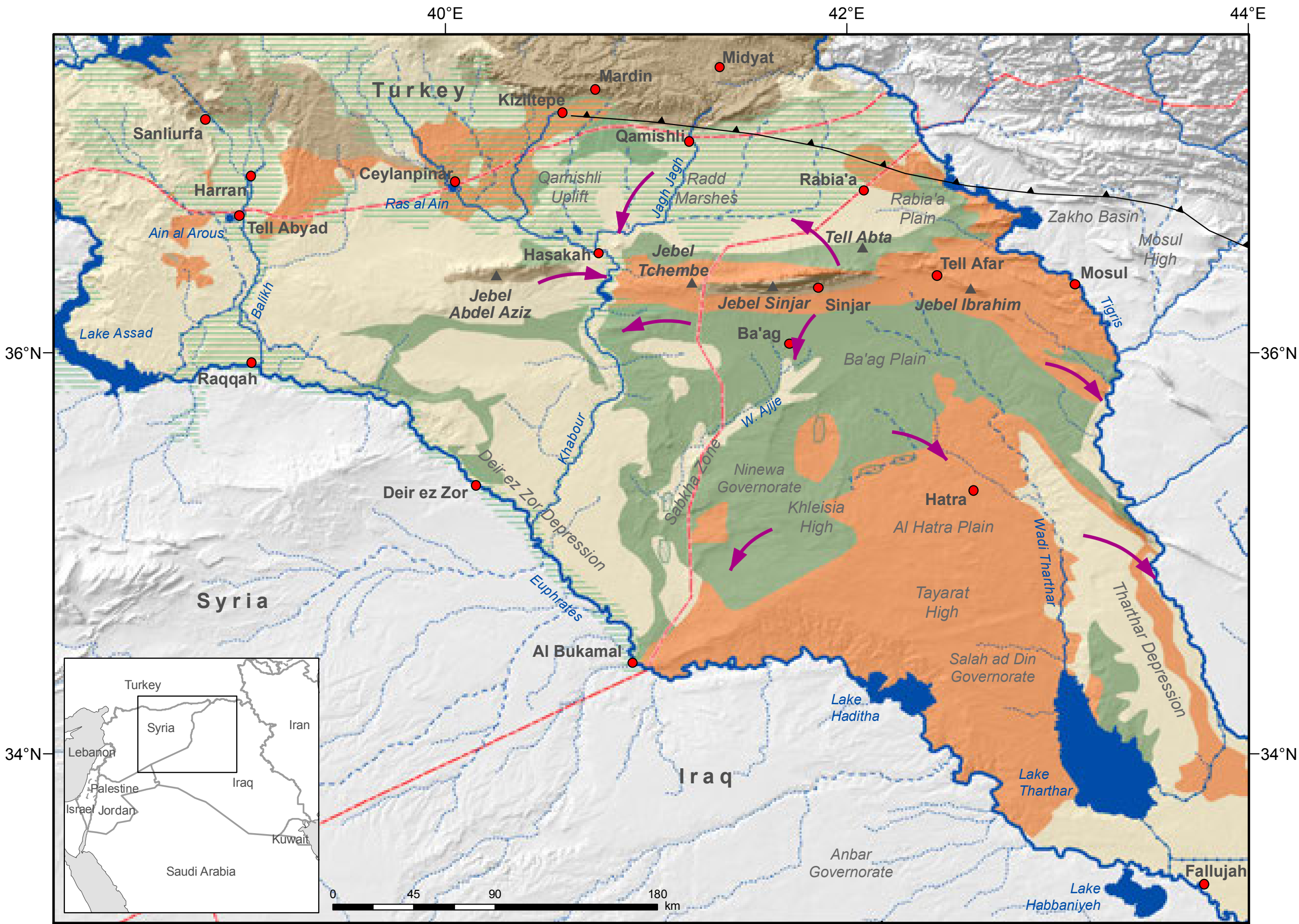
Groundwater flow across the political border is generally directed towards river courses and salt flats. Groundwater in both aquifer parts is generally brackish (4,000-≥20,000 mg/L TDS), with relatively more freshwater in the upper layers (<1,000 mg/L) especially in the northern areas where the aquifer is recharged by precipitation and surface water.

Groundwater is abstracted from wells, in addition to a small number of bore-holes that are concentrated in the vicinity of elevated areas around the Sinjar-Abdel Aziz Mountains. Groundwater use is generally restricted by high salinity levels and low well yields, and water for domestic consumption can only be abstracted from the upper aquifer up to a depth of 25 m bgl.

BASIN FACTS

RIPARIAN COUNTRIES	Iraq, Syria
ALTERNATIVE NAMES	Iraq: Fatha-Injana Syria: Lower and Upper Fars
RENEWABILITY	Medium to High (20 - >100 mm/yr)
HYDRAULIC LINKAGE WITH SURFACE WATER	Good
ROCK TYPE	Porous
AQUIFER TYPE	Unconfined to confined
EXTENT	65,000 km^2
AGE	Cenozoic (Neogene)
LITHOLOGY	Sandstones
THICKNESS	Generally 500-550 m with a pronounced decrease in thickness north of the Sinjar Uplift
AVERAGE ANNUAL ABSTRACTION	..
STORAGE	..
WATER QUALITY	Most common: brackish to saline (2,000-4,000 mg/L TDS) Recharge areas: ≤ 1,000 mg/L TDS Discharge areas: 5,000 - ≥ 20,000 mg/L TDS
WATER USE	Agriculture and domestic
AGREEMENTS	-
SUSTAINABILITY	Risk of salinization if wells are deepened and/or infiltration of surface water from irrigated areas

OVERVIEW MAP



Neogene Aquifer System (North-West), Upper and Lower Fars: Jezira Basin

- Selected city, town
- International boundary
- River
- Intermittent river, wadi
- Canal, irrigation tunnel
- Freshwater lake
- Sabkha
- Mountain
- Upper Fars Formation outcrop } Miocene
- Lower Fars Formation outcrop } Miocene
- Pre-Miocene outcrops
- Approximate subsurface extent of the aquifer formations
- Direction of groundwater flow
- Zone of agricultural development (selection)
- Thrust belt

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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.

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Introduction

LOCATION

The Upper and Lower Fars Formations also known as Injana and Fatha in Iraq occur across the Mesopotamian Plain in north-eastern Iraq and north-western Syria, in the area situated between the Euphrates and Tigris Rivers known as the Jezira[1] (see Overview Map).[2] The Khabour River in Syria cuts through a narrow ridge,[3] forming a subsurface drain for groundwater from the east and west.[4] The river constitutes the western boundary of the Neogene Aquifer System (North-West) that extends across the Jezira Basin to Wadi Tharthar and Lake Tharthar in Iraq, which form the boundary between two key morphological zones in Iraq.[5]

AREA

For the purpose of this Inventory, the Jezira Basin is defined by the following geo-physiographic features:

- The thrust belt of the Taurus-Zagros system[6] and the Qamishli Uplift,[7] which allow groundwater to flow southward toward the Jezira Basin.
- The Jagh Jagh River, where the Paleogene sediments drop to great depths,[8] suggesting that the river channel may represent a fault.
- The Khabour River, which flows through a gorge into which groundwater discharges from the east and west.[9]
- The Mosul High (or Mosul Uplift), which was active during the deposition of the Lower Miocene age formation and along which the Tigris River flows.[10] It defines the eastern limit of the Western Sinjar Basin,[11] which extends into Syria.
- Wadi Tharthar and Lake Tharthar, which divide two major morphological zones in Iraq: the Alluvial Fans Zone and the Jezira Basin.

The above-mentioned boundaries have been used to calculate the area of the shared aquifer system, which covers around 65,000 km^2, of which 78% (49,000 km^2) lies in Iraq and the remaining 22% (16,000 km^2) in Syria. The Miocene age outcrops cover an area of around 51,000 km^2, which corresponds to around 70% of the total area of the delineated basin (see Overview Map).

The topography of the Jezira Basin is dominated by plains and valleys at altitudes of 340-400 m asl. High ridges between 950 m asl (Jebel Abdel Aziz) and 1,460 m asl (Jebel Sinjar)[12] divide the area into northern and southern parts. The most prominent features in the northern section of the aquifer system are the Rabia'a Plain and the Radd Marshes. The southern section is dominated by the Khleisia-Tayarat Highs and the Deir ez Zor Depression, which are separated by a sabkha zone in the border area.

CLIMATE

The climate in the area of the Neogene Aquifer System (North-West) is arid to semi-arid. Average annual precipitation ranges from 150 mm in the south to 300 mm in the north, increasing to more than 400 mm in the Jebel Sinjar area, where snowfall also occurs. Average annual temperature is 18°C-21°C, while evaporation is estimated at 2,800 mm/yr.[13]

POPULATION

The total population in the delineated basin is estimated at around 4.6 million inhabitants, with around 3.5 million people living in the parts of the basin situated in the Iraqi governorates of Anbar, Ninewa and Salah ad Din[14] and 1.1 million people living in the Syrian governorates of Deir ez Zor and Hasakah.[15]

OTHER AQUIFERS IN THE AREA

The Jezira Tertiary Limestone Aquifer System (Eocene-Oligocene, see Chap.24), which is exploited in the Ras al Ain area, constitutes a potential aquifer, particularly in the vicinity of uplifted areas. The Quaternary deposits also form local aquifers in morphologic depressions and in alluvial fans at the foot of Jebel Sinjar.[16]

INFORMATION SOURCES

Most of the information about the Neogene Aquifer System (North-West) in Syria is drawn from a 1966 survey of groundwater resources in Syria.[17] Information on the Iraqi section of the aquifer system is more recent and specific to the Jezira Basin. The Overview Map was delineated based on various local and regional references drawn from both riparian countries.[18]

Hydrogeology - Aquifer Characteristics

AQUIFER CONFIGURATION

The Sinjar-Jebel Abdel Aziz Uplift had a significant effect on the development and configuration of the basin in which the Upper and Lower Fars Formations were deposited. North of this structure, the formations are generally thinner and overlain by substantial Pliocene-Quaternary deposits (see Overview Map),[19] while to the south they are significantly thicker and outcropping in plateau areas. The thickest deposits in the aquifer system occur in the vicinity of the Sinjar High.[20]

Table 1. Lithostratigraphy of the Neogene Aquifer System (North-West)

PERIOD	FORMATION	LITHOLOGY
Pliocene-Quaternary	Bakhtiari	Sands, gravels and conglomerates.
Upper Miocene	Upper Fars	Sandstone, marl, clay and gypsum.
Middle Miocene	Lower Fars	Anhydrite, gypsum, interbedded with limestone and marl.
Eocene-Lower Oligocene	Jezira Tertiary Limestone	Limestone with some dolomites and marly dolomites.

Source: Compiled by ESCWA-BGR based on Jassim and Buday, 2006; Brew et al., 1999; Burdon and Safadi, 1963.

STRATIGRAPHY

The Neogene Aquifer System (North-West) comprises two formations: the Upper and Lower Fars. They were deposited in a period when the open sea was being irregularly but persistently pushed south-eastward towards the current-day Gulf shoreline. During this period, marine sedimentation was replaced by depositions in saline lagoons, followed at times by freshwater lakes.[21] Table 1 shows the main lithology of the formations in the Jezira Basin. Lateral variations in lithology across the area are described below.

Lower Fars (Fatha)

In the Iraqi part of the Jezira Basin, the Lower Fars consists of several cycles of sedimentation deposited in a shallow lagoonal environment in a semi-closed marginal part of the Gulf Basin, characterized by sabkhas and saline tidal flats with deposition of carbonates and evaporites.[22] The cyclic sequences usually start with massive red claystone or marl, and contain thin limestones and thick layers of evaporites such as gypsum and anhydrite. Eleven such cycles were reported in the southern Jezira area.[23]

In the Syrian part of the Jezira Basin, the formation consists of shale and mudstone, gypsum and marine limestone, indicating the final extension of the open sea into this area. Halite occurs near the centre of the deposition basins.[24]

Kawkab Mountain in Hasakah Governorate, Syria, 2009. Source: Haitham Alfalah.

Upper Fars (Injana)

In the Iraqi part of the Jezira Basin, the formation conformably overlies the Lower Fars Formation and is characterized by the appearance of siltstone beds. It consists of cyclic alternations of claystone, siltstone and sandstone with a few thin freshwater limestone and gypsum layers. The formation is overlain in some areas by Quaternary deposits, e.g. alluvial fans near Jebel Sinjar and thick soil cover in the Rabia'a Plain.

In the Syrian part of the Jezira Basin, the surface exposure of the Upper Fars is limited in area as it is eroded in uplifted areas around Jebel Abdel Aziz and remains covered by younger deposits in the area of the Khabour River flood plain. In general, the formation is conformably underlain by Lower Miocene (Helvetian) deposits (Jeribe Formation) made up of sandstone with interbedded siltstone and mudstone.

AQUIFER THICKNESS

The Upper and Lower Fars Formations are easily recognized in the area of Kirkuk in Iraq to the east of the study area, where they reach a combined thickness of 1,240 m.[25] Within the delineated area, the thickness is reduced to 500-550 m as recorded in oil wells along the Iraqi-Syrian border (Figure 1). The most pronounced decrease in thickness is in the areas north of the Sinjar Uplift.

AQUIFER TYPE

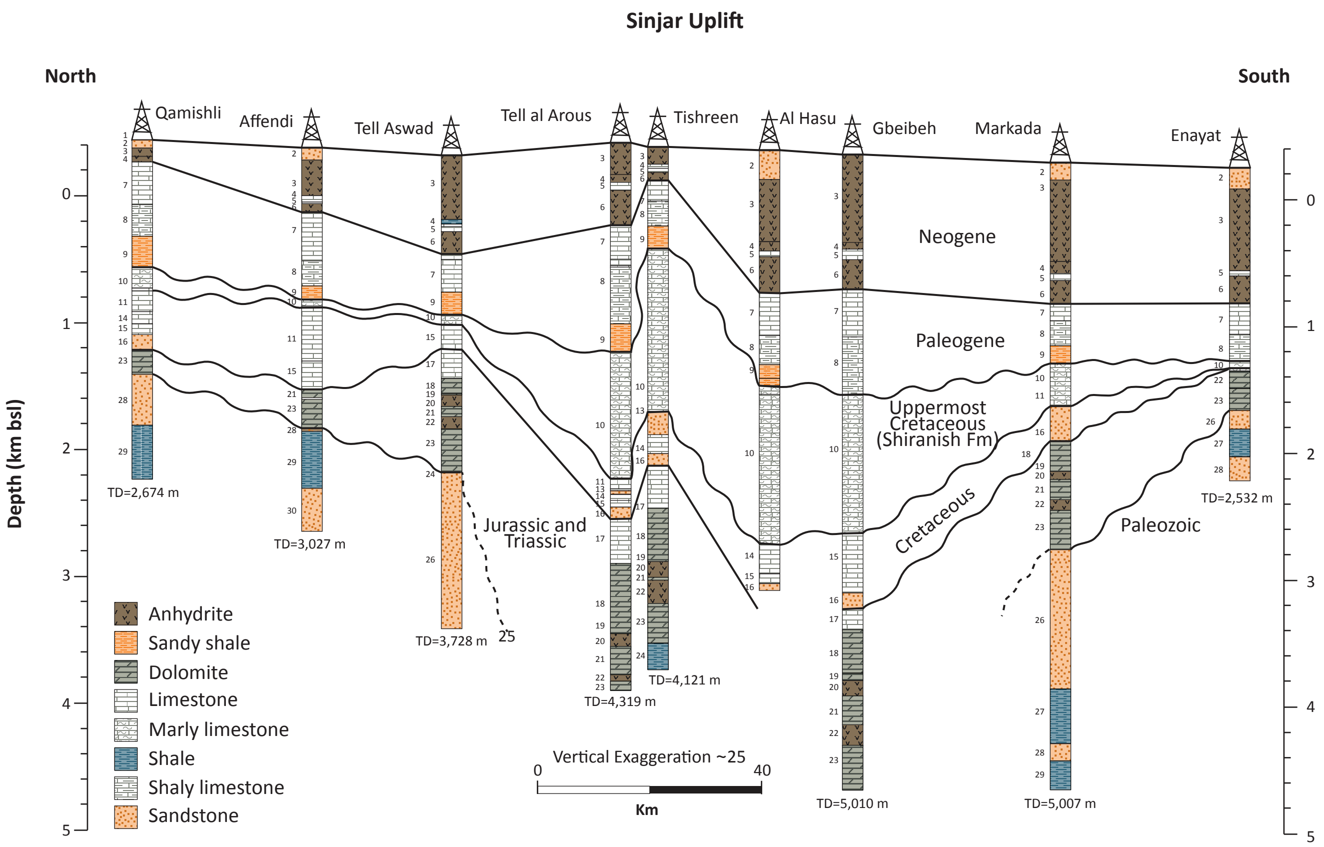
The Neogene Aquifer System (North-West) is unconfined in most areas of the Jezira Basin. The aquifer system is confined in some morphologically lower areas, where it is covered by younger sediments, and in deeper aquiferous sections, which are overlain by impermeable layers. Unconfined conditions prevail in outcrop areas of karstified gypsum and anhydrite beds of the Lower Fars Formation in the southern Jezira in Iraq. Locally, perched aquifers occur in the outcrop areas. The aquifer system comprises karstified and porous sections.[26]

AQUIFER PARAMETERS

In the Iraqi part of the Jezira Basin, hydraulic parameters vary widely due to karstification.[27] A range of $2.3x10^{-5}$ to $1.5x10^{-2}$ m^2/s was reported for the northern areas, with a median value of $4.5x10^{-4}$ m^2/s.[28] Lower values were reported in the Rabia'a Plain, varying from less than $1.2x10^{-5}$ to $1.8x10^{-3}$ m^2/s. Storage coefficients in the Rabia'a Plain are in the order of $5x10^{-4}$.[29]

Bore-hole tests of the aquifer system in Syria indicate a high heterogeneity of gypsum formation. Transmissivity values are reported at $1.6x10^{-4}$ to $8.1x10^{-2}$ m^2/s.[30]

Figure 1. Well correlation section across the western portion of the Sinjar Uplift in Syria



Source: Redrawn by ESCWA-BGR based on Brew et al., 1999.

Hydrogeology-Groundwater

RECHARGE

Three main factors contribute to present-day recharge in the Neogene Aquifer System (North-West):[31]

- The occurrence of rainfall in excess of 250 mm, mainly in the northern areas but also in localized uplifted areas.
- Thick accumulation of alluvial deposits, which allows recharge of the aquifer system after heavy storms, directly from precipitation and indirectly via runoff from the higher areas and surface water from the Khabour River.
- The occurrence of gypsum karstification, especially in areas where the Lower Fars Formation is exposed on the surface.

In the Iraqi part of the Jezira Basin, recharge rates are estimated at 68 mm/yr on limestone outcrops on the northern flank of Jebel Sinjar, and at 14 mm/yr in the soil-covered plain. In the Tell Afar area, which is characterized by low rainfall and a thick cover of silty to clayey soil, recharge is considered to be negligible. Further north in the Rabia'a Plain, an annual average recharge of 53 MCM is reported.[32] On the Ba'ag Plain, recharge of the exposed Upper Fars Formation is estimated at an annual average of around 110 MCM.[33] On the Al Hatra Plain, recharge takes place on the karstified surface of the Lower Fars Formation, mainly through sinkholes, resulting in localized infiltration of around 31.5 mm/yr.[34]

In the Syrian part of the Jezira Basin, groundwater from the overlying Quaternary Aquifer and adjoining Eocene Aquifers seeps into the Neogene Aquifer System (North-West) in the Radd Marshes. About 347 MCM/yr infiltrates into the Pliocene-Quaternary Radd Aquifer.[35] Water from numerous small springs in early Miocene and Eocene aquiferous rocks along the Jebel Abdel Aziz-Jebel Sinjar range re-infiltrates into the Neogene Aquifer System (North-West) through the Quaternary Aquifer. In the Upper Khabour Basin, infiltration takes place at an estimated rate of 50.5 mm/yr, which corresponds to about 18% of the average annual precipitation (282 mm). Overall groundwater recharge to the Upper and Lower Fars Aquifers in Syria has been estimated at 60-90 MCM and 16 MCM in the northern and southern Jezira Basin respectively.[36]

FLOW REGIME

The groundwater flow pattern in this aquifer system more or less follows the steep gradients of the local topography and may not represent a regional groundwater flow system.[37] Groundwater flow in the Lower Fars Formation appears to be karstic, with minor circulation systems directed to morphologic depressions. These depressions act as local groundwater discharge zones to form salt marshes or sabkhas. The overall groundwater flow pattern (see Overview Map) in the area suggests the following:[38]

- North of the Abdel Aziz-Sinjar Uplift, groundwater flow is oriented toward the upper part of the Tigris and Khabour Rivers within the study area and the Radd Marshes.
- South of the Abdel Aziz-Sinjar Uplift, the flow is toward low-lying sabkhas and depressions (Deir ez Zor and Tharthar Depressions), which terminate in the lower part of the Tigris and Khabour Rivers within the study area.

STORAGE

Information on groundwater storage was not available.

DISCHARGE

The main discharge area of the Neogene Aquifer System (North-West) is situated at Wadi Tharthar and Lake Tharthar. Discharge from the Upper Fars Formation provides the base flow in major wadis in the Jezira Basin in Iraq, with a discharge of 0.274 MCM/yr recorded in Wadi al Murra in October 1979.[39] Groundwater from the Lower Fars Formation seeps into local sabkhas along the Hadr-Bekhme Fault. In these sabkha areas[40] and at Jebel Ibrahim in the Tell Afar area, there are many small springs with discharges of around 0.095 MCM/yr. The springs originate in karstified gypsum-anhydrite beds of the Lower Fars Formation, with a total flow rate of 11 MCM/yr.

The largest spring at Tell Afar reportedly had a discharge of 6.3 MCM/yr in 1975.[41]

In the area of Jebel Abdel Aziz, numerous small springs discharge into closed depressions and sabkhas. A number of these springs that rise from the Lower Fars Formation discharge between 31.5 and 63 MCM/yr. There are 35 springs along the Tual al Abta-Jebel Abdel Aziz-Jebel Tchembe range. Relatively high discharge rates are reported for the Khatounye (15.7 MCM/yr), Ain Hol (approx. 9.47 MCM/yr) and Tell Taban (18.93 MCM/yr) Springs.[42]

WATER QUALITY

Groundwater in the Neogene Aquifer System (North-West) is generally brackish to saline and sulphate-type. Fresh bicarbonate-type water with less than 1,000 mg/L TDS is frequently encountered in shallow wells. On average, groundwater salinity in the Upper Fars is lower than in the Lower Fars.

In the Rabia'a Plain, salinity varies from less than 1,000 to 4,000 mg/L TDS in most wells.[43] Further south in the Ba'ag Plain, salinity in wells penetrating the Upper Fars Formation exceeds 4,500 mg/L TDS. Groundwater salinity in the Lower Fars Formation lies in the range of 3,000-5,000 mg/L TDS, increasing to 20,000 mg/L in sabkhas.[44] The following ranges were reported for groundwater salinity in the Jezira Basin in Iraq: less than 500 mg/L TDS in some shallow wells, 5,000-20,000 mg/L TDS in deeper wells, and saline water of more than 30,000 mg/L TDS in playas and salt lakes.[45]

Groundwater in the Lower Fars in the Jezira Basin in Syria is prevailingly brackish Ca-SO_4 water with salinities of about 2,000-4,000 mg/L TDS. At greater depths, groundwater salinity may exceed 10,000 mg/L TDS; fresh HCO_3-type groundwater occurs at a few locations.[46] The situation is similar in the Upper Fars Formation, which contains mainly Ca-SO_4 water with salinities of 2,000-4,000 mg/L TDS increasing with depth to 8,000 mg/L TDS.[47] Some small springs yield HCO_3-type freshwater.

EXPLOITABILITY

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

- **Depth to top of aquifer:** When not outcropping, the top of the Upper and Lower Fars Formations lie a few hundred metres below the surface. Hence, depth to top of the aquifer is not a limiting factor.
- **Depth to water level:** Depth to groundwater is usually less than 50 m bgl and as little as 20 m bgl as on the Khleisia High. [48] Therefore water level is also not a limiting factor.
- **Water quality:** Groundwater TDS varies widely and can reach 30,000 mg/L, except in shallow depths of 15-25 m where salinity is usually below 1,000 mg/L. [49] Salinity is therefore the main limiting factor to exploitability, both vertically and laterally.[50]

Based on the above, the aquifer system is exploitable within the delineated area up to a depth of 25 m bgl, except in and around sabkha areas where it may not be suitable for exploitation at all.

Kurdistan, northern Iraq, 1991. Source: Ed Kashi/VII.

Groundwater Use

GROUNDWATER ABSTRACTION AND USE

In the past, groundwater was abstracted from shallow wells in the Quaternary-Pliocene formations (mostly in the northern areas) and in the Neogene Aquifer System (North-West) around and to the south of the Sinjar-Abdel Aziz Uplift. Drilling of deeper bore-holes occurs where conditions are favourable, such as in the Ba'ag Plain.[51] In general, however, low aquifer productivity and poor water quality restrict the exploitability of the Neogene Aquifer System (North-West), and many wells abstracting from the aquifer system in Iraq have been abandoned due to low discharge.[52] Similarly, withdrawal from the section of the aquifer system in Syria is thought to have been significantly reduced due to salinization, with increased penetration of saline groundwater into the Lower Fars Formation.

The implementation of a number of irrigation projects in the area may help improve groundwater quality as fresh surface water percolates into the aquifer system.
The 60,000 ha Rabia'a Irrigation Project initiated in 1989 in Iraq transfers Tigris River water from Lake Mosul to the Rabia'a Plain. The project uses sprinkler irrigation on an area of 20,000 ha and furrow irrigation on 35,000 ha, allowing for the artificial recharge of groundwater in the Upper Fars Aquifer at an annual rate of about 130 MCM. As a result, the groundwater table has risen up to 4.5 m in certain areas. The infiltration of river water has also slightly improved water quality.[53] The expansion of the irrigated area in the Jezira Basin in Syria following the 1975 construction of Tabqa Dam on the Euphrates River has also led to artificial recharge of the Quaternary Aquifer and the Neogene Aquifer System (North-West).[54]

In the mid-1960s, there were more than 50,000 hand-dug wells and several hundred bore-holes in the northern part of the Jezira Basin in Syria.[55] These wells tap Miocene (i.e. Upper-Lower Fars) or Pliocene-Quaternary Aquifers. The quantity of water extracted from dug wells is generally limited (approx $1x10^{-3}$ MCM/yr), with quantities of up to about $3.6x10^{-3}$ MCM/yr near riverbeds.[56] Groundwater abstraction in Syria has probably decreased considerably in recent years as the relatively freshwater in the upper layers of the aquifer system is likely to have been exhausted.

In the Rabia'a Plain in the Jezira Basin in Iraq near the Tigris River, the Upper Fars Formation forms a key water source, as no other exploitable aquifers exist in the area. At least 66 drilled wells are in use in the plain, with productivity rates ranging between about $9x10^{-3}$ and $5x10^{-1}$ MCM/yr. They are complemented by numerous shallow hand-dug wells.[57] Around the city of Rabia'a, groundwater has low salinity rates and is suitable for human consumption, but in general it is mainly used for agricultural purposes or livestock watering. In the Ba'ag Plain, the Upper Fars Aquifer is exploited through more than 100 drilled wells with discharge rates of around 1.45 MCM/yr.

Further south, hundreds of shallow hand-dug wells and a number of drilled deeper wells exploit the Lower Fars Aquifer, with discharge rates varying between $1x10^{-1}$ and $4.2x10^{-1}$ MCM/yr.[58] The water is mainly used for domestic supply and livestock watering.

GROUNDWATER QUALITY ISSUES

The groundwater in the Neogene Aquifer System (North-West) is not suitable for human consumption in many areas. Groundwater use for irrigation purposes is also restricted because of generally low well yields and elevated salinity. Good-quality water with less than 1,000 mg/L TDS is commonly found in areas with secondary permeability, which is restricted to the upper 15-25 m of the aquifer system.[59] Irrigation with low-salinity water from the Euphrates, Khabour and Tigris Rivers may improve water quality in shallow aquifers.

SUSTAINABILITY ISSUES

Groundwater exploitation in this aquifer system is limited by low aquifer productivity and water quality problems. A number of surface water irrigation projects initiated over recent decades in Iraq and Syria have contributed to artificial recharge of the aquifer.

Agreements, Cooperation & Outlook

AGREEMENTS

There are no water agreements in place for the Neogene Aquifer System (North-West), which is shared between Iraq and Syria.

COOPERATION

The riparian countries do not cooperate over any aspect of water management or use.

OUTLOOK

The quality of water abstracted from wells in the Neogene Aquifer System (North-West) could be improved through the conjunctive use of surface water and groundwater. The construction of large-diameter dug wells would allow for the withdrawal of freshwater from superficial layers, and avoid mixing with brackish water contained in deeper layers. Such an approach could also allow for an increase in the amount of water abstracted from the aquifer system.

Near Aqrah, Iraq, 1991. Source: Ed Kashi/VII.

Notes

1. Jezira means "Island" in Arabic.
2. The formations extend beyond the main channels of the Euphrates and the Tigris. However, the Overview Map in this chapter limits itself to the area between the two rivers.
3. FAO and UNDP, 1966.
4. ACSAD, 1984.
5. The two zones are the Alluvial Fans Zone and the Jezira Basin (Krasny et al., 2006).
6. Kazmin, 2002.
7. Best et al., 1993.
8. ACSAD et al., 2003.
9. ACSAD, 1984.
10. Jassim et al., 1997.
11. As opposed to the Eastern Sinjar Basin which extends to Iran.
12. Kattan, 2001.
13. Al-Jiburi and Al-Basrawi, 2009.
14. Central Organization for Statistics in Iraq, 2012.
15. Central Bureau of Statistics in the Syrian Arab Republic, 2005.
16. Kattan, 2002.
17. FAO and UNDP, 1966.
18. Krasny et al., 2006; BGR-UNESCO, 1998; Robertson, 1987; Kazmin, 2002; Best et al., 1993.
19. Brew et al., 1999; Sawaf et al., 1993.
20. Ibid.
21. Burdon, 1954.
22. Tucker and Shawket, 1980.
23. Maala and Al-Kubaysi, 2009.
24. Burdon, 1954.
25. Jassim and Buday, 2006.
26. Al-Jawad, 1982.
27. Krasny et al., 2006.
28. Al-Jiburi and Al-Basrawi, 2009.
29. Al-Jawad, 1982.
30. FAO and UNDP, 1966.
31. Krasny et al., 2006.
32. Al-Jawad, 1982.
33. Faugere et al., 1976.
34. Jassim and Goff, 2006 .
35. FAO and UNDP, 1966.
36. Ibid.
37. Al-Jiburi and Al-Basrawi, 2009.
38. Figures 1 and 2 in FAO and UNDP, 1966.
39. Al-Jawad, 1982.
40. Krasny et al., 2006.
41. IARNR, 1974.
42. FAO and UNDP, 1966.
43. Al-Jawad, 1982.
44. Jassim and Goff, 2006.
45. Al-Jiburi and Al-Basrawi, 2009.
46. Ponikarov, 1967.
47. Ibid.
48. Krasny et al., 2006.
49. Ibid.
50. See section on groundwater quality issues below.
51. Al-Jiburi and Al-Basrawi, 2009.
52. Krasny et al., 2006.
53. Al-Naif, 2007.
54. Al-Jawad, 1982.
55. FAO and UNDP, 1966.
56. Ponikarov, 1967.
57. Al-Naif, 2007.
58. Al-Jiburi and Al-Basrawi, 2009.
59. Krasny et al., 2006.

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