Chapter 17

Wadi Sirhan Basin

Tawil-Quaternary Aquifer System

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

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Tawil-Quaternary Aquifer System

Wadi Sirhan Basin

EXECUTIVE SUMMARY

The Wadi Sirhan Basin is situated in Jordan and Saudi Arabia and forms a central depression surrounded by basalt and sedimentary plateau areas in the north and south. The basin surface is covered by Paleogene and Quaternary deposits, which make up the upper part of the exploited aquifer system. In the subsurface, thick deposits of Cretaceous and Tawil-Sharawra Formations occur in the depression and along the boundaries of the aquifer system. They constitute the lower part of an aquifer system that is denoted as the Tawil-Quaternary Aquifer System in this Inventory.

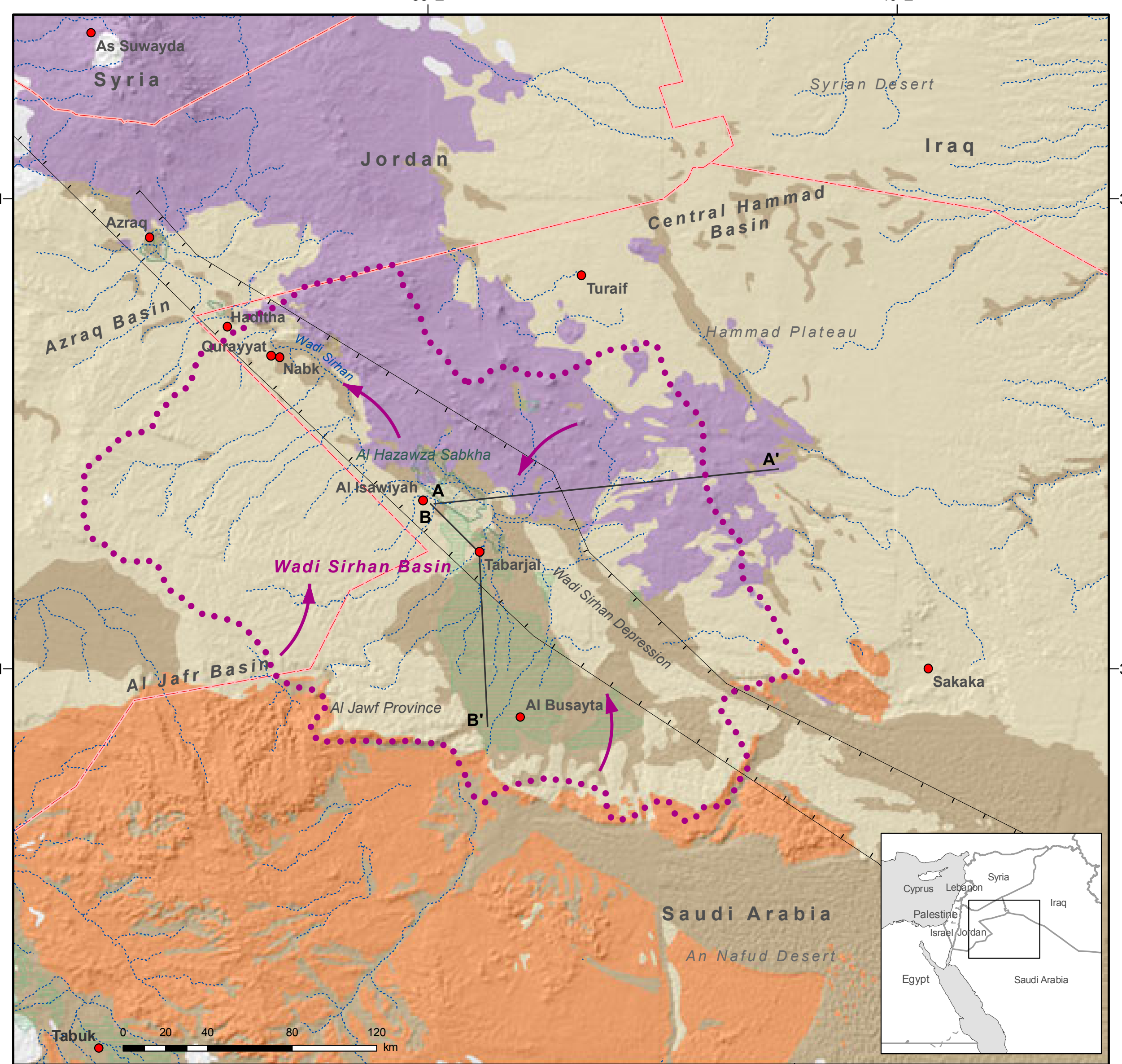
This aquifer appears to have evolved as part of the groundwater system in the Sakaka-Azraq areas, with limited recharge entering the system in the form of Mediterranean-type rainwater. Groundwater flows from the basalt and limestone plateau areas towards the central depression where it follows the hydraulic gradient in a south-east/north-west direction.

Since exploitation of the aquifer system started in 1986, annual abstraction for irrigation purposes has risen from about 100 MCM in 1984 to almost 3,500 MCM in 2004. However, the lower part of the aquifer system appears to have potential for further exploitation as only a few of the approximately 100 wells tapping this part of the aquifer system show signs of significant drawdown.

BASIN FACTS

RIPARIAN COUNTRIES	Jordan, Saudi Arabia
ALTERNATIVE NAMES	Azraq Graben, Secondary-Tertiary-Quaternary Aquifer Complex (STQ), Sharawra, Sirhan Basin, Sirhan-Hamza Graben
RENEWABILITY	Very low (0-2 mm/yr)
HYDRAULIC LINKAGE WITH SURFACE WATER	Weak
ROCK TYPE	Porous to fractured
AQUIFER TYPE	Mainly unconfined
EXTENT	~44,000 km^2
AGE	Upper part: Upper Cretaceous to Quaternary Lower part: Early Devonian-Silurian
LITHOLOGY	Basalt, alluvium, limestone and sandstones with some marl
THICKNESS	Upper part: <1,300 m Lower part: 200-300 m
AVERAGE ANNUAL ABSTRACTION	1984: 100 MCM 2004: 3,500 MCM
STORAGE	22 BCM
WATER QUALITY	Fresh to saline
WATER USE	Irrigation
AGREEMENTS	-
SUSTAINABILITY	Over-exploitation of the upper part of the aquifer system, especially in the south for irrigation

OVERVIEW MAP



Tawil-Quaternary Aquifer System: Wadi Sirhan Basin

- Selected city, town
- International boundary
- Intermittent river, wadi
- Zone of agricultural development (selection)
- A A' Approximate location of cross-section
- Sabkha
- Graben
- Quaternary - Neogene basalts
- Quaternary - Neogene (undifferentiated)
- Cretaceous - Paleogene
- Silurian - Early Devonian (Tawil Formation)
- Direction of groundwater flow
- Boundary of Wadi Sirhan Basin

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Inventory of Shared Water Resources in Western Asia

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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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LOCATION

The An Nafud Desert in northern Saudi Arabia is separated from the Syrian Desert (Badiyet esh Sham) by the Hammad Plateau, which extends across the borders of Iraq, Jordan, Saudi Arabia and Syria. On the basis of surface water drainage and the directions of groundwater flow, six hydrogeological basins have been defined in the Hammad Plateau.[1] The Tawil-Quaternary Aquifer System (Wadi Sirhan Basin), which extends from the eastern boundaries of the Basalt Aquifer (South-East) (see Chap. 22) towards the Sakaka-Al Jawf area, constitutes the south-western region of the Hammad Plateau.[2] This chapter covers the aquifers within the Wadi Sirhan Basin. In order to place the aquifer system in a regional context, however, the geographical extent of its formations beyond the boundaries of the Tawil-Quaternary Aquifer System is shown on the Overview Map. A brief description of these aquifers is also provided.

AREA

The Tawil-Quaternary Aquifer System constitutes the southern part of a large depression along the eastern edge of the Jordan Uplift (Wadi Sirhan Depression), in which thick Paleogene and Neogene-Quaternary sediments have accumulated.[3] The basin is largely shaped by its geomorphologic landscape,[4] which can be divided into three main regions:[5]

- The central topographic depression, which runs in a north-west/south-east direction at an altitude of 500-600 m asl.
- The western Widyan area (900-1,100 m asl), from where the main tributaries of the Wadi Sirhan drain.
- The basalt plateau (800-900 m asl), which extends over about 220 km from the Jebel al Arab region into Saudi Arabia.

The boundaries of the basin are defined by:

- Surface water divides that separate the Wadi Sirhan Basin from the Al Jafr and Azraq Basins in the west and the Central Hammad Basin in the east (see Overview Map).
- The Wadi Sirhan Graben structure, which largely controls groundwater flow.

Based on the boundaries described above, the basin covers an area of about 44,000 km^2, of which about 80% (35,000 km^2) lies in Saudi Arabia, and the remaining 9,000 km^2 (20%) in Jordan. A range of outcrops occur in the basin, including Quaternary-Neogene undifferentiated outcrops (10,000 km^2), volcanic outcrops (12,000 km^2), Cretaceous- and Paleogene-age outcrops (20,000 km^2), and Silurian- and Early Devonian-age outcrops.

CLIMATE

The Tawil-Quaternary Aquifer System lies in an arid region with an average annual precipitation of 35-120 mm and average temperatures between 16°C and 21°C. Annual evapotranspiration is estimated at 1,460-1,680 mm. Aridity generally increases from north to south. The area along the southern Jordanian border commonly receives less than 50 mm/yr of rainfall, which occurs in the form of infrequent, short rain storms of varying intensity.[6] Potential evaporation is more than 3,500 mm/yr,[7] while actual evaporation is greater than 90% of total rainfall.[8]

POPULATION

In 1980, one third of the total population of the Hammad Plateau (33,000 people) lived in the Wadi Sirhan Basin.[9] Since then, the population has increased significantly due to rapid agricultural development, mainly in Saudi Arabia.

Most of the population presently abstracting water from the aquifer system lives in the lower depression areas in Al Jawf Province in Saudi Arabia. The total population in this province has been estimated at about 440,000 inhabitants,[10] who mainly live between the towns of Al Jawf in the south and Al Haditha in the north.

OTHER AQUIFERS IN THE AREA

Other aquifer systems in the area include the underlying Saq-Ram and Jubah-Jawf Aquifers (Paleozoic).[11] The Jubah-Jawf is exploited in the Sakaka area along the eastern end of the Tawil-Quaternary Aquifer System, while the Saq-Ram Aquifer System (West) (see Chap. 10) is exploitable in the north-eastern part of the Wadi Sirhan Basin towards the Azraq Basin (see Chap. 22).[12]

INFORMATION SOURCES

Key information on the aquifer system and the delineation of the basin are based on reports from 1983 and 1990,[13] which are complemented by data from more recent publications.[14] The Overview Map was delineated based on various local and regional references.[15]

Area north and north-west of Al-Jafr, Jordan, 2008. Source: Robert Bewley, Aerial Photographic Archive for Archaeology in the Middle East.

Hydrogeology - Aquifer Characteristics

AQUIFER CONFIGURATION

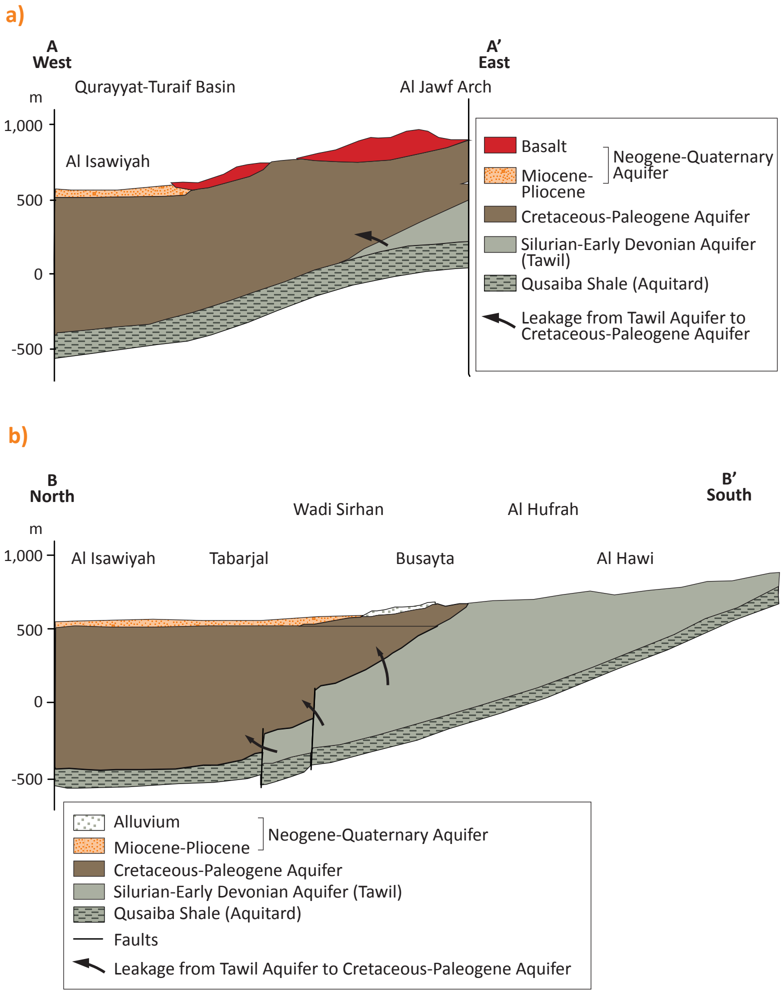
The Wadi Sirhan Basin presents water-bearing sediments/formations in a zone of subsidence shaped by subsurface faults associated with major crustal movements. These water-bearing formations were subjected to deep and significant fracturing with large vertical displacement (50-1,500 m), which affected the deposition of the Upper Cretaceous layer. Subsequent faults created smaller displacements during the Paleogene-Neogene.[16] This tectonic setting resulted in the deposition of thick sediments since the late Cretaceous time, which dip towards the centre of the depression.

In the subsurface, the Tawil-Quaternary Aquifer System is a narrow and very deep asymmetrical trough, with a steep slope on the northern flank and a gentler slope on the southern flank.[17] The graben is filled with geological units that have different aquifer properties and range in age from the Cambro-Ordovician to the Quaternary. Thick deposits of these geological units are found inside the graben and along its western boundary. Outcrops of the younger formations (Paleogene to Quaternary) cover the surface of the basin, while the Cretaceous and older formations are found only in the subsurface (Figure 1).

STRATIGRAPHY

The Tawil-Quaternary Aquifer System is made up of an upper part (Upper Cretaceous to Quaternary) and a lower part (mainly Silurian-Early Devonian) as shown in Table 1. Within the lowlands of the Wadi Sirhan Graben, the Early Devonian Tawil Formation disappears and the water from this formation flows through the Upper Cretaceous to the Quaternary Formations. As a result, this water-bearing formation becomes vertically connected with overlying layers (Figure 1). This is confirmed by the chemical composition of the groundwater, which suggests that it is a result of mixing of fresh Tawil water with brackish Wadi Sirhan water.[18] These two aspects (i.e. upward flow and northern joining) create a strong direct linkage which allows for the Neogene-Quaternary Aquifer, the Cretaceous-Paleogene Aquifer[19] and the Tawil Aquifer to be treated as one aquifer system within the basin's geographical area.

Figure 1. (a) East-west and (b) north-south cross-section of the Tawil-Quaternary Aquifer System



Source: Redrawn by ESCWA-BGR based on BRGM and CNABRL, 1985.

AQUIFER THICKNESS

The following range of thicknesses has been reported:[20]

- Neogene to Quaternary sediments: <200 m
- Basalt: <560 m
- Paleogene: <560 m
- Upper Cretaceous: ~300 m
- Early Devonian: ~200-300 m

However, values obtained from well data may be significantly different from these modelling results. For example, the thickness obtained

Table 1. Lithostratigraphy of the Tawil-Quaternary Aquifer System in the Wadi Sirhan Basin

NAME	AGE	HYDROGEOLOGICAL UNIT		LITHOLOGY	COMMENTS
		JORDAN	SAUDI ARABIA		
Upper part	Neogene (N) to Quaternary (Q)	Alluvium	Alluvium	Gravel, sand, silt, clay and different basalt flows and volcanic tuffs (Q); sand, marl and limestone (N).	Mostly in low areas.
		Basalt	Basalt		
	Paleogene (Eocene-Paleocene)	Shallala (B5)	Mira-Umm Wu'al	Sequence of marl, limestone (marly or silicified) and chert.	-
		Rijam (B4)			
		Muwaqqar (B3)	-		
	Upper Cretaceous	Amman-Wadi as Sir (A7/B2)	Wasia-Aruma	Limestone, dolomites and marl with some chert and sand intercalations.	Considered in Jordan as Middle Aquifer System; exploitation in the eastern part of the country limited due to high salinity.
Lower part	Upper Cretaceous	Ajlun (A1/A6)	Wasia-Aruma	Limestone, dolomites and marl with some chert and sand intercalations.	Known as the Lower Ajlun Aquitard, but changes into sandy facies in eastern Jordan to form an aquifer.
	Lower Cretaceous	Kurnub (K1-2)	Biyadh-Wasia (probably Buwaib)	Sandstones and sandy limestones with some shale and clays.	Exploitation proved unsuccessful due to high salinity and low productivity.
	Silurian-Early Devonian	Worm Burrows-Alna[a]	Tawil-Sharawra	Sandstone with some gypsum near the top.	A good to moderate aquifer which feeds the STQ[b] in Saudi Arabia and extends into Jordan.

Source: Compiled by ESCWA-BGR based on UN-ESCWA, 1990; Margane et al., 2002; Abunayyan Trading Corporation and BRGM, 2008; Barthelemy et al., 2010.
(a) Abunayyan Trading Corporation and BRGM, 2008 reported that the Tawil, which crops out in the Saudi Arabian part of the Tawil-Quaternary Aquifer System, disappears towards the north. However, more recent regional investigation has confirmed its extension into Jordan within the Tawil-Quaternary Aquifer System and further north-east to the Iraqi border. It is apparently equivalent to unnamed formations described on the 1:250,000-scale geological map of Jordan as 'Worm Burrows' and 'Red Brown Argillaceous Sandstones' (Barthelemy et al., 2010).
(b) Secondary-Tertiary-Quaternary Aquifer Complex.

for the Basalt (300 m and 480 m)[21] and the Paleogene (>550 m) formations in the Wadi Sirhan Depression do not differ significantly from the modelling results.[22] However, the value obtained for the Tawil Formation (550 m) from well data is significantly different.[23]

AQUIFER TYPE

The Quaternary-Neogene sediments are usually unconfined, but confined conditions occur in areas where the wadi deposits comprise both Quaternary sands and calcareous Neogene deposits. In general, confined conditions could be more dominant towards the central parts of the basin.[24] The Eocene-Paleocene formations are usually confined, except in some outcrop areas along the plateau. The Cretaceous and the Devonian-Silurian formations are also mostly confined,[25] except in outcrop areas in the southern part of the basin.

AQUIFER PARAMETERS

Table 2 shows the range of transmissivity and storativity values obtained for aquifers in the Tawil-Quaternary Aquifer System. The highest transmissivity ($3.5x10^{-2}$ m²/s) and the lowest storativity ($1.0x10^{-5}$) values for the Tertiary formations were found in the Al Isawiyah area.[26] The highest transmissivity for the Neogene formations ($1.8x10^{-1}$ m²/s) was obtained from a 150 m deep bore-hole.[27]

Table 2. Hydraulic parameters of the Tawil-Quaternary Aquifer System

AQUIFER	TRANSMISSIVITY (m²/s)		STORATIVITY	
Quaternary-Neogene	$1.1x10^{-4}$-$3.4x10^{-3}$	$2.8x10^{-3}$-$1.8x10^{-1}$	$1.0x10^{-2}$	$1.0x10^{-5}$-$3.7x10^{-2}$
Eocene-Paleocene	$5.8x10^{-4}$-$2.9x10^{-4}$	$2.8x10^{-3}$-$1.8x10^{-1}$	..	$1.0x10^{-5}$-$3.7x10^{-2}$
Cretaceous	$1.1x10^{-3}$-$4.0x10^{-3}$	$5.0x10^{-3}$-$1.0x10^{-2}$	$1.0x10^{-2}$	$1.0x10^{-2}$
Early Devonian	$1.1x10^{-3}$-$4.0x10^{-3}$	$1.0x10^{-4}$-$2.3x10^{-2}$	$1.0x10^{-2}$	$3.0x10^{-2}$
Source	ACSAD, 1983a.	BRGM and CNABRL, 1985.	ACSAD, 1983a.	BRGM and CNABRL, 1985.

Source: Compiled by ESCWA-BGR.

Hydrogeology - Groundwater

RECHARGE

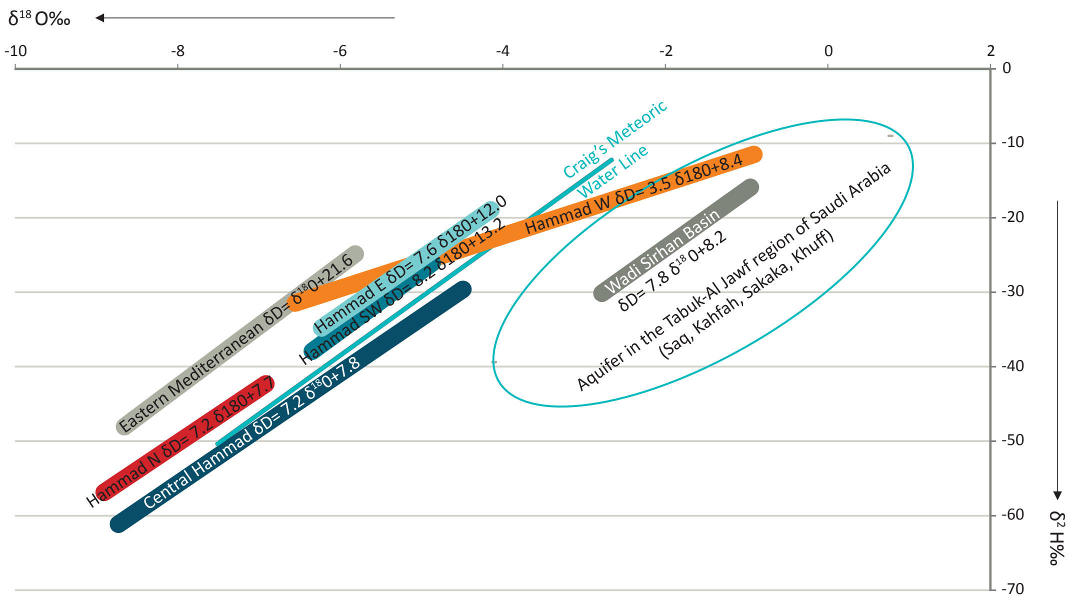
The Wadi Sirhan Basin receives an estimated total annual precipitation of 600 MCM[28] of which 5% or 30 MCM/yr is expected to infiltrate the shallow aquifer systems as natural recharge.[29] This corresponds to an annual recharge of less than 2 mm, which means the aquifer system can be considered to have limited renewability. Carbon-14 and tritium data have revealed recent recharge in shallow deposits in Wadi Sirhan.[30] This recharge water comes from the Mediterranean and displays isotopic similarities with the Basalt Aquifer System[31] (see Chap. 22) and the Paleozoic-Mesozoic Aquifers in the Al Jawf-Sakaka area.[32] The groundwater in the Wadi Sirhan Basin of the Hammad Plateau has been shown to be unique (Figure 2) in that the aquifers were recharged by rain of continental rather than Mediterranean origin in previous pluvial periods.[33] This major Southern Pluvial period ended 26,000 years ago and was followed by two younger pluvial periods 20,000-16,000 years ago (Northern Pluvial) and 8,500-3,900 years ago (Neolithic Pluvial).[34]

These findings suggest that, unlike the rest of the groundwater systems in the Hammad Plateau, the groundwater in the Wadi Sirhan Basin evolved as part of the groundwater system in the Sakaka-Azraq areas. The close similarity of the isotope composition of groundwater in this area and in the Tabuk area to the south-west confirms the southern continental origin of the groundwater in the Wadi Sirhan Basin.

FLOW REGIME

In general, groundwater follows the direction of surface water flow, which is south-west from the basalt plateau area and north-east from limestone plateau area. Groundwater flow is then directed towards the main wadi channel, which runs in a north-east/south-west direction across the Jordanian-Saudi border. The hydraulic gradient in the central depressions is about 0.002.[35] The flow direction of groundwater beneath the wadi bed has been depicted in the carbon-14 age of groundwater, which increases from 5,300 years in the north-west to

Figure 2. Meteoric Water Lines ($\delta^2H/\delta^{18}O$ graph) of the various hydrogeological regions in the Hammad Plateau



Source: Redrawn by ESCWA-BGR based on Geyh et al., 1985.
Note: The Global Meteoric Water Line (GMWL) is an equation developed by Craig, 1961 and states the average relation between hydrogen (δ^2H) and oxygen ($\delta^{18}O$) isotope ratios in natural terrestrial waters, expressed as a worldwide average. Craig's line is specifically global in application, and is an average of many local or regional meteoric water lines which differ from the global line due to varying climatic and geographic parameters (USGS, 2004).

30,000 years in the south-east.[36] Before heavy abstraction from the aquifer system started in the 1990s, depth to water was reported at less than 10 m bgl.[37]

STORAGE

Before heavy abstraction from the Tawil-Quaternary Aquifer System started in the 1990s, groundwater reserves at 300 m depth were estimated at 58 BCM or more, of which about 17 BCM were located in the until-then untouched Tawil Formation.[38] In 2005, a total of 876 MCM was abstracted from the Tawil. This was reported to be equivalent to 4% of exploitable reserves in this formation, which would mean that these reserves were reassessed at about 22 BCM.[39]

DISCHARGE

The Wadi Sirhan Basin is considered a closed basin, in which groundwater discharges upward (Figure 1). Discharge at the surface is evidenced by a large number of mud flats and salt lakes in the central part of the basin[40] including the approximately 400 km^2 Al Hazawza Sabkha.[41] The presence of a number of saline springs and a clear increase in soil salinity in wide zones along the main wadi bed provide further evidence of internal groundwater discharge.[42]

Table 3. Groundwater reserve estimates in the Tawil-Quaternary Aquifer System

DEPTH (m bgl)	STORAGE (BCM)		
	TAWIL FORMATION	CRETACEOUS-TERTIARY FORMATIONS[a]	TOTAL
100	0.70	8.50	9.2
200	6.84	22.66	29.5
250	11.39	30.71	42.1
300	16.88	40.93	57.81
Top of aquifer is less than 1,500 m bgl.			

Source: Compiled by ESCWA-BGR based on BRGM and CNABRL, 1985.
(a) BRGM and CNABRL, 1985 does not explicitly mention why the Quaternary deposits were not included in the assessment. However, as the only abstraction from the Wadi Sirhan Basin in Saudi Arabia during 1983-1984 was from the Paleogene-Neogene formations, it is possible that groundwater reserve in the Quaternary was negligible.

Table 4. Water levels in different bore-holes in the Wadi Sirhan Basin (1978-1980)

NAME	AQUIFER UNIT	TOTAL DEPTH (m)	DEPTH TO WATER (m bgl)
Nabk abu Kasr	Wadi deposits (Quaternary Alluvium)	50	7.7
Al Qurayyat	Wadi deposits (Miocene-Eocene)	223	Flowing
Al Isawiyah	Wadi deposits (Miocene-Pliocene)	180	8.8
Al Haditha	Eocene deposits	200	17.7

Source: Compiled by ESCWA-BGR based on ACSAD, 1983b.

WATER QUALITY

Analysis of groundwater samples collected in 1980 from the Neogene Aquifer in the central depression zone indicated natural salinity levels that were generally below 3,000 mg/L, though higher salinities up to 4,000 mg/L were observed in some wells.[43] The salinity level of the Paleogene formations beneath the Quaternary-Neogene Aquifer was reported to be in the range of 1,000-1,500 mg/L.[44] Salinity increased to 800-2,000 mg/L in the south-eastern part of the basin and 2,000-3,000 mg/L in the north-western part, reflecting the longer residence time of the groundwater as indicated by isotopic signature. This trend was observed across all formations.

Available data indicates that water in the Tawil Formation is fresh (less than 500 mg/L TDS) in the heavily exploited Al Busayta area south-west of the Wadi Sirhan Depression.[45] Inside the graben, salinity generally increases with depth and TDS values of 7,280-9,200 mg/L have been measured in deep wells in the group overlying the Disi Formation.[46] Moreover, Electrical Conductivity (EC) values of up to 10,000 µS/cm (about 7,000 mg/L TDS) were measured in some localities along the central depression zone.[47]

This substantial increase in salinity can be attributed to the effect of evaporation from sabkhas and shallow water levels, rather than upconing of saline water from depth.

EXPLOITABILITY

Until the mid-1980s, the shallow aquifer units (Quaternary-Tertiary) were the main target of water resource development. Table 4 shows that water level and drilling depth did not limit exploitation. Groundwater salinity in the main zone of abstraction (Al Isawiyah-Qurayyat) was 1,000-3,000 mg/L TDS,[48] indicating that the quality of water was not a limiting factor.

The deepest formation in the aquifer system, the Tawil, has the following characteristics:[49]

- **Depth to top of aquifer:** ≤1,000 m bgl.
- **Depth to water level:** 250 m bgl maximum.
- **Water quality:** <10,000 mg/L TDS.

Hence it can be concluded that the aquifer system is exploitable throughout the basin.

Groundwater Use

GROUNDWATER ABSTRACTION AND USE

Currently, only Saudi Arabia exploits the aquifer system in the Wadi Sirhan Basin. The Jordanian part of the basin has not yet been developed.[50] In 1979, there were only 80 wells in the Wadi Sirhan Basin with an estimated abstraction of 2.5 MCM/yr. Most of these dug wells were located in the central depression where agricultural activities were being developed.[51]

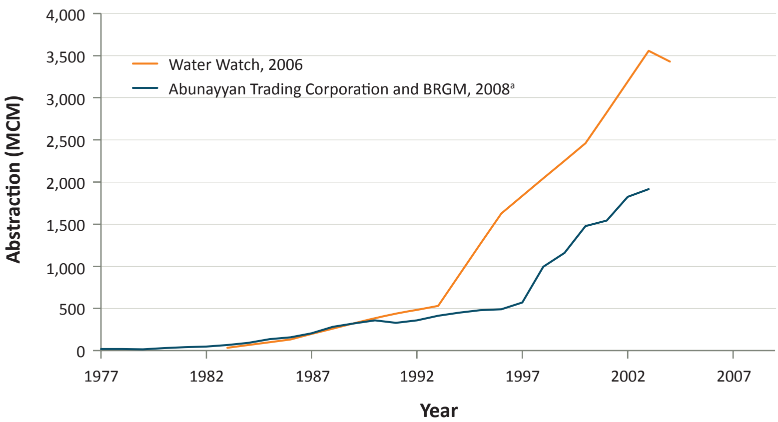
In the following years the number of wells in the basin increased rapidly to reach nearly 1,000 in 1982 and over 1,500[52] in 1986, mainly in the Tubarjal-Al Isawiyah area in Saudi Arabia. As a result, abstraction increased from around 100 MCM/yr in 1984 to at least 500 MCM/yr and maybe as much as 1,000 MCM/yr in the mid-1990s (Figure 3). Agricultural activities were further expanded after 1996, increasing abstractions in Al Jawf Province to between 1,900 MCM (2003) and 3,500 MCM (2004).

In the early years, groundwater production focused on shallow wells in the Wadi Sirhan Depression that tapped the Quaternary-Neogene Aquifer System, but after 1996 deeper aquifer layers were also exploited. The most relevant aquifers in the Tawil-Quaternary Aquifer System are the Tawil-Sharawra Formations and the Secondary-Tertiary-Quaternary (STQ) Aquifer Complex.[53] In the period from 1984 to 2005, abstractions rose from 39 to 876 MCM/yr in the Tawil Aquifer and from 141 to 1,388 MCM/yr in the STQ Aquifer Complex, resulting in a total abstraction of 2,264 MCM in 2005[54] (including abstractions from areas outside the Tawil-Quaternary Aquifer System as defined in this Inventory). Domestic and industrial water consumption in Al Jawf Province is estimated at 27.9 MCM/yr, or 1.4% of total abstractions.[55]

Agricultural census data from Al Jawf Province is available from 1989 onwards, but other studies have estimated groundwater-irrigated area at just 7 ha in 1979,[56] mainly in the central part of the depression. At the time, agricultural production only took place in small farms which cultivated dates, wheat and vegetables for personal and local consumption. From the mid-1980s onwards, the area became the focus of large-scale agricultural development projects and the irrigated area expanded to 30,000-40,000 ha in 1996 (Figure 4 and 5). [57]

The real boom in agricultural development took place after 1996 with ambitious land reclamation projects irrigating 160,000 ha[58] in the Al Jawf area between 2004 and 2007. A remote-sensing assessment suggested that by 2004, 24 BCM were abstracted from the Tawil.[59]

Figure 3. Historical abstraction in Al Jawf Province in Saudi Arabia (1977-2004)

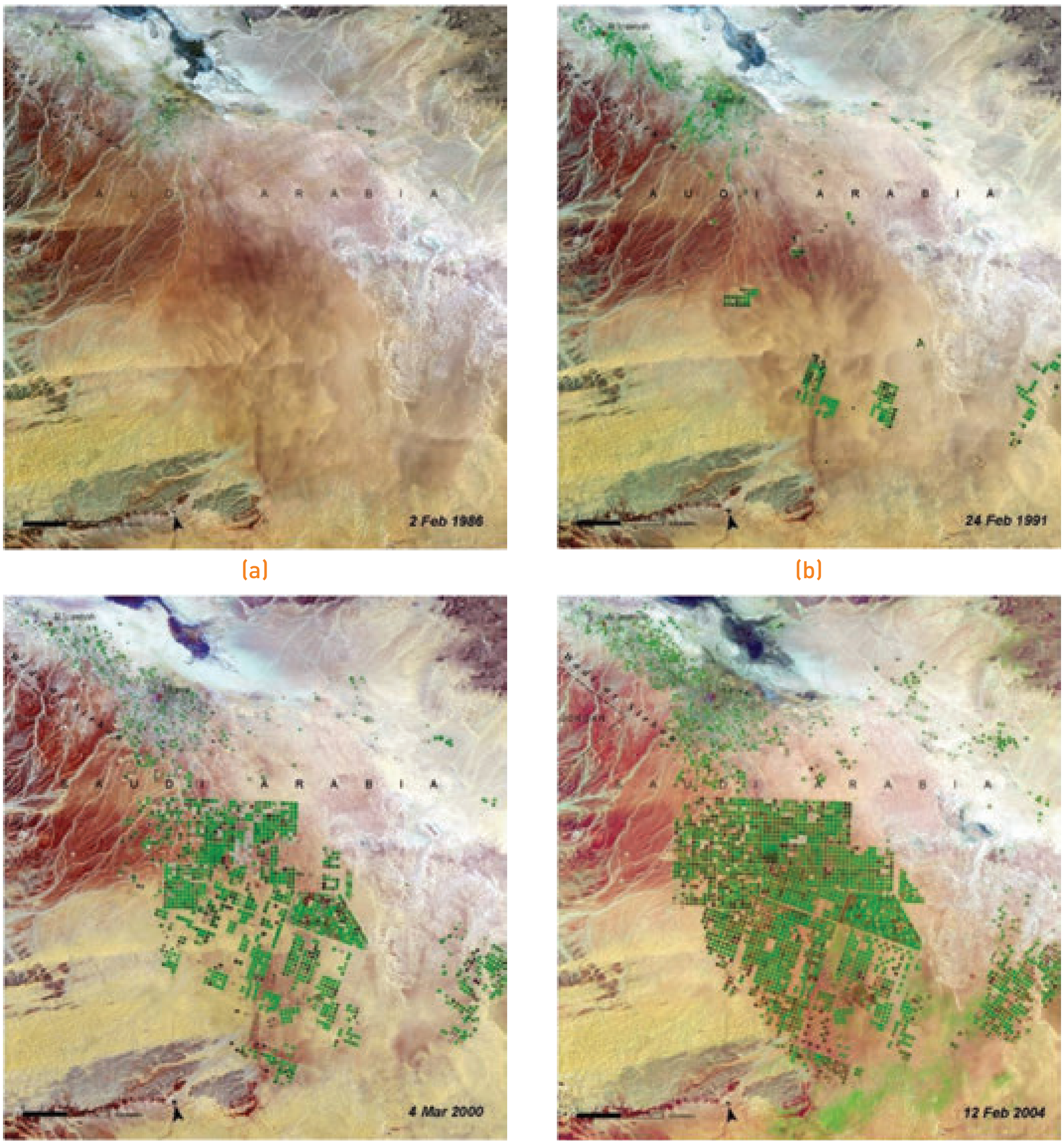


Source: Compiled by ESCWA-BGR.
Note: Census data as well as study estimates are usually available for the Al Jawf Province, which encompasses all development in the Wadi Sirhan basin, including the Tubarjal-Al Isawiyah areas. Smaller developments in the Sakaka area, outside the Wadi Sirhan basin, are also part of Al Jawf Province and hence included in this data.
(a) Data on abstraction in Al Jawf Province was digitized from the electronic version of the report (Figure 24, p.42), with resulting inaccuracies.

Large commercial farms were established, mainly in the Al Busayta area south and south-west of Tabarjal, where most of the wells tap the Tawil and Sharawra Formations. The largest farming corporations include the NADEC Al Jawf (7,200 ha),[60] Watania (30,000 ha),[61] JADCO (60,000 ha)[62] and Domat Al-Jandal (60,000 ha)[63] Farms.

Cropping patterns in Al Jawf Province also changed over the years. In 1990, around 30% of the agricultural area was dedicated to wheat cultivation (8,871 ha). Permanent cultures accounted for 40% of production yield and fodder production was marginal (Figure 6). Wheat production rapidly decreased after 1990 (possibly in response to a reduction in agricultural subsidies), reaching a low in 1996 when it covered only 16% of the area. While other cereals (26% of area) and fodder crops (25% of area) had gained dominance at the start of the second agricultural boom in 1996, wheat quickly recovered in the late 1990s. Wheat production peaked between 2004 and 2007, covering up to 76% (124,000 ha) of all irrigated areas in Al Jawf province with a production of around 800,000 ton/yr. Fodder production was also significant in these years, at around 200,000 ton/yr, even though it covered less than 8% of all irrigated areas in Al Jawf Province.

Figure 4. Centre-pivot irrigation systems in the Al Isawiya-Tabarjal-Al Busayta area (Saudi Arabia) in (a) 1986; (b) 1991; (c) 2000; and (d) 2004



Source: Compiled by ESCWA-BGR based on UNEP, 2008-2009.

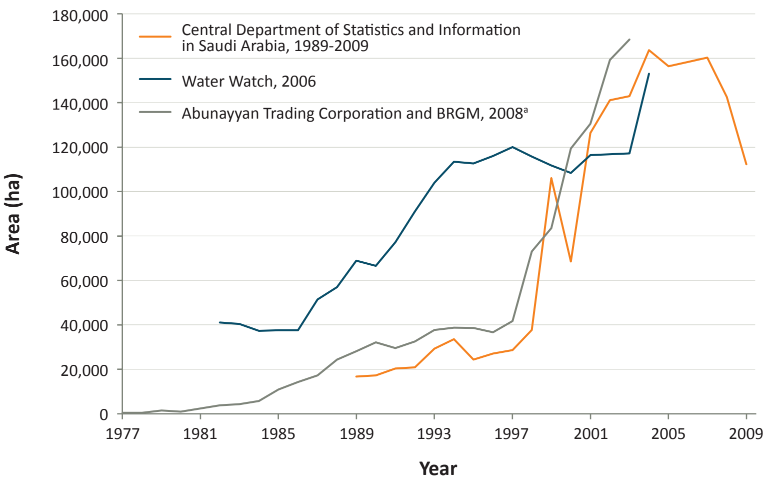
Overall, agricultural development in Al Jawf Province took place later than in other parts of Saudi Arabia.

Using the abstraction estimates above, cumulative total abstraction from the different aquifers in Al Jawf Province in Saudi Arabia between 1977 and 2011 ranges between 25.8[64] and 49.3 BCM.[65] These values include abstractions from areas outside the Wadi Sirhan Basin as defined in this Inventory.

Effect of abstraction on water tables

Calculations based on transmissivity values and gradient for an estimated inflow zone of about 400 km² revealed that the abstractions in 1982 were already far above the safe yield of 17.5 MCM/yr of the aquifer system and twice the

Figure 5. Irrigated area in Al Jawf Province in Saudi Arabia



Source: Compiled by ESCWA-BGR.
Note: See note in Figure 3.
(a) Data on abstraction in Al Jawf Province was digitized from the electronic version of the report (Figure 22, p.42), with resulting inaccuracies.

total volume of freshwater inflow (50 MCM/yr). Yet a drawdown of only one metre was observed in heavy abstraction areas. This slow rate of groundwater depletion was attributed to the fact that abstraction is taking place in the discharge area and groundwater is being refilled from recharge areas of the Neogene deposits in the plateau areas. This is confirmed by the pressure head, and it is therefore likely that the rate of depletion will accelerate significantly as the overdraft progresses and extends to the Paleogene Formations below.[66] Available data shows that this is not yet the case.

GROUNDWATER QUALITY ISSUES

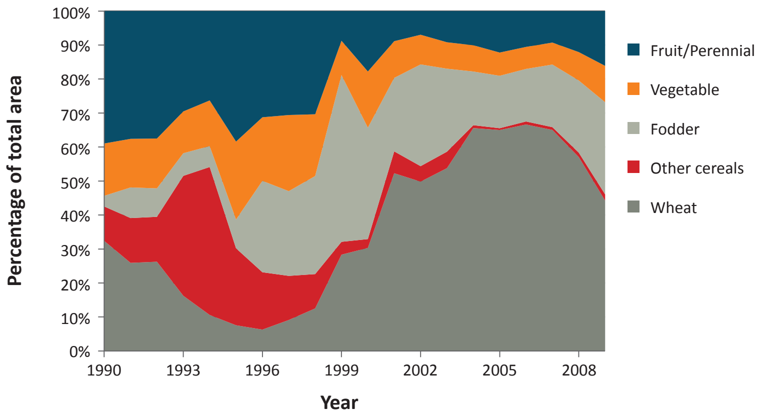
The Quaternary and Neogene deposits are rich in gypsum and gypsiferous soils are common in the southern and south-western parts of the basin.[67] Saline deposits rich in sodium (Na) also accumulate in sabkha areas along the central depression where the water table can be quite shallow. This has led to an increase in groundwater salinity and poses a risk of further groundwater quality deterioration. The rapid expansion of large-scale agriculture in the area endangers human health through the use of pesticides and the potential rise in nitrates in the groundwater from leaching of fertilizers. Also, the continuous reduction in upward flow of freshwater from the Tawil Formation, which normally dilutes the brackish water in the overlying aquifers, is expected to lead to a rise in groundwater salinity in the Tawil-Quaternary Aquifer System.

SUSTAINABILITY ISSUES

There are two important factors that make groundwater development in this basin critical: (1) the present-day recharge to the aquifer system is limited, and (2) the closed nature of the basin. This means that the ongoing heavy abstraction of water for agricultural production is depleting the aquifer system (quantity issues) and increasing the deposition of salts and other irrigation-related chemicals and toxic elements on the surface (quality issues). The rapid growth in well numbers between 1980 and 1982 led scientists to recommend a complete stop in well drilling. Such measures were, however, never implemented and no plan for the development of the aquifer systems within the above-mentioned limitations appears to exist.

The fact that only a few of the wells tapping the Tawil Aquifer show significant drawdown (≥40 m) and that remote areas south of Al Busayta are not yet affected by abstraction suggest that the volume of groundwater removed from storage is still small. Model calculations indicate that at the present extraction rate, about 20% of the reserves will have been abstracted by 2055.[68] These contradictory conclusions need to be resolved in order to understand the status of the aquifer system with respect to sustainability.

Figure 6. Main crops in Al Jawf Province in Saudi Arabia as a percentage of production yield



Source: Compiled by ESCWA-BGR based on Central Department of Statistics and Information in Saudi Arabia, 2011.

Agreements, Cooperation & Outlook

AGREEMENTS

There are no water agreements in place for the Tawil Quaternary Aquifer System, which is shared between Jordan and Saudi Arabia.

COOPERATION

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

OUTLOOK

The effect of heavy abstraction on the shallow aquifer over the past years should be assessed. There may be opportunities for more abstraction from the deeper aquifer in a sustainable and cooperative manner.

Agricultural fields in the Wadi Sirhan Basin, Saudi Arabia, 2012. Source: Expedition 30 Crew.

Notes

1. The six hydrogeological basins are (1) Wadi al Miyah; (2) Eastern Hammad; (3) Central Hammad; (4) Wadi Sirhan; (5a) Azraq; (5b) Sabkhat Munq'a or Rutba; and (6) Sabkhat al Moh (ACSAD, 1983a).
2. Ibid.; UN-ESCWA, 1990.
3. Khoury, 1982.
4. ACSAD, 1983a.
5. UN-ESCWA, 1990.
6. ACSAD, 1983a.
7. Ibid.
8. Ministry of Interior in Saudi Arabia, 2010.
9. Ibid.
10. Central Department of Statistics and Information in Saudi Arabia, 2011. Note that the terms "province", "region" or "emirat" are used interchangeably in official sources but all three refer to the same area geographically.
11. Abunayyan Trading Corporation and BRGM, 2008.
12. Ibid.
13. ACSAD, 1983a; UN-ESCWA, 1990; ACSAD, 1983b.
14. Abunayyan Trading Corporation and BRGM, 2008; Barthelemy et al., 2010.
15. ACSAD, 1983a; USGS and Central Energy Resources Team, 2004; BRGM and CNABRL, 1985.
16. UN-ESCWA, 1990.
17. Abunayyan Trading Corporation and BRGM, 2008.
18. Ibid.
19. BRGM and CNABRL,1985 and Abunayyan and BRGM, 2008 treat these two aquifers as one and refer to it as the Secondary-Tertiary-Quaternary Aquifer Complex (STQ).
20. Abunayyan Trading Corporation and BRGM, 2008. The thickness range corresponds to the maximum thickness encountered within the areas derived from the geological model. The formation thickness encountered at the outcrop is in most cases largely inferior to the maximum thickness found towards the centre of the sedimentary basin.
21. ACSAD, 1983a; Margane et al., 2002.
22. Margane et al., 2002.
23. BRGM and CNABRL, 1985.
24. BGR et al., 1999.
25. Abunayyan Trading Corporation and BRGM, 2008.
26. Ibid.
27. Ibid.
28. This is total precipitation in the central part of the basin, which covers about 9,500 km^2. This brings the total annual precipitation to 63 mm.
29. ACSAD, 1983a.
30. BGR et al., 1999.
31. UN-ESCWA et al., 1996.
32. BGR et al., 1999.
33. ACSAD, 1983a.
34. BGR et al., 1999.
35. ACSAD, 1983b.
36. Geyh et al., 1985.
37. ACSAD, 1983b.
38. BRGM and CNABRL, 1985.
39. Abunayyan Trading Corporation and BRGM, 2008.
40. ACSAD, 1983a.
41. UN-ESCWA, 1990.
42. ACSAD, 1983b.
43. Ibid.
44. UN-ESCWA and BGR, 1999.
45. Abunayyan Trading Corporation and BRGM, 2008.
46. Barthelemy et al., 2010.
47. Geyh et al., 1985.
48. BRGM and CNABRL, 1985.
49. Abunayyan Trading Corporation and BRGM, 2008; Barthelemy et al., 2010.
50. BRGM and Ministry of Water and Irrigation in Jordan, 2010.
51. ACSAD, 1983a; BRGM and Ministry of Water and Irrigation in Jordan, 2010.
52. Abderrahman, 2006.
53. The Saq Aquifer, although present, is too deep for economic production in the Wadi Sirhan-Al Jawf area.
54. Abunayyan Trading Corporation and BRGM, 2008.
55. Abunayyan Trading Corporation and BRGM, 2008, p. 46: public groundwater abstractions out of a total abstraction of 1,934 MCM for an unspecified year.
56. ACSAD, 1983b.
57. Approximate value in the census data around 30,000 ha; similar results of around 40,000 ha obtained in remote sensing study by Abunayyan Trading Corporation and BRGM, 2008.
58. Census and remote sensing data by Abunayyan Trading Corporation and BRGM, 2008 on total crop area or irrigated area respectively, generally correspond for the Al Jawf region, in contrast to values obtained by Water Watch, 2006 for the period before the late 1990s.
59. Water Watch, 2006 estimated that up to 28 BCM of groundwater was abstracted from the Tawil-Jawf Aquifers between 1983 and 2004. As 86%, or 937 wells out of a total of 1,086 abstracting wells in Al Jawf Province were tapping the Tawil Aquifer (Abunayyan Trading Corporation and BRGM, 2008), this ratio is used to adjust the Water Watch data.
60. Nadec, 2010.
61. Al Watania Agri, 2010.
62. JADCO, 2008.
63. Talib, 2010.
64. Based on annual abstraction data digitized from Abunayyan Trading Corporation and BRGM, 2008, p. 42, figure 24, resulting in a considerable degree of uncertainty for calculated cumulative abstraction; for the missing years 2004-2011 an abstraction of 1,500 MCM/yr was assumed.
65. Based on results by Water Watch, 2006; for the missing years 2005-2011 an abstraction of 2,500 MCM/yr was assumed.
66. ACSAD, 1983b.
67. Ibid.
68. Abunayyan Trading Corporation and BRGM, 2008.

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