Hydropolitical Baseline of the Yarmouk Tributary of the Jordan River

> Technical Annex B <

WATER SECURITY RESEARCH CENTRE
UNIVERSITY OF EAST ANGLIA

Hydropolical Baseline Study of the Yarmouk
Tributary of the Jordan River

TECHNICAL ANNEX B

This study was written by Mark Zeitoun, Muna Dajani, Chadi Abdallah, Sharif Youmans, Sa'eb Khresat and Heather Elaydi of the Water Security Research Centre of the University of East Anglia (UEA). The research was supported financially by the UEA and the Swiss Agency for Development and Cooperation (SDC).

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Cover photo: The al Wehdeh Dam Reservoir on the Yarmouk tributary viewed from Jordan, November 2015. *Source*: Heather Elaydi.

Technical Annex B

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Figures

Tables and Boxes

B1 Morphometric characteristics

The morphometric characteristics were studied per sub-basin (Figure B 1.2). They included the Strahler stream ordering, the Bifurcation Ratio, the Degree of development, the Gravelius shape index and the longitudinal profiles.

Strahler's 1957 classifiction of stream order reflects the degree of ramification of the hydrographic network from upstream to downstream. Watercourses without tributaries are considered of first order; the stream formed by the confluence of two streams of different orders keeps the highest order of the two; while the order of the stream formed by the confluence of two streams of same order is higher by one than the other two. Following this classification, the Hareer and Zeidi sub-basins are richest in small streams of 1st and 2nd order, while the Yarmouk mainstream is the only sub-basin to contain a stream of 7th order (Figure B 1.1 and Table B 9.10).

The Bifurcation Ratio (BR) is the ratio between the number of streams from two consecutive orders in Strahler's stream ordering (Table B 9.10). Higher BR values are the characteristics of structurally more disturbed basins with a prominent distortion in drainage pattern and vice versa. The maximum BR shows an early hydrograph peak (smaller basin lag time), which also indicates strong structural control on the drainage development for this basin. The minimum BR indicates delayed hydrograph peak.

$$BR = \frac{N(n+1)}{Nn}$$

Where *N(n+1)* is the number of streams in the order n+1; *Nn* is the number of streams in the order n.

The Degree of development of the hydrographic network was introduced by Horton (1954), who defined it as the rapport between the total length of the hydrographic network and the surface of the basin (Musy 2001) (Table B 9.9). It is mainly affected by geology, climate, soil permeability, surface gradient and precipitation properties (Alhusban 2016).

$$Dd = \frac{\sum Li}{A}$$

Dd is the Degree of development of the hydrographic network (km/km^2); Li is the length of the stream (km); and A is the surface of the basin (km^2).

The Gravelius shape index KG is the relation between the perimeter of the basin and that of a circle with a surface equal to that of a basin (Table B 9.9). The shape of a basin influences the shape of its characteristic hydrograph. For example, a long basin generates, for the same rainfall, a lower outlet flow, as the concentration time is higher. A fan-shaped basin presents a lower concentration time, and generates higher flow (Musy 2001). The closer the basin's shape is to a circle, the closer KG is to 1. The more elongated the basin, the higher the value of KG. KG from this study is equal to 2.3; which implies that it has an irregular shape.

$$KG = \frac{P}{2\sqrt{\pi . A}} \approx 0.28 \frac{P}{\sqrt{A}}$$

A is the basin area (km^2); P is the basin perimeter (km)

Figure B 1.1 Relationship between the stream number and the stream order for the sub-basins. *Source*: Authors, based on multiple sources listed in the text.

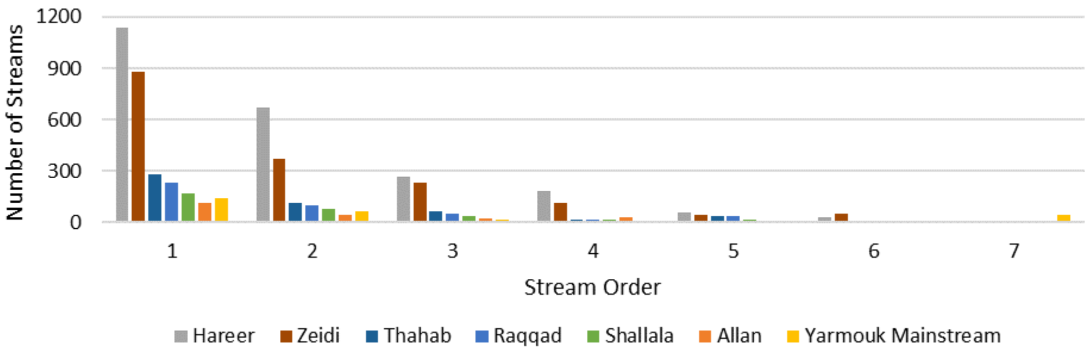

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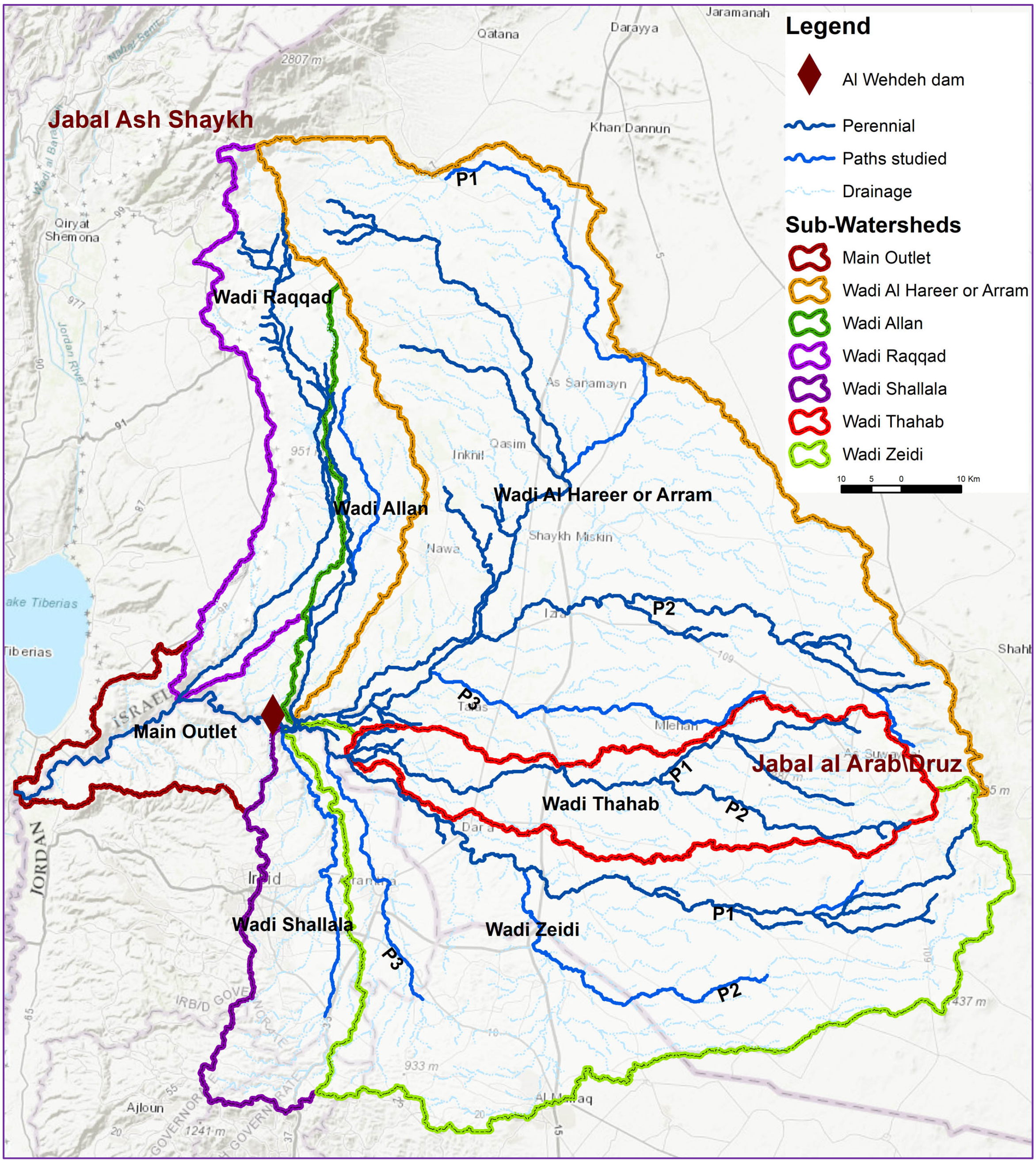
Figure B 1.2 Main sub-basins and tributaries of the Yarmouk, providing also an indication of which tributaries are perennial and which are temporary. *Source*: Authors, based on multiple sources listed in the text.



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A is the basin area (km^2); P is the basin perimeter (km).

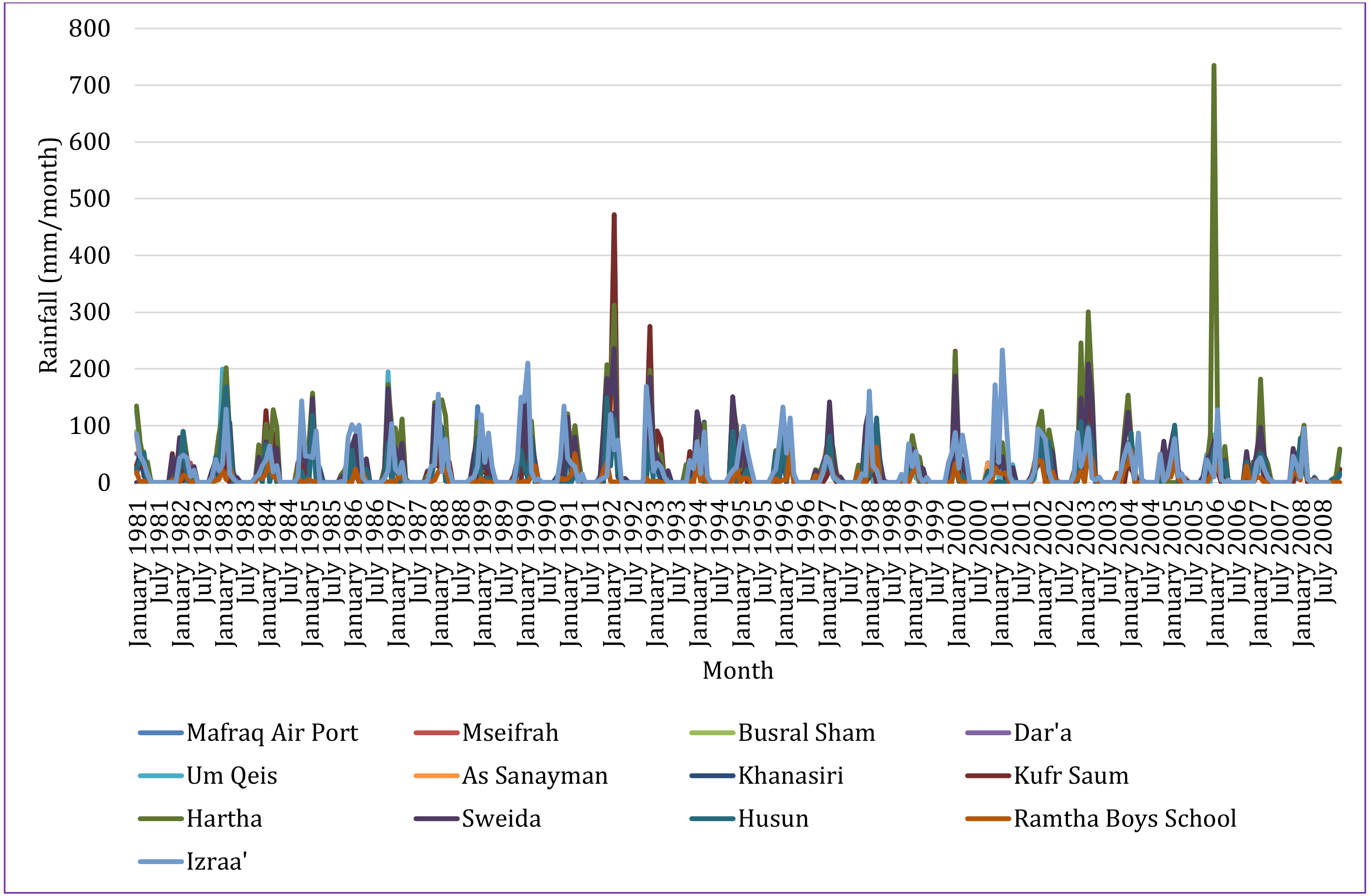
B2 Climatic Characteristics

B2.1 CHIRPS and ground-gauging stations bias correction

CHIRPS is a 30+-year quasi-global rainfall dataset, based on different satellites with a spatial resolution of 0.05x0.05 degree. Data acquired were from 1981 (start of CHIRPS data) to 2016. Ground stations data were acquired from JVA and Orient (2011) for 28 stations in Syria and Jordan, data between 1981 and 2008 (the last year provided).

From the 28 stations considered, seven showed a good fit and six showed a moderate fit between the CHIRPS data and the data of the ground gauges (Table B 9.11). However, these stations are not equally distributed over the whole basin and are particularly lacking in the north-west, which is the region that experiences the most precipitation. It follows that the actual precipitation in this area is underestimated. The average precipitation over the Yarmouk tributary basin was interpolated for the period between 1981 and 2008 from the ground-gauge data of the 13 stations that showed good fit (see Figure B 2.1).

Figure B 2.1 Gauged rainfall data trend. Outlier years were excluded by BIAS correction. *Source*: Authors, based on multiple sources listed in the text.



B2.2 Calculation of indices from Landsat

Indices were derived from Landsat 5 and Landsat 8 images (Tables B 9.3 and 9.4) to study the characteristics of the basin during two main periods, 1985/87 and 2014/16. Four images were required to cover the basin, for which spring season images were acquired.

The maximum Land Surface Temperature (LST) is derived from the thermal bands of the Landsat (Tables B 2.1, B 2.2 and B 2.3). Temperature is derived using Plank's law from the Top of the Atmosphere radiances measured by the TIR (Thermal Infrared) sensors of the Landsat (Dash*, et al.* 2002, Faour*, et al.* 2015). Average Maximum temperature in the basin increased between the 1980s and 2010s, regional decrease is however noted in the agricultural areas. Surface temperature is related to the water content in soil and vegetation and to the water bodies. Note that in the eastern part of the basin, there is an increase in the temperature that can be due to the cloud contamination in this area of the images in the 1980s.

Table B 2.1 Processing steps and formulas for the conversion from Digital Number to LST. Source: Faour et al. 2015.

Processing Steps	Formulas	
Conversion of DN (Digital Number) to At-Satellite Brightness Temperature	$TB = K2 / ln((K1 / L\lambda) + 1)$	• K1 = Band-specific thermal conversion constant (in watts/meter squared * ster * μm); • K2 = Band-specific thermal conversion constant (in kelvin); • Lλ is the Spectral Radiance at the sensor's aperture, measured in watts/(meter squared * ster * μm)
Calculation of the Land Surface Temperature in Kelvin	$T = TB / [1 + (\lambda * TB / \rho) ln\varepsilon]$	• λ = wavelength of emitted radiance • ρ = h * c/σ (1.438×10^{-2} m·K) • h = Planck's constant (6.626×10^{-34} J·s) • σ = Boltzmann constant (1.38×10^{-23} J/K) • c = velocity of light (2.998×10^{8} m/s) • ε = emissivity, which is given [31] by: ε = 1.009 + 0.047 ln (NDVI)
Conversion from Kelvin to Celsius	$Tc = T - 273$	• T = land surface temperature in Kelvin; • Tc = land surface temperature in Celsius.

Table B 2.2 K1 and K2 constants of Landsat. *Source*: Faour (2015).

Constant	Landsat 4	Landsat 5	Landsat 7	Landsat 8 (Band 10)	Landsat 8 (Band 11)
K1 (watts/meter squared * ster * μm)	671.62	607.76	666.09	774.89	480.89
K2 (Kelvin)	1284.30	1260.56	1282.71	1321.08	1201.14

Table B 2.3 Values of the centre wavelength of Landsat. *Source*: Faour (2015).

Satellite	Band	Center Wavelength (μm)
Landsat 4, 5, and 7	6	11.45
Landsat 8	10	10.8
Landsat 8	11	12

The Normalized Difference Vegetation Index (NDVI) is derived from the reflectance of the Red and Near-Infrared Bands. It ranges between -1 and +1, and is calculated using the following formula:

$$NDVI = \frac{Red - NIR}{Red + NIR}$$

Where Red is the Red band, and NIR is the Near-Infrared band.

NDVI results (Figure B 9.6) show that water bodies (negative NDVI values) are dispersed across the basin, while the urban areas and bare lands (NDVI values between 0 and 0.1) are present mainly in the north-eastern and south-eastern part of the basin. The mean NDVI values increase from the 1980s to the 2010s (Table B2.4).

Table B 2.4 Mean NDVI in the Yarmouk tributary basin. *Source*: Authors, based on multiple sources listed in the text.

Area	1985-1987	2014-2016	Difference (2010s–1980s)
Yarmouk tributary basin	0.16	0.2	0.04
Syrian side	0.15	0.2	0.05
Jordanian side	0.17	0.2	0.03

Another important factor calculated was the Reference Evapotranspiration or ET_0 – see Figure B 9.7. that was calculated from meteorological data using FAO-Penman-Monteith equation prepared by (Allen*, et al.* 1998):

$$ET_0 = \frac{0.408\,\Delta\,(Rn - G) + \gamma\,\frac{900}{T+273}\,u_2\,(e_s}{\Delta + \gamma\,(1 + 0.34\,u_2)}$$

Where:

ET_0: Reference evapotranspiration (mm/d)

Rn: Net radiation at the crop surface (MJ/m^2/day)

G: Soil heat flux density (MJ/m^2/day)

T: Mean daily air temperature at 2 m height (°C)

u_2: Wind speed at 2 m height (m/s)

e_s: Saturation vapour pressure (kPa)

e_a: Actual vapour pressure (kPa)

e_s - e_a: Saturation vapour pressure deficit (kPa)

Δ: Slope vapour pressure curve (kPa/°C)

γ: Psychrometric constant (kPa/°C).

Data were collected from twelve stations covering the basin area, from February to October, with means over the period from 1960s to 2010s (Table B 9.12). However, gaps exist in the data and were estimated from remote sensing data. ET_0 was highest in August, ranging between 6.13 and 8.17 mm, and it was lowest in February, ranging between 1.9 and 2.8 mm.

B2.3 Calculation of SPI

The Standardized Precipitation Index (SPI), used to study the long-term precipitation over a certain area, is a dimensionless index. The negative values of the SPI indicate drought conditions, while positive values indicate wet conditions. The SPI can be computed for different timescales, and is thus used to study both short-term agricultural and long-term hydrological droughts. *Meteorological drought* is the lack of precipitation over a large area. It is usually measured for long-term rainfall records; *agricultural drought* is mainly concerned with the effects of water shortages on crops and grasses and other forages. The *hydrological drought* refers to deficiencies in surface and subsurface water supplies and can be measured as stream, river flow, lake, reservoir, groundwater levels and spring discharge (Abou Zakhem and Hafez 2010). The SPI is calculated using the following equation; the intensity, categories and probability of occurrence are listed in Table B2.5 (Abou Zakhem and Hafez 2010; Abou Zakhem and Kattaa 2015):

$$SPI = \frac{Pi - X}{STD}$$

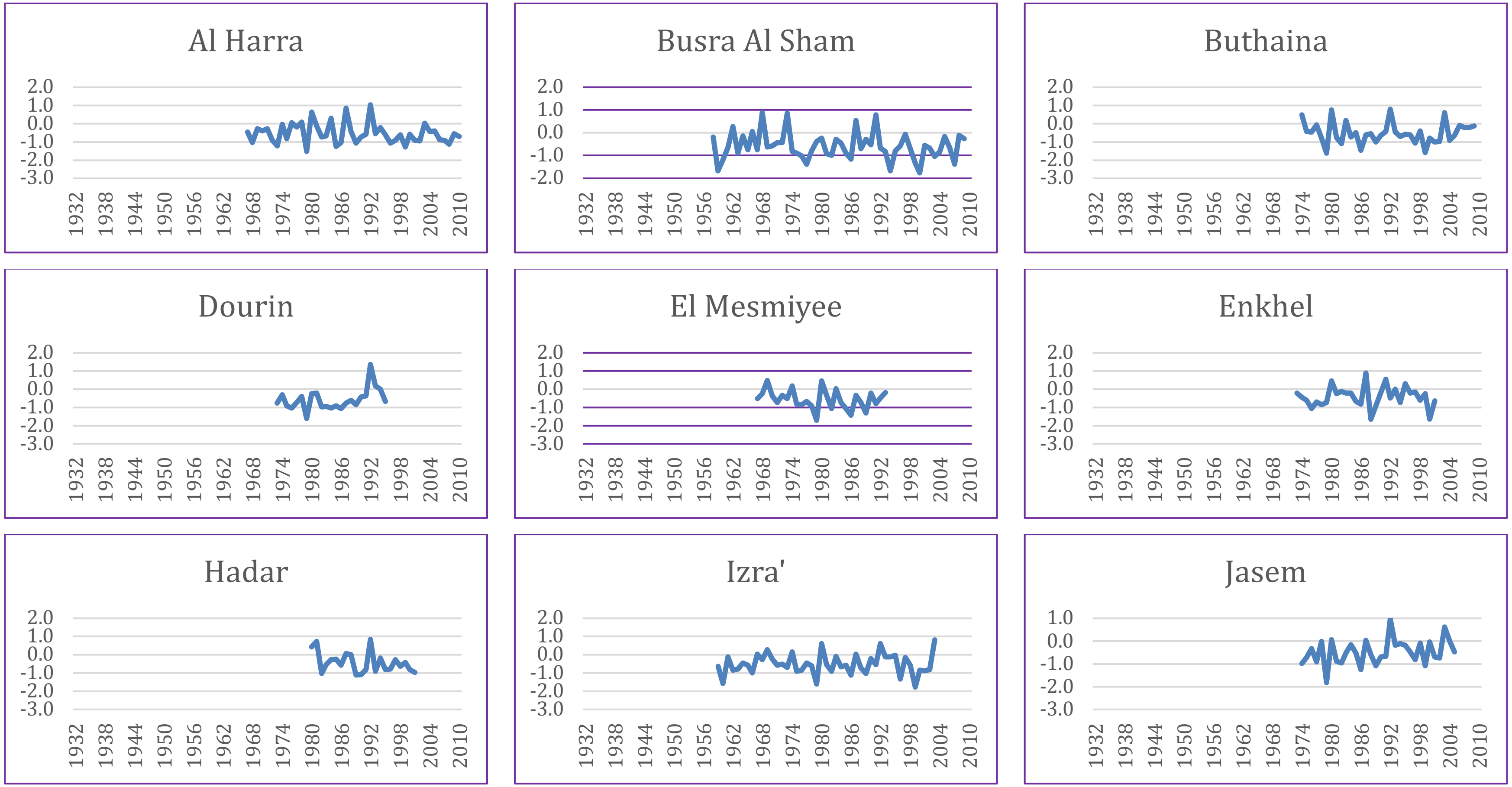
Pi is the precipitation, *X* is the long-term mean annual precipitation, and *STD* is the standard deviation.

Table B 2.5 Wet and drought period classification by SPI and the corresponding event probabilities. Source: Abou Zakhem and Hafez 2010.

SPI	Category	Probability (%)
≥ 2	Extremely wet	< 2.3
1.5 – 1.99	Very wet	6.7
1 – 1.49	Moderately wet	15.9
-0.99 – 0.99	Normal	50
-1.49 – -1	Moderately dry	15.9
-1.99 – -1.5	Severely dry	6.7
≤ -2	Extremely dry	< 2.3

This study examined the long-term meteorological (twelve months - Figure B 2.2) and short-term agricultural (three months - Figure B 2.3) droughts for 21 stations in Syria, generally from 1958 to 2010. Though some stations had older data (Al Suweida, for example, starts in 1931), these years were retained for the analysis because of the presence of sufficient stations with data (five or more stations). To minimise the fragmentation of the periods following the SPI classification, only years that have 20% or more of their stations classified as dry (extreme, very or moderate) were classified as dry in this study (see Table B 9.5).

Figure B 2.2 Long-term meteorological droughts (twelve months) – SPI per station. *Source*: Authors, based on multiple sources listed in the text.



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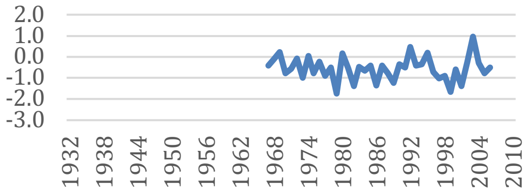

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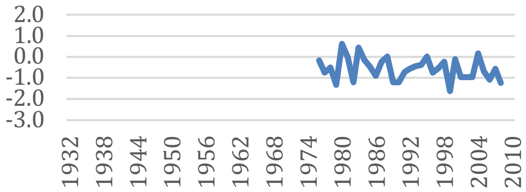

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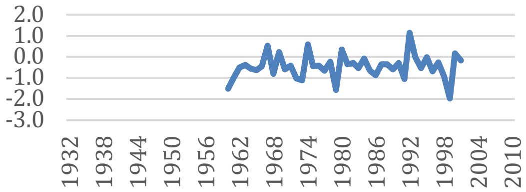
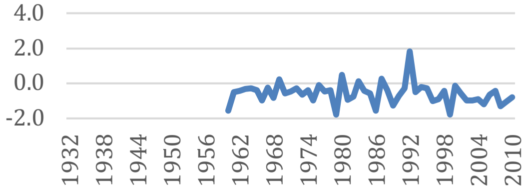


Nab'Sakher

Nawa



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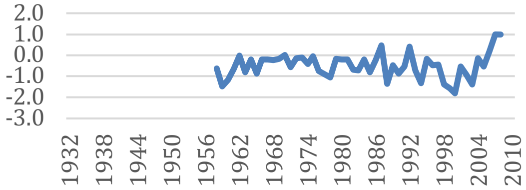

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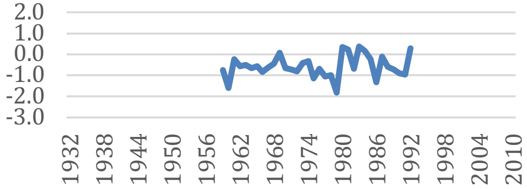

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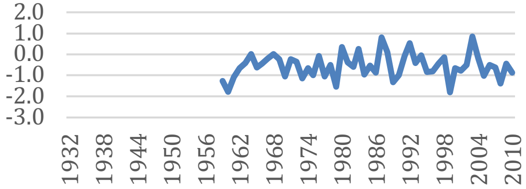

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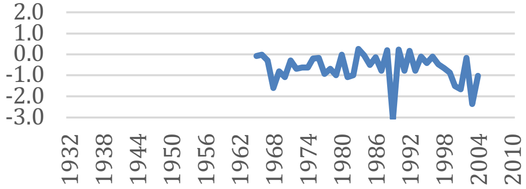

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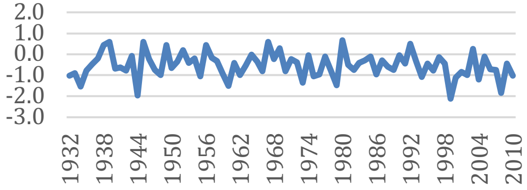

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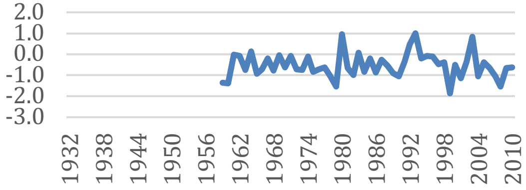

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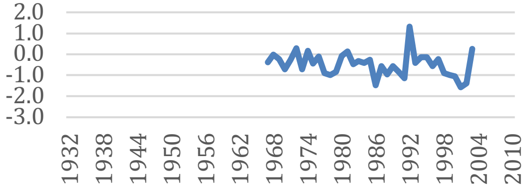
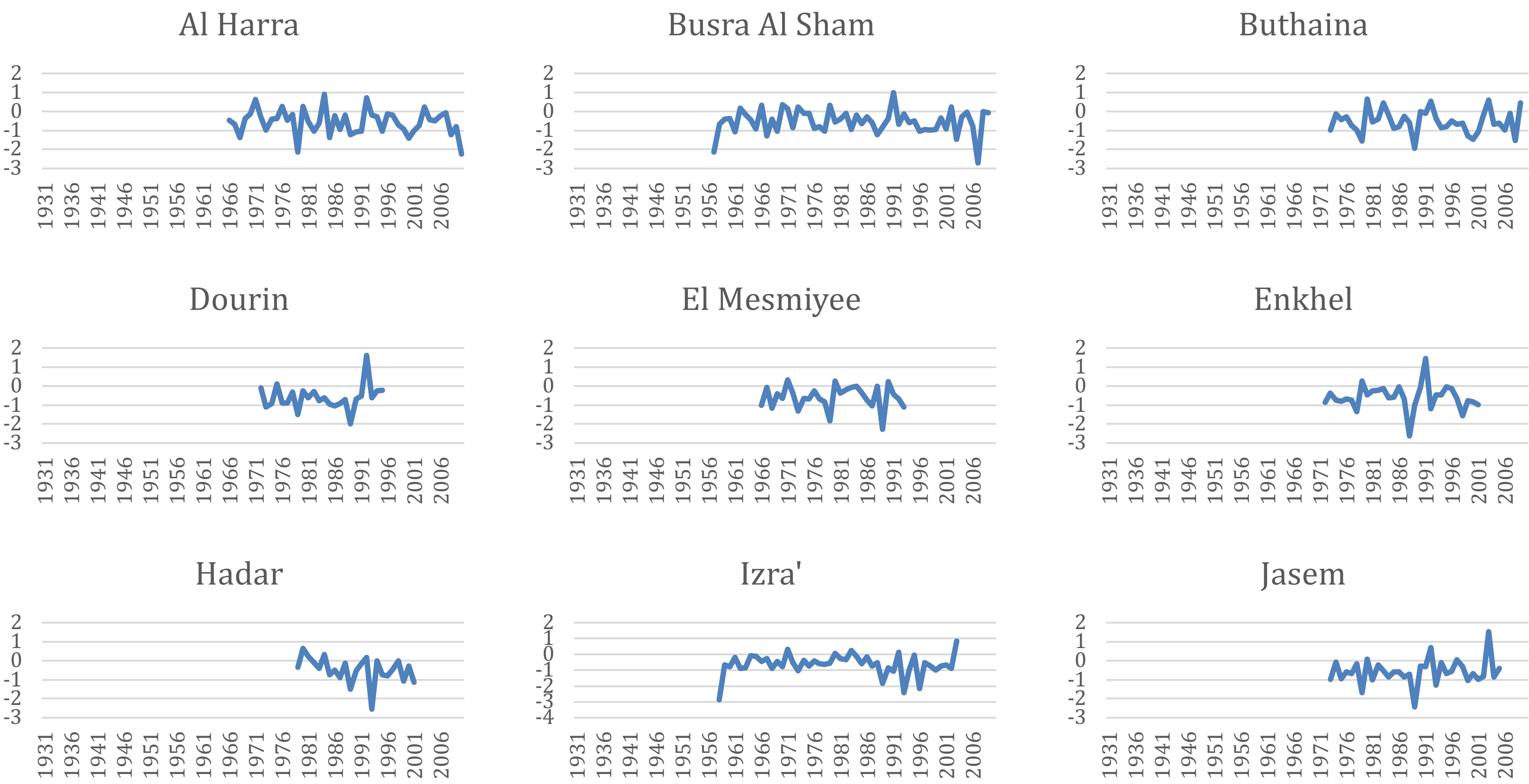
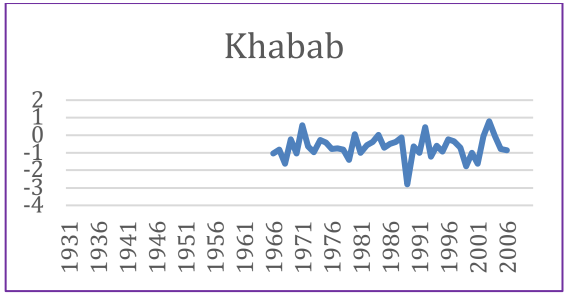


Figure B 2.3 Short-term agricutural (three months) droughts – SPI per station. *Source*: Authors, based on multiple sources listed in the text.

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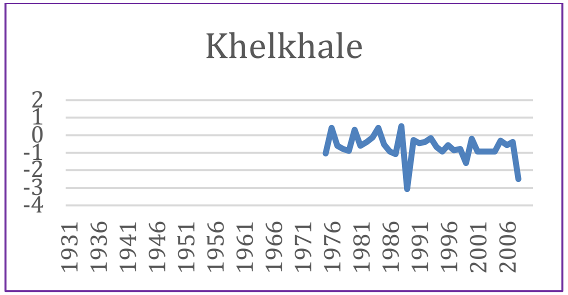
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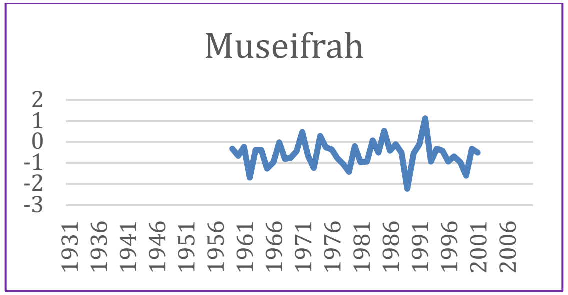
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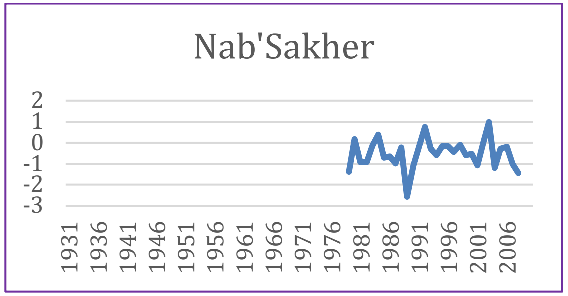
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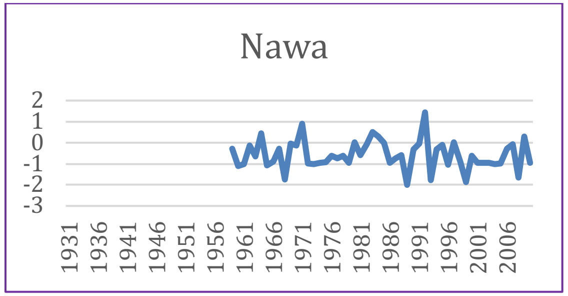
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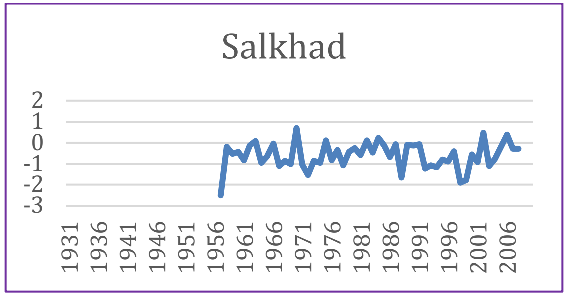
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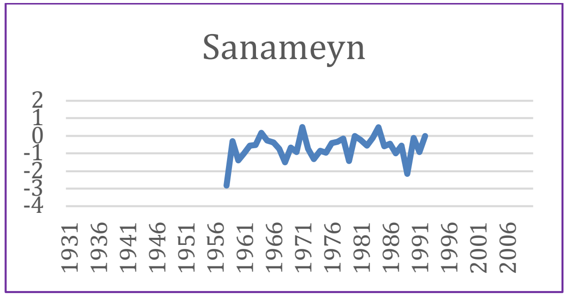
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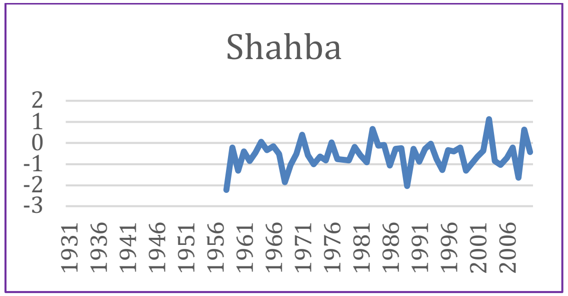
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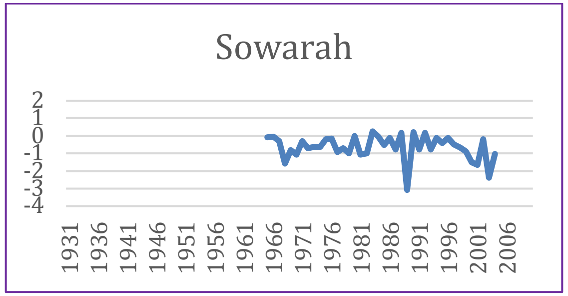
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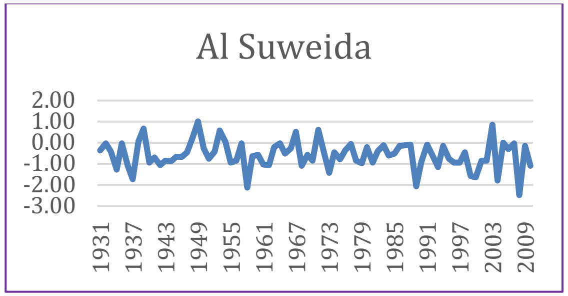
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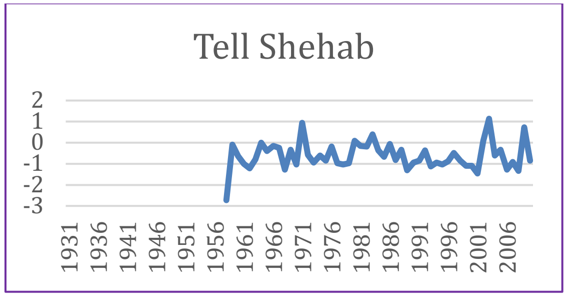
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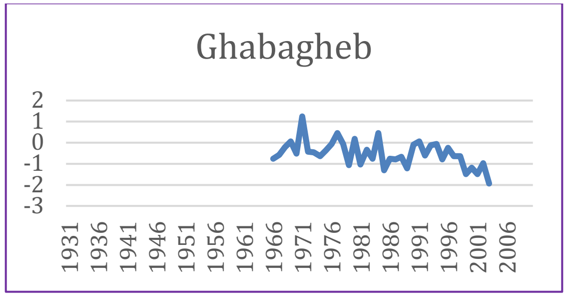
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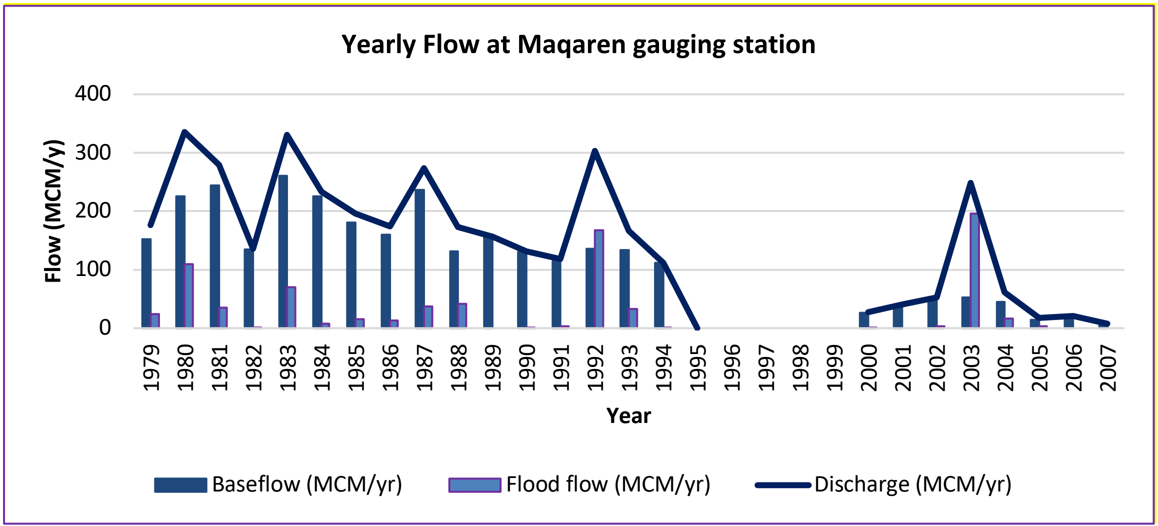
B3 Hydrology

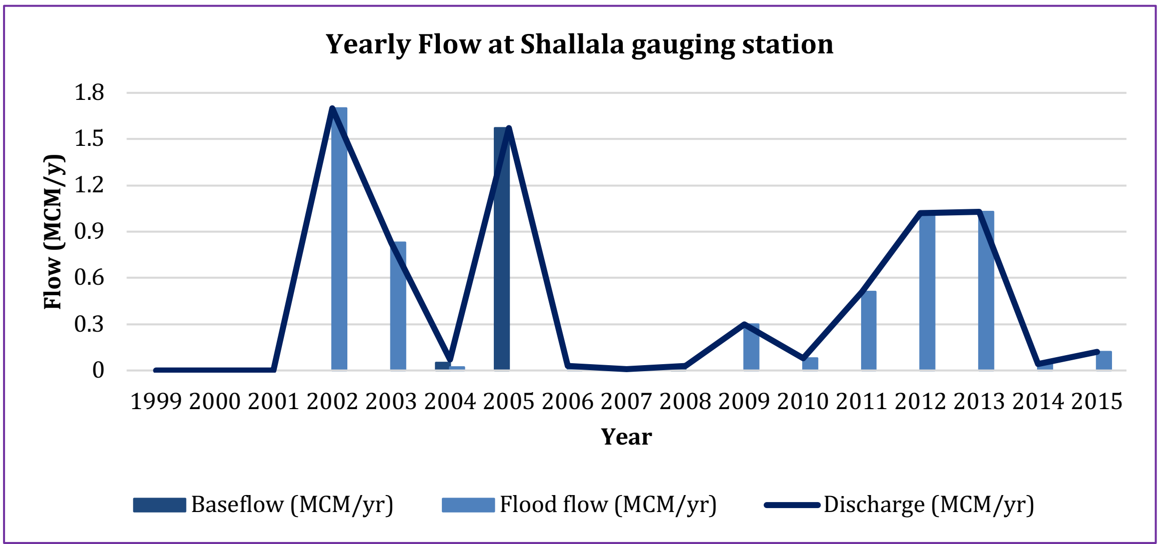
The flow data comes from four Jordanian gauging stations monitored by JVA (Adassiyeh, Maqaren, Shallala, Shummar – see Table B 3.1 and Figure B 3.1) and two gauging stations monitored by HSI (Gate 121 and Naharayim – Table B 3.2 and Figure B 3.2). As the following tables show, the flows decreased in all studied stations.

Table B 3.1 Average (MCM/y) and change (%)in Jordanian flow gauging stations. The wet years 1992 and 2003 have been excluded. 'Change' compares the average of the first- and last-studied periods. No data is available for years 2002-2004. Source: JVA data.

	Baseflow (MCM/y)	Change (%)	Flood flow (MCM/y)	Change (%)	Discharge (MCM/y)	Change (%)
Adassiyeh						
1979-1988	146		84		229	
1989-1998	53	-64	19	-77	72	-69
1999-2007	25	-54	6	-67	31	-57
2008-2015	28	16	11	73	39	28
Long-term change (%)		-81		-97		-83
Maqaren						
1979-1988	195		36		231	
1989-1998	108	-45	6	-83	114	-51
1999-2007	29	-73	3	-43	32	-48
Long-term change (%)		-85		-90		-86
Shummar						
2001-2007	0.00		0.38		0.38	
2008-2015	0.00	0	0.36	-6	0.36	-6
Shallala						
1999-2007	0.18		0.22		0.42	
2008-2016	0.00	-98	0.34	57	0.35	-18

Figure B 3.1 Flow at Maqaren, Shallala and Shummar stations (monitored by JVA).





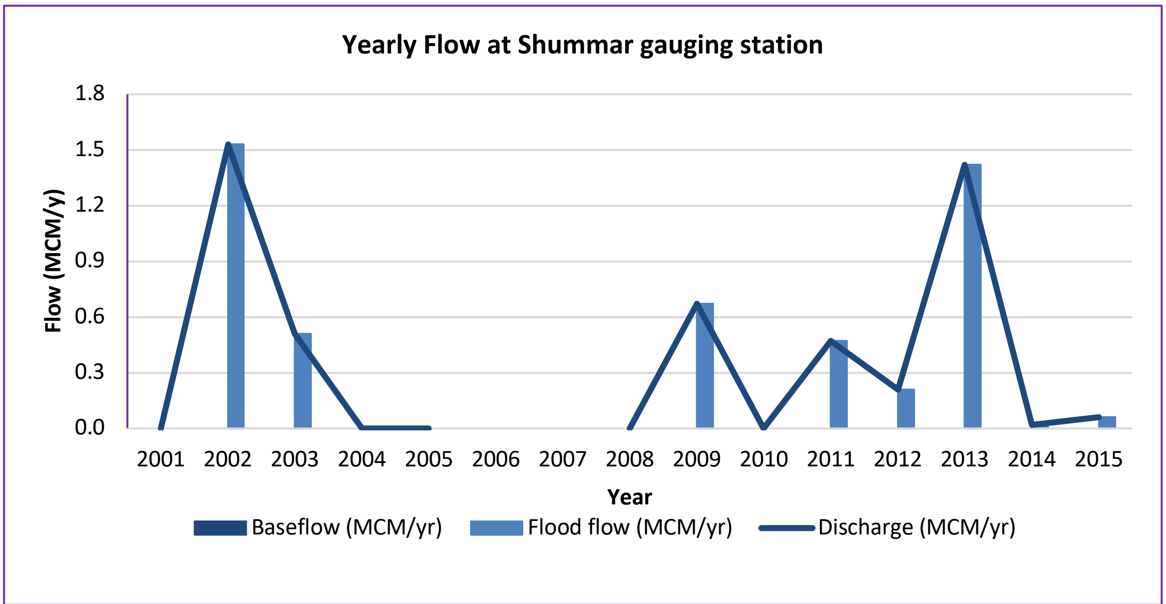
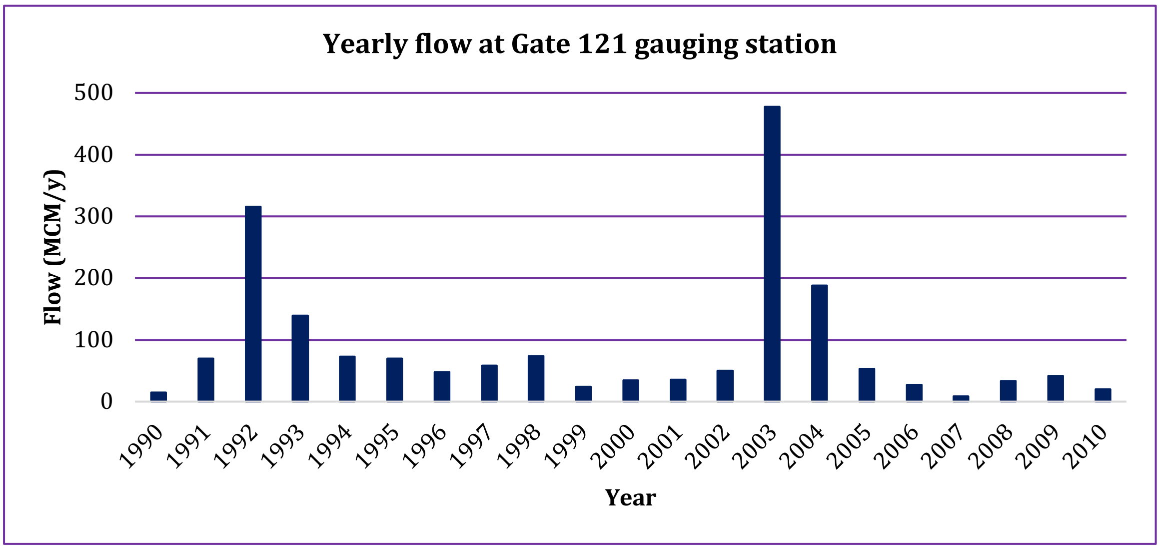


Table B 3.2 Average and change (%) in Israeli flow gauging stations monitored by HSI. Wet years 1992 and 2003 were excluded from averages, the 'Change' compares the average of the first- and last-studied period. *Source*: Authors, based on multiple sources listed in the text.

	1978-1989 (MCM/y)	1990-1999 (MCM/y)	2000-2010 (MCM/y)	Change (%)
Naharayim/Al Baqura	194.6	82.5	(n.d.)	-57.6
Gate 121		63.3	49.2	-22.2

Figure B 3.2 Flow at Gate 121 and Naharayim/Al Baqura (monitored by HSI). Records for Naharayim stop at 2000. *Source*: Authors, based on multiple sources listed in the text.



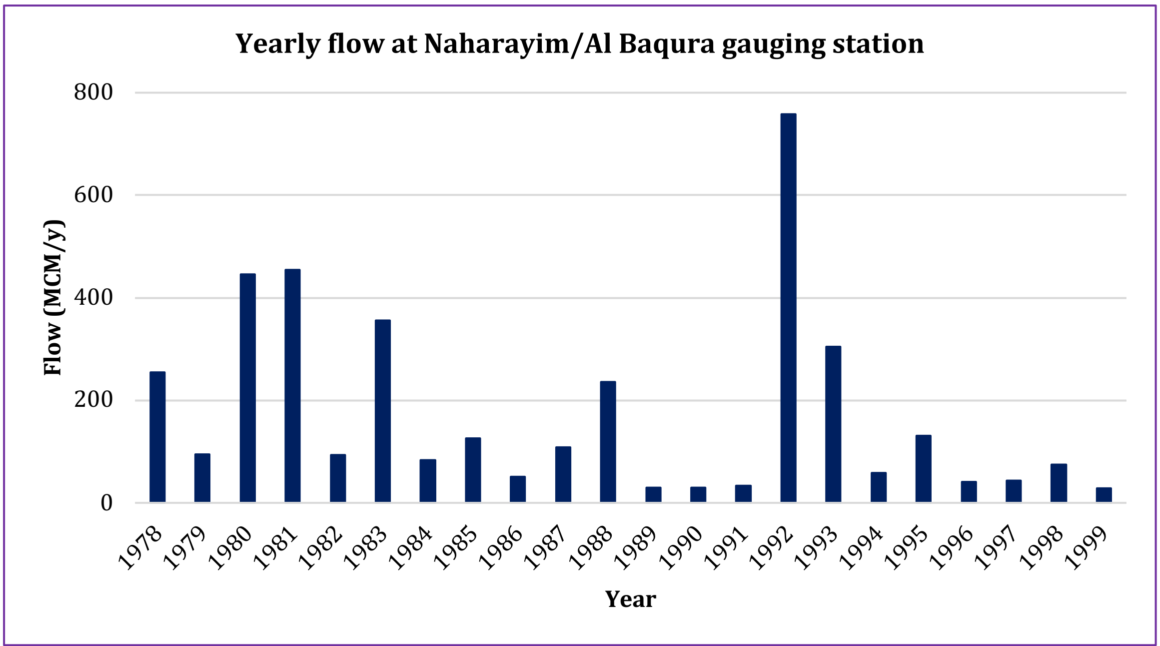
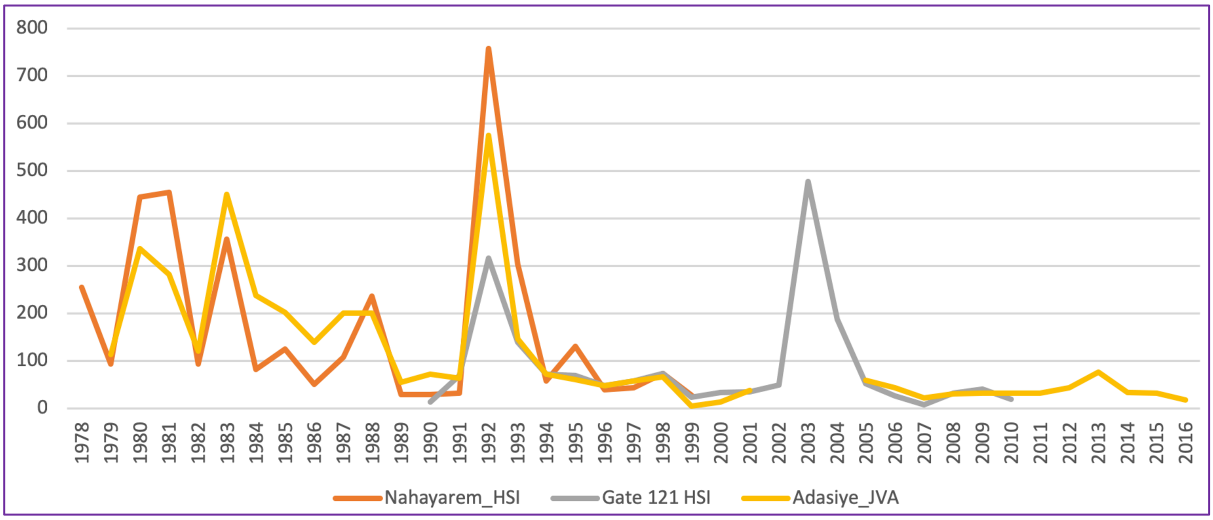


Figure B 3.3 Comparison of Flows at Gate 121 (gauged by HSI), Adassiyeh (JVA), and Naharayim/Al Baqura (HSI). Records for Naharayim stop at 2000.



B4 Geology & hydrogeology

B4.1 Lithostratigraphic correlation

To better study the geology and hydrogeology of the Yarmouk tributary basin, a lithostratigraphic correlation between the Syrian and Jordanian names was carried out, as presented in Table B4.1.

Table B 4.1 Main Hydrogeological Systems in the Yarmouk tributary basin area. Source: Authors' compilation based on Margane 2015; Orient 2011.

System	Formation			Main lithology	Age	Type of aquifer
Upper Aquifer System	Basalt			basalt	Neogene - Quaternary	aquifer
Upper Aquifer System	B4/B5 - Pg_2^2/Pg_2^3	Umm Rijam/Wadi Shallala		chalky limestone, some marl (Syria)	Eocene	aquifer
B3 - Pg_1-Pg_2^1		Muwaqqar		marl, chalky limestone	Paleocene	aquitard
Middle Aquifer System	A7/B2 - Cr_2cn cp / Cr_2m-d	Wadi as Sir/Amman - Al Hissa		chalky limestone, limestone, dolomitic limestone	Upper Cretaceous: Coniacian - Maastrichtian	aquifer
Middle Aquifer System	A1/A6 - Cr_2cm-t	A5/A6	Shueib	chalky limestone, marl	Turonian - Coniacian	aquitard
Middle Aquifer System	A1/A6 - Cr_2cm-t	A4	Hummar	limestone, dolomites, marly limestone	Cenomanian-Turonian	aquifer
Middle Aquifer System	A1/A6 - Cr_2cm-t	A3	Fuheis	limestone, marl	Cenomanian-Turonian	aquitard
Middle Aquifer System	A1/A6 - Cr_2cm-t	A1/A2	Naur	limestone, dolomites, marl	Cenomanian-Turonian	aquifer
Deep Aquifer System	K - Cr_1-Cr_2 t	Kurnub		sandstone	Lower Cretaceous: Barriasian - Albian	aquifer
Deep Aquifer System	Z	Zarqa		sandstone, siltstone, limestone	Permian - Jurassic	aquifer
Deep Aquifer System	KH	Khreim		siltstone, mudstone, sandstone	Paleozoic - Silurian	aquitard
Deep Aquifer System	D	Ram		sandstone, dolomite, limestone	Cambrian - Ordovician	aquifer

B4.2 Lithology of main aquifers (Basalt and A7/B2-Cr_2cn cp/Cr_2m-d)

The basalts are present in the Syrian part of the Yarmouk tributary basin. There are two main types of basalt: the Plateau type of Neogene (mainly Pliocene) age, frequent in the Hauran Plain; and the Shield Basalts of Quaternary (Pleistocene) age, frequent in the Yarmouk Valley area. In the Hauran Plain, the relief was formed by superposition of relatively thin individual basaltic flows, while the basalt cones found in this region were formed around the volcanic cones, where the basalt accumulated with bigger thickness. The Quaternary lava flows are narrow, thin valley fillings. Shield Basalts reach a maximum thickness of 100 m, and have a very limited soil cover (Bourgoin et al. 1948; Burdon et al. 1954; Dafny et al. 2003; Hobler et al. 2001; UN-ESCWA/BGR 2013; Wagner and Geyh 1999).

The A7/B2 - Cr_2cn cp / Cr_2m-d Aquifer is mainly outcropped in the Jordanian part of the Yarmouk tributary basin. Because of the importance of this aquifer, the description of its formations is detailed in Jordanian literature. From top to bottom, three formations can be distinguished:

The Amman-Al Hissa Formation (B2) of Campanian-Maastrichtian age is the most recent formation. It consists of massive chert beds interbedded with limestone beds, marl and chalk of varied thickness. A highly productive urban aquifer, it is exposed mainly to the west of Irbid where its reaches a thickness of 60 m, on the mountain slopes and the side wadis of the Yarmouk and Jordan Rivers. In some areas, the B2 is confined under the B3 - Pg_1-Pg_2^1 Aquitard (Abu-Jaber and Kharabsheh 2008; Bandel and Salameh 2013; Hobler et al. 1994; Wagner and Geyh 1999);

The Wadi Umm Ghudran Formation (B1), aged from Late Coniacian/Santonian to Campanian, marks the beginning of the Belqa Group. It is formed of massive grey chalk and marl, often eroded and rarely exposed. In the north of Jordan, its thickness is around 50 m, but it can be thinner especially around Irbid area (Abu-Jaber and Kharabsheh, 2008; Bandel and Salameh, 2013; Hobler et al., 1994).

The Wadi Es Sir Formation (A7), aged from Coniacian-Santonian, is the last formation of the Ajloun Group. It is karstified, formed of massive limestone, dolomitic limestone and dolomite with intercalated beds of sandy limestone, marl, gypsum and chert. Change to chalk, which marks the transition to the Belqa Group, occurs at the top of the A7. Exposed in the Ajloun Highlands and in some incised wadi channels, the thickness of the A7 in northern Jordan decreases in general from the north-west to the south-east. It generally has a thickness of more than 200 m (Abu-Jaber and Kharabsheh 2008; Bandel and Salameh 2013; Hobler et al. 1994; Wagner and Geyh 1999).

B4.3 Age of groundwater in main aquifers

Groundwater in the Basalt Aquifer is relatively recent. In the region of Jabal Al Arab/Druze and Al Suweida recharge occurs from present-day precipitation, as indicated by tritium levels, while water is slightly older in the eastern Hauran Plain as indicated by carbon-14 levels. In other areas of the Basalt Aquifer, the water becomes older: water originating from Jabal al Sheikh, for example, is assumed to be aged around 3,300 years BP. Groundwater becomes older as it gets closer to the discharge areas: around 5,000 years BP in the Dera'a-Izra' area and more than 10,000 years in the south near the Syrian/Jordanian border (Figure B 9.10) (UN-ESCWA/BGR 2013; Wagner and Geyh 1999).

Groundwater in the A7/B2 - Cr_2cn cp/Cr_2m-d Aquifer is also recent, as confirmed by tritium isotopes analysis from different springs and wells in the outcropped areas. However, in areas where the aquifer is confined by the B3 - Pg_1-Pg_2^1 Aquitard, the groundwater becomes older, as confirmed by carbon-14 isotopes analysis in the Mukheibeh well field in the lower reaches of the Yarmouk tributary basin (Hobler et al. 2001; Orient 2011).

B4.4 Main groundwater fluctuations and movements

Groundwater in the Paleogene in Syria:

In the eastern part of the Yarmouk tributary basin, groundwater infiltrates from the Basalt Aquifer to the B4/B5 – Pg_2^2 / Pg_2^3, while in the western part, the B4/B5 – Pg_2^2 / Pg_2^3 Aquifer feeds the Basalt Aquifer through upward leakage. A groundwater divide is found between Yadoudah and Tissiya in Dera'a Governorate in Syria. In the south of this divide, groundwater flows towards Jordan, probably due to overexploitation of the groundwater in the Cretaceous (A7/B2 - Cr_2cn cp / Cr_2m-d) and Paleogene (B4/B5 - Pg_2^2/Pg_2^3) Aquifers (Youmans 2017).

Age of B3 – Pg_1-Pg_2^1 aquitard in literature

Hobler et al. (1994) considered it ages between the Maastrichtian and the early Eocene, taking into consideration that the early Paleogene is missing because of the unconformity at the Cretaceous-Tertiary boundary. While Burdon (1954) in Syria considered it part of the Santonian, Wagner and Geyh, (1999) estimated it to be of Lower and Middle Eocene age. Bandel and Salameh, (2013) considered it part of the Maastrichtian, before the Paleogene of Jordan. Nevertheless, the most recent study, Margane, (2015) considered it of Paleocene age.

Connection between A7/B2 Aquifer and other aquifers:

In the east of the basin, in the Jabal al Arab area, an upward leakage to A7/B2 - Cr2cn cp/Cr2m-d from other aquifers exists (Hobler et al. 2001; Orient 2011). Groundwater from deeper aquifers (mainly the K - Cr1-Cr2 t Aquifer) also recharges the A7/B2 - Cr2cn cp/Cr2m-d Aquifer in the Yarmouk Valley, mainly around the geothermal springs as the temperature of groundwater in some springs was found to be higher than in others (Hobler et al. 2001). Another explanation for this change in the groundwater temperature is the presence of an intrusive basaltic body (as in the Hamat Gader and Meizar areas), or the presence of a deep groundwater circulation system (Siebert*, et al.* 2014). On the other hand, groundwater from the basaltic Hauran Plain feeds some springs in the Lower Yarmouk Gorge (Siebert*, et al.* 2014).

Change of groundwater regime due to the overexploitation of the A7/B2 - Cr2cn cp/Cr2m-d Aquifer in Jordan (Margane, 2015):

In 1995, the groundwater divide between the Yarmouk and the Azraq Basins was to the east of the Yarmouk tributary basin, in the Umm al Quttayn and Corridor well field in Jordan (i.e. present in the Azraq Basin). However, due to water-level decline caused by groundwater abstraction in both Syria and Jordan, the groundwater regime in the area has been altered. In fact, the limestone A7/B2 - Cr_2cn cp/Cr_2m-d Aquifer is partly recharged from the Jabal al Arab area (like before), but the groundwater divide between the Azraq and Yarmouk Basins has shifted 40 m to the east of its previous 1995 location. In 2013, the groundwater in the Dhuleil-Hallabat area in northern Jordan flowed towards the Yarmouk (north and north-west), while in 1995 it flowed to the west. The groundwater flow is modest until the Mafraq area in Yarmouk, increasing towards the Yarmouk mainstream in the north, which threatens to increase the salinity of groundwater in the Yarmouk (Mafraq area, Somaya and Jaber well fields).

B5 Agricultural water

Rainfed and irrigated agriculture are extensively practised throughout the basin in Syria and Jordan. The western part of the basin in Jordan is planted mainly with rainfed field crops, olive trees and vegetables, while the eastern parts are open for grazing and are mainly planted with rainfed barley. Irrigated agriculture is practised chiefly in the northern, middle and eastern parts of the basin, especially in the Ramtha area where groundwater is a major source of water (Al- Bakri 2015). As irrigation with groundwater is illegal in the area between the Adassiyeh Weir and the Wehdeh Dam, the guava and citrus trees are irrigated with surface water (Abed (pers. comm.) 2017).

The agricultural water requirement is the amount of water used by crops and planted trees. The crop water requirement (CWR) is estimated through the crop evapotranspiration using the following formula:

$$CWR = \frac{ETc(in\ vegetative\ zone) \times Pixel\ size \times num}{10^9}$$

CWR is the crop water requirement (MCM); the pixel size is 30 m; and *ETc* is the crop evapotranspiration (mm/d), which is calculated using the formula:

$$ETc = Kc \times Kr \times ET_0$$

Kc is the crop coefficient; *Kr* is the correction factor; ET_0 is the reference evapotranspiration (mm/d) calculated previously. Kc is not crop dependent, it is estimated from satellite images via NDVI using the following formula: $Kc = 1.25 \times NDVI + 0.2$ (Akdim, *et al.* 2014). The Kr is related to the fractional cover (*Fc*), which is the percentage of the vegetative cover on the ground, calculated using the following formula:

$$Fc = \frac{NDVI - NDVImin}{NDVImax - NDVImin}$$

$NDVI_{min}$ is the value of NDVI for the bare soil, and $NDVI_{max}$ is the value of a pixel with 100% vegetative cover. The Kr is taken into consideration when the percentage of the fractional cover is <50%, as recommended by the International Olive Council (1997). Table B 5.1 shows the values of Kr for the corresponding Fc.

Table B 5.1 Values of Kr and Fc. *Source*: Authors, based on multiple sources listed in the text.

Fc (%)	Kr
> 50	1.00
40 – 50	0.90
35 – 40	0.80
30 – 35	0.75
< 30	0.70

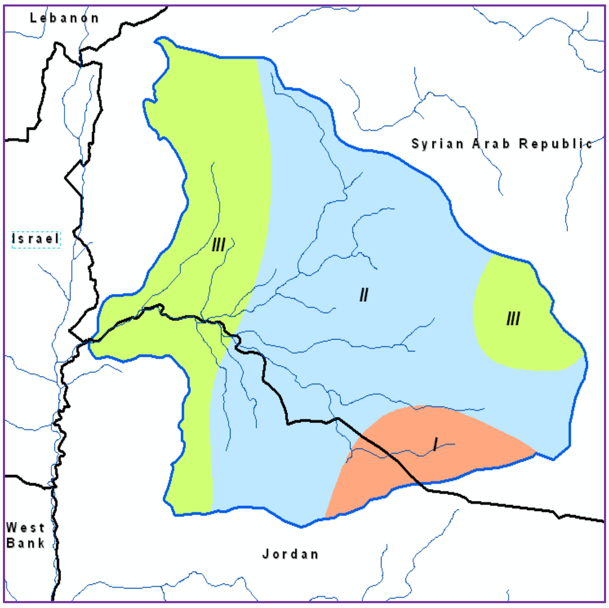
Considering the tree water requirement (TWR), trees in Zone 1 are considered to have an irrigated water need of 5,600 m^3/ha for vines, 7,000 m^3/ha for olives, and 8,000 m^3/ha for fruit trees (Al- Bakri 2015; Youmans 2016; Etana 2016 Orient 2011). The areas planted with trees and falling inside Zone 1 were identified from the LUC map of 2011, and their water requirements – provided by irrigation – were calculated. A total of 1,301.75 ha of fruit trees, 4,570.87 ha of olives and

1,579.73 ha of vines are planted in Zone 1, requiring 72 MCM/y of water. These results were compared with the results of the TEMPUS study mentioned by Orient (2011) and found to be coherent.

Table B 5.2 Water requirements for trees per sub-basin. *Source*: Authors, based on multiple sources listed in the text.

Sub-basin	Planted area (ha)			Water requirement (MCM/y)
	Fruit Trees	*Olive*	*Vine*	
Main Outlet	13	456	2.9	3.3
Wadi Al Hareer/Arram	873	1,336	1,003	22
Wadi Thahab	289	1,255	516	14
Wadi Zeidi	75	443	53	24
Wadi Al 'Allan	48	910	0.84	6.8
Wadi Raqqad	3.4	172	4.4	1.3

Figure B 5.1 Agro-climatic zones of the Yarmouk tributary. *Source*: Orient 2011.



Zones	Rainfall range (mm)
I	< 200
II	200 – 400
III	>400

B6 Soil Moisture

B6.1 Rough estimate of soil moisture

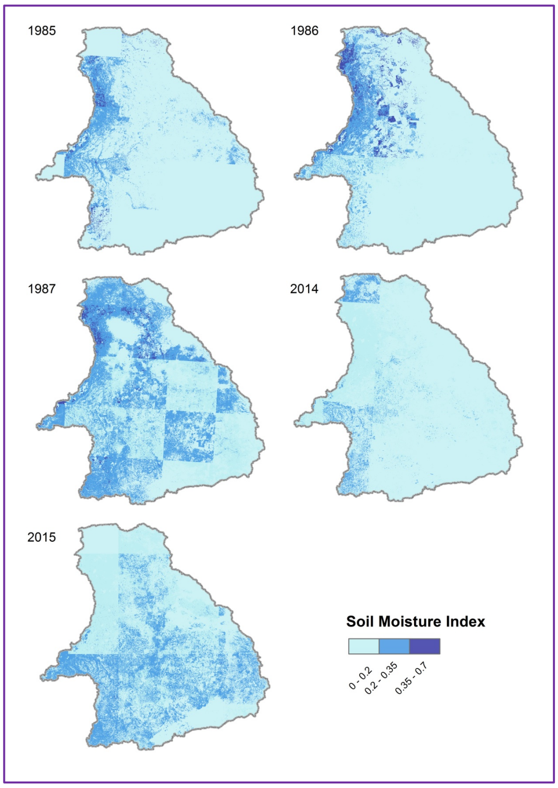
The soil water content was estimated very coarsely between 1 November 1978 and 31 December 2015, using several remote sensing instruments by the Earth Observation Data Centre for Water Resources Monitoring GmbH, which is part of the ESA Climate Change Initiative Phase II – Soil Moisture.[1] Because of the low spatial resolution (0.25°) of the radar soil-moisture datasets, they were downscaled to 30 m based on Landsat images using the methodology presented in Mhawej et al. (2014) (Annex B6). Figure B6.1 shows the Soil Moisture Index (SMI) for the vegetated areas in the Yarmouk tributary basin.

Keeping in mind the coarseness of the data, the SMI has decreased by approximately 31% over the past three decades. Only small dispersed regions close to water bodies present an increase in SMI values (Table B 6.1). The decrease in SMI presents a tendency toward desertification in the area (Zeng, *et al.* 2004), and is probably caused primarily by a higher global temperature and increase in the duration and intensity of dry season.

Table B 6.1 Coarse estimates of the Mean Soil Moisture Index (SMI) (m^3/m^3) in the Yarmouk tributary basin. *Source*: Authors, based on multiple sources listed in the text.

Area	1985-1987	2014-2015	Difference
Yarmouk tributary basin	0.26	0.18	0.08
Syrian side	0.26	0.17	0.09
Jordanian side	0.23	0.21	0.02

Figure B 6.1 Changes in Soil Moisture Index (SMI) in the Yarmouk tributary basin from 1985 to 2015 (30 m resolution). *Source*: Authors, based on multiple sources listed in the text.



B6.2 Soil Moisture Index

The data for the Soil Moisture Index (SMI) calculation contain three types of datasets: the ACTIVE product, which is

[1] www.esa-soilmoisture-cci.org/sites/default/files/documents/ESA_CCI_SM_PSD_D1.2.1_v1.9.pdf

the output of merging scatterometer-based soil moisture data, derived from AMI-WS and ASCAT (Metop-A and Metop-B); the PASSIVE product, that merges data from SMMR, SSM/I, TMI, AMSR-E, WindSat, AMSR2, and SMOS; and the COMBINED product, that merges the ACTIVE and the PASSIVE products. The merging algorithm is an evolution of the algorithm described in (Dorigo*, et al.* , Liu*, et al.* 2011, Liu*, et al.* 2012, Wagner*, et al.* 2012). The homogenised and merged products present the surface soil moisture with a global coverage and a spatial resolution of 0.25°, and a temporal resolution of one day with a reference time at 0:00 UTC. The processing level is 'L3S' (super-collated), where observations from multiple instruments are combined into a space-time grid.

The downscaling of the radar soil moisture datasets to 30 m was done using the method proposed in Mhawej et al. (2014) and based on Landsat images. This approach used the average of two soil-moisture radar values corresponding to the nearest two dates where the Landsat images were collected. The Moisture Index (MI), retrieved from the Near Infrared Band divided by the Blue Band, is also added to the input data. The sum of the Moisture Index in each 0.25° grid was produced. The ratio between Moisture Index and the sum of the Moisture Index in each grid provides the weighting factor that was multiplied by the radar soil moisture values to evaluate the newly created soil moisture datasets in the Yarmouk tributary basin at a spatial resolution of 30 m.

Box B1: Syrian projects to reduce consumption of irrigation water

After the Government of Syria reconsidered its water consumption, many projects were implemented in the Yarmouk tributary basin to reduce water consumed for irrigation. These included the modernisation of the old irrigation network between 1996 and 2002, and the national plan adopted in 2000 that intended to convert old irrigation systems to modern ones, decrease irrigation consumption and allow groundwater regeneration. In 10 years, 10,000 ha were supposed to be turned to modern irrigation in Dera'a (Al-Nahas 2011). Different projects were implemented in Dera'a Governorate. Among them is the 1983 MoAAR reforestation project 'Green Belt', which resulted in the planting of 1.5 million fruit trees (95% of which were olive). The main challenges reported about the project were the lack of water resources in the area and low rainfall, especially given the fact that the saplings require irrigation during the first three years (Agri-News 2011). The JICA-supported irrigation efficiency improvement project DEITEX (Development of Efficient Irrigation Techniques and Extension) that ran from 2005-2008 was renewed from 2009 to 2012. The objective of this project was to encourage farmers to self-select a water-saving irrigation system. Project reports assert that by 2010, 86.4% of farmers in Dera'a were using modernised irrigation systems, compared to 53.4% in 2009, while the amount of water used for irrigation decreased by 50%, 39% and 31% for tomato, watermelon and grapes, respectively, between 2009 and 2010 (JICA*, et al.* 2012).

B7 Dams and storage

B7.1 Storage capacity and purpose of dams

More information on the storage capacity of the dams inside the Yarmouk tributary (and administrative) basins is provided in Table B7.1. Note that within the hydrological basin, there are three dams in Jordan (storage capacity: 3.1 MCM); four built by Israel in the Occupied Syrian Golan (10.1 MCM); one Jordanian-Syrian (the Wehdeh Dam; storage capacity: 110 MCM), and 32 in Syria (total storage capacity: 205 MCM (but see summary statistics at end of table and Section 7.3.2).

Summary statistics from Table B7.1 (see also Section 7.2.3)**:**

- Number of dams in Syria within the Yarmouk tributary basin: 32;
- Estimated storage capacity of Syrian dams within the Yarmouk tributary basin (including 2 listed as not contributing to the Yarmouk (al Rumi and al Butm): 205 MCM;
- Number of dams named in the 1987 Water Agreement: 26 (+2 listed as not contributing to the Yarmouk (al Rumi and al Butm));
- Storage capacity of the 26 dams named in the 1987 Agreement: 134 MCM;
- Estimated storage capacity of the 26 dams named in the 1987 Agreement: 190 MCM;
- Names (and storage capacity) of dams built within the basin that are not named in the 1987 Agreement: Jowayleen (0.5 MCM, built in 1988), Qanawat (6.2 MCM, 1991), Al Raha (0.45 MCM, 2000), and Al Asleha Dam (0.04 MCM, 1968). Their total capacity = 7.2 MCM. Not including the four dams built within the basin by Israel (on the occupied Golan);
- Total estimated storage capacity of Syrian dams within the Yarmouk tributary basin: 197 MCM (not including al Rumi and al Butm).

Table B 7.1 Details of dams in the Yarmouk tributary (and administrative) basin, sorted by sub-basin. Compiled from (Al-Husein 2007, UN-ESCWA/BGR 2013, Etana 2015, CBS 2016, FAO 2016, MWI 2016a, Youmans 2016, JVA 2017).

Note: J: Jordan; S: Syria; G: Occupied Syrian Golan; LW: Livestock Watering; I: Irrigation; NA: Not Available; D: Drinking; FF: Fish Farming; EP: Electricity Production; O: Organisation.

Name (+ alternative appellation)	Arabic	Sub-basin	Country	Governorate	Year of const'n	Actual estimated Storage Capacity (MCM)	Purpose	Notes	Within or outside hydrological basin?	Named in 1987 Agreement?
Al 'Allan al Ghar (al Ghar)	العلان	Al 'Allan	S	Dera'a	1990	5.25	I (525 ha)	Out of service	In	YES
Al Hujah (Al Hishah)	الهجة	Al 'Allan	S	Dera'a	1982	0.85	I (125 ha)		In	YES
Saham al Golan (al Jawlan)	سهم الجولان	Al 'Allan	S	Dera'a	1995	20	I (700 ha)		In	YES
Taseel (Tasil)	تسيل	Al 'Allan	S	Dera'a	1982	6.628	I (652 ha)		In	YES
Abta' al Sagheer (Ibta' 1)	أبطع الصغير	Hareer/ Arram	S	Dera'a	1972	0.5	I (500 ha)	Out of service/polluted	In	YES
Abta' al Kabeer (Ibta' 2)	أبطع الكبير	Hareer/ Arram	S	Dera'a	1972	3.5	I (515 ha)	Out of service/polluted	In	YES
Adwan	عدوان	Hareer/ Arram	S	Dera'a	1986	5.8	I (552 ha)	Polluted	In	YES
Al Rom (al Rumi)	الروم	Hareer/ Arram	S	Suweida	1977	6.4	D, FF		In	YES
Al Sheikh Maskin (Miskin)	الشيخ مسكين	Hareer/ Arram	S	Dera'a	1982	15	I (1,350 ha)	Out of service (military)/pollution	In	YES
Gharbi Tafs (Tafas)	غربي طفس	Hareer/ Arram	S	Dera'a	1982	2.1	I (210 ha)	Polluted	In	YES

Jowayleen	جوالين	Hareer/ Arram	S	Suweida	1988	0.5	O		In	NO
Qanawat	قنوات	Hareer/ Arram	S	Suweida	1991	6.1	NA		In	NO
Wehdeh	الوحدة	Mainstream	J		2007	110	I, EP		In	N/A
Al Mantara (al Manzarah)	المنظرة	Raqqad	S	Quneitra	2001	40.2	NA		In	YES
Al Raqad (Jisr al Raqqad)	الرقاد	Raqqad	S	Suweida	1991	9.2	I (700 ha), D	Polluted	In	YES
Burayqah	بريقه	Raqqad	S	Dera'a	1987	1.1	I (100 ha), D		In	YES
Ghadir al Bustan	غدير البستان	Raqqad	S	Dera'a	1987	10.8	I (6,538 ha)		In	YES
Kudnah	كودنة	Raqqad	S	Quneitra	1994	30	I (1,700 ha)		In	YES
Ruwayhaniyah	رويحنية	Raqqad	S	Quneitra	1982	1.03	I (60 ha)		In	YES
Abeedeen (Abidin)	عابدين	Raqqad	S	Dera'a	1989	5.6	I (525 ha)		In	YES
Al Butmeih	البطمية	Raqqad	G	Golan	1974	0.3		Benign/suitable for drinking	In	NO
Kheital	خيتال	Raqqad	G	Golan	1970	5		Benign/suitable for drinking	In	NO
Meitsar	ميتسار	Raqqad	G	Golan	1994	0.6		Effluent	In	NO
Merom Golan/Bental	مروم جولان	Raqqad	G	Golan	1968	4.2		Benign/suitable for drinking	In	NO
Al Asleha	الأصلحة	Thahab	S	Suweida	1968	0.04	LW	Polluted / unexploited	In	NO
Al Ghariyah al Sharqiyah	الغارية الشرقية	Thahab	S	Dera'a	1982	5	I (250 ha)	Out of service	In	YES
Al Raha	الرحي	Thahab	S	Suweida	2000	0.45	NA		In	NO
Ghadir al Suf	غدير السوف	Thahab	S	Dera'a	1968	0.16	LW		In	YES

Rasas	رساس	Thahab	S	Suweida	1964	0.03	D		In	YES
Sahwet al Blata (Al-Sahwah (Al-Balatah))	سهوة البلاطة	Thahab	S	Suweida	1979	1	I (80 ha)		In	YES
Uthman	عثمان	Thahab	S	Dera'a	1998	0.65	LW		In	YES
Al Ain	العين	Zeidi	S	Suweida	1965	1.35	D		In	YES
Al Batm (al Butm)	البطم	Zeidi	S	Dera'a	1989	2.14	I, LW	Out of service	In	YES
Al Bouwayda	البويضة	Zeidi	J	Irbid	1967	0.7	I, LW	0.1 MCM filled, rest is sediments	In	n/a
Al Muta'iyah	المتاعية	Zeidi	S	Dera'a	1967	1	LW		In	YES
Dar'a al Sharqi	درعا الشرقي	Zeidi	S	Dera'a	1970	15	I (850 ha)	Polluted	In	YES
Ghadir al Abyad	غدير الأبيض	Zeidi	J	Mafraq	1966	0.7	I, LW	0.4 MCM filled, rest is sediments	In	n/a
Hebran (Harran?)	حبران	Zeidi	S	Suweida	1980	1.95	D	Polluted	In	YES
Sahwet al Khoder (Sahwat al-Khidr)	سهوة الخضر	Zeidi	S	Suweida	1986	8.75	I (300 ha), LW		In	YES
Sama al Sarhan	سما السرحان	Zeidi	J	Mafraq	1966	1.7	I, LW	1.2 MCM filled, rest is sediments	In	n/a
Al Ghaydha	الغيضة		S	Suweida	1988	2	D		Out	
Al Mushanaf al Janoubee	المشنف جنوبي		S	Suweida	2002	0.45	D		Out	
Al Mushanaf al Shemalee	المشنف شمالي		S	Suweida	1980	1.2	D		Out	
Al Tiba	الطيبة		S	Suweida	1989	2	D		Out	

Al Zolf	الزلف		S	Suweida	1985	14	I (500 ha), LW		Out	
Jabal el Arab	جبل العرب		S	Suweida	1987	19.5	D	Polluted	Out	
Khazma	خازمة		S	Suweida	1965	0.25	D		Out	
Qaysma	قيصما		S	Suweida	1968	0.013	LW		Out	
Salkhad	صلخد		S	Suweida	1991	0.55	D		Out	
Shahba	شهبا		S	Suweida	1986	2	D		Out	

B7.2 How the storage was calculated

The volume of water retained by 21 major dams that represent 92% of the total dam storage capacity in the Yarmouk tributary basin in two periods of time – 1985-87 and 2000-16 – was calculated through a volume-area relation from Landsat satellite images (Table B 9.6) based on Liebe et al. (2005).

From Landsat images, the NIR band is extracted and used because of its sensitivity to water bodies, since it has a very low water reflectance. The dams' area is delimited using GIS tools, based on the location of the dams, acquired from literature. The spring and summer seasons are considered because the dams are supposed to be filled to their maximum capacity for the concerned year in spring (right after the winter input and before the start of irrigation demands), while in summer, they are at their minimum capacity, due to extraction for irrigation demands and evaporation losses.

The volume of water retained is calculated based on the area, the height of the dam, the maximum storage capacity, and the maximum area. The equation used for this purpose is based on Liebe et al. (2005), where the shape of the reservoir is represented by a square-based, top-down pyramid, diagonally cut in half ($V_{\text{half pyramid}} = l \times A \times d/6$), where *A* ($m^2$) is the area defined by the square of its characteristic side length *l* (m), and *d* (m) is the depth.

However, the only information available for all dams were their theoretical capacities, yearly actual storage was available only as estimations for some dams in certain years. A field visit was impossible because the area is a conflict zone, therefore the formula used by Liebe et al. (2005) was modified, and the shape of the dams in the Yarmouk was represented by a square-based top-down pyramid, and the used formula is $V = A \times D / 3$, where V is the volume of water retained (m^3), *A* is the area of the dam (m^2), and *D* is the depth of water (m).

To validate this formula, the maximum volume that could be retained by a certain number of dams has been calculated and compared to the maximum theoretical retention capacity provided in the literature. The accuracy of the results was about 80%, meaning that this method is efficient to estimate the volume of the water retained by the dams via remote sensing techniques, with the lack of field data.

Most of the dams retained for volume calculation are purposed for irrigation, therefore the amount of water used for irrigation purposes (DI) was estimated using the following formula (Table B 9.7):

$$DI = (\text{V Spring} - \text{V Summer}) - \text{ET Dam}$$

V_{Spring} is the storage of the dam in spring, estimated previously; V_{Summer} is the storage of the dam in summer, estimated previously; and ET_{Dam} is the amount of water lost by evaporation over the dam's surface, estimated from the Water Productivity Open Access Portal (FAO 2017).

B8 Water quality and pollution

The Jordan Valley Authority water-quality data from 2008 to 2016 is provided below, with the recognition that knowledge of water quality is one of the largest gaps. Measurements were taken on random days, mostly once a month, but sometimes twice a month, and at other times entire months were skipped. Different parameters were measured in two stations: JV0 ('Al Wehdeh Dam site') and JV1 ('Yarmouk – tunnel exit'). XY coordinates are not provided.

The standards to which the measurements are compared are EU standards for drinking water; and the Irrigation Water Guidelines (IWG_1) and the Irrigation Water Guidelines for South Africa (IWG_2).

Table B 8.1 Thresholds used to classify pollution as low, medium and high. *Source*: Authors, based on multiple sources listed in the text.

Parameter		Unit	Low	Medium	High
B	Boron	mg/l	< 0.5	0.5 – 1	> 1
Ca	Calcium	mg/l	< 40	40 – 120	> 120
Cl	Chloride	mg/l	< 100	100 – 140	> 140
E. coli	Escherichia coli	MPN/100 ml	< 1	1 – 1,000	> 1,000
EC	Electrical Conductivity	ppm	< 960	960 – 1,920	> 1,920
HCO_3^-	Bicarbonate	mg/l	< 120		> 120
K	Potassium	mg/l	< 5	5 – 10	> 10
Mg	Magnesium	mg/l	< 6	6 – 24	> 24
Na	Sodium	mg/l	< 70	70 – 115	> 115
NH_4^+	Ammonium	mg/l	< 0.3		> 0.3
NO_3^-	Nitrite	mg/l	< 5	5 – 30	> 30
NO_2^-	Nitrate	mg/l	< 0.5		> 0.5
pH	pH		< 6.5	6.5 – 8.4	> 8.4
SAR	Sodium Adsorption Ratio		< 2	2 – 8	> 8
SO_4^{2-}	Sulfate	mg/l	< 250		> 250
TN	Total Nitrogen	mg/l	< 5	5 – 30	> 30

Table B 8.2 JV0 – all parameters. 0: No data; 1: Low; 2: Medium; 3: High.

Year	Month	B	Ca	Cl	E. coli	EC	HCO_3^-	K	Mg	Na	NH_4^+	NO_3^-	NO_2^-	pH	SAR	SO_4^{2-}	TN
2008	Jan.	2	2	2	2	2	3	2	3	2	3	1	1	2	2	0	0
	Feb.	1	2	2	2	2	3	2	3	2	1	1	1	2	1	0	0
	Mar.	2	2	2	2	2	3	3	3	2	1	1	1	3	2	0	0
	Apr.	2	2	2	2	2	3	2	3	2	1	1	1	3	1	0	0
	May	2	2	2	2	2	3	2	3	2	3	3	1	3	2	0	0
	Jun.	1	2	3	2	2	3	3	3	3	3	1	1	3	2	0	0
	Jul.	2	1	3	2	2	1	2	3	3	1	1	1	3	2	0	0
	Aug.	1	2	2	2	2	3	2	3	2	1	1	1	2	2	0	0
	Sep.	2	2	3	2	2	3	2	3	3	1	1	1	3	2	0	0
	Oct.	1	2	3	2	2	3	2	3	3	1	1	1	3	2	0	0
	Nov.	2	2	3	2	2	3	2	3	3	1	1	1	3	2	0	0
	Dec.	2	2	3	2	2	3	2	3	2	1	1	1	2	2	0	0
2009	Jan.	2	1	2	2	2	3	2	3	2	1	1	1	2	2	0	0
	Feb.	2	1	2	3	2	3	3	3	2	1	1	1	3	2	0	0
	Mar.	1	1	2	2	2	3	3	3	3	1	1	1	3	2	0	0
	Apr.	1	1	2	2	2	3	3	3	2	1	1	1	3	2	0	0
	May	1	1	3	2	2	3	2	3	2	1	1	1	2	2	0	0
	Jun.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Jul.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Aug.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Sep.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Oct.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Year	Month	B	Ca	Cl	E. coli	EC	HCO_3^-	K	Mg	Na	NH_4^+	NO_3^-	NO_2^-	pH	SAR	SO_4^{2-}	TN
	Nov.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Dec.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2010	Jan.	1	2	3	2	2	3	2	3	3	1	1	1	2	2	0	0
	Feb.	1	2	2	2	2	3	3	3	2	1	1	1	2	2	0	0
	Mar.	1	2	3	2	2	3	3	3	2	1	1	1	3	2	0	0
	Apr.	2	2	3	2	2	1	2	2	2	1	1	1	3	2	0	0
	May	1	2	3	2	2	1	3	3	3	1	1	1	3	2	0	0
	Jun.	1	2	3	2	2	3	3	3	3	1	1	1	2	2	0	0
	Jul.	1	2	3	3	2	1	3	3	3	1	1	1	3	2	0	0
	Aug.	1	1	3	2	2	3	3	3	3	1	1	1	3	2	0	0
	Sep.	2	2	3	2	2	3	3	3	3	1	1	1	3	2	0	0
	Oct.	1	2	3	2	2	3	3	2	3	1	1	1	3	2	0	0
	Nov.	2	2	3	2	2	3	3	3	3	1	1	1	2	2	0	0
	Dec.	1	2	3	2	2	3	2	3	3	1	3	1	2	2	0	0
2011	Jan.	1	2	3	2	2	3	2	3	3	1	1	1	2	2	0	0
	Feb.	1	2	2	2	2	3	2	3	2	3	1	1	2	2	0	0
	Mar.	1	2	2	2	2	3	2	3	2	3	1	1	3	2	0	0
	Apr.	1	2	2	2	2	3	2	3	2	3	1	1	3	2	0	0
	May	1	2	2	2	2	3	2	3	2	3	1	1	3	2	0	0
	Jun.	1	1	2	2	1	1	2	3	2	3	1	1	3	2	0	0
	Jul.	1	1	2	2	1	1	2	3	2	3	1	1	3	2	0	0
	Aug.	1	1	2	2	1	1	2	3	2	3	1	1	3	2	0	0
	Sep.	2	1	3	2	2	3	3	3	3	3	1	1	3	2	0	0

Year	Month	B	Ca	Cl	E. coli	EC	HCO_3^-	K	Mg	Na	NH_4^+	NO_3^-	NO_2^-	pH	SAR	SO_4^{2-}	TN
	Oct.	1	2	3	2	2	3	3	3	3	3	1	1	2	2	0	0
	Nov.	1	2	2	2	2	3	2	3	3	3	1	1	2	2	0	0
	Dec.	1	2	3	2	2	3	2	3	2	3	1	1	2	2	0	0
2012	Jan.	1	2	3	2	2	3	2	3	3	3	1	1	2	2	0	0
	Feb.	1	2	2	2	2	3	2	3	2	3	1	1	2	2	0	0
	Mar.	1	2	2	2	2	3	2	3	2	3	1	1	3	2	0	0
	Apr.	1	2	2	2	2	3	2	3	2	3	1	1	3	2	0	0
	May	1	2	2	2	2	3	2	3	2	3	1	1	0	2	0	0
	Jun.	1	2	3	2	2	3	2	3	2	3	1	1	0	2	0	0
	Jul.	2	2	3	2	2	3	2	3	2	3	1	1	0	2	0	0
	Aug.	2	1	3	2	2	1	2	3	2	3	1	1	3	2	0	0
	Sep.	2	2	3	2	2	3	3	3	3	3	1	1	3	2	0	0
	Oct.	2	0	2	2	2	3	2	3	2	3	1	1	3	2	0	0
	Nov.	1	2	3	2	2	3	2	3	2	3	1	1	2	2	0	0
	Dec.	2	2	2	2	2	3	2	3	2	3	1	1	2	2	0	0
2013	Jan.	1	2	1	2	1	3	2	2	1	3	1	1	2	1	0	0
	Feb.	1	2	2	0	2	3	2	3	3	3	1	1	2	2	1	2
	Mar.	1	2	1	2	1	3	2	2	1	3	1	1	2	1	1	2
	Apr.	1	2	1	2	1	3	2	3	2	3	1	1	3	1	1	2
	May	1	2	1	2	1	1	2	3	2	3	1	1	3	2	1	2
	Jun.	1	1	2	2	1	1	2	3	2	3	1	1	3	2	1	2
	Jul.	1	1	2	2	1	1	2	3	2	3	1	1	3	2	1	2
	Aug.	1	1	2	2	1	1	2	3	2	3	1	1	3	2	1	2

Year	Month	B	Ca	Cl	E. coli	EC	HCO_3^-	K	Mg	Na	NH_4^+	NO_3^-	NO_2^-	pH	SAR	SO_4^{2-}	TN
	Sep.	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
	Oct.	1	2	2	2	1	3	2	3	2	3	1	1	3	2	1	2
	Nov.	1	2	2	2	1	3	2	3	2	3	1	1	3	2	1	2
	Dec.	1	2	3	2	1	3	2	3	2	3	1	1	2	2	1	2
	Jan.	1	2	2	2	1	3	2	3	2	3	1	1	2	2	1	2
	Feb.	1	2	1	2	1	3	2	3	2	3	1	1	2	2	1	2
	Mar.	2	2	2	2	1	3	2	3	2	3	1	1	3	2	1	2
	Apr.	1	2	2	2	1	3	2	3	2	3	1	1	3	2	1	2
	May	1	1	2	2	1	3	2	3	2	3	1	1	3	2	1	2
2014	Jun.	1	1	2	2	1	1	1	3	2	3	1	1	3	2	1	2
	Jul.	1	2	2	2	2	3	2	3	2	3	1	1	2	2	1	2
	Aug.	1	2	2	2	2	3	2	3	2	3	1	1	2	2	1	2
	Sep.	2	2	2	2	2	3	2	3	2	3	1	1	2	2	1	1
	Oct.	1	2	2	2	2	3	2	3	2	3	1	1	2	1	1	1
	Nov.	2	2	2	2	2	3	2	3	2	3	1	1	2	2	1	1
	Dec.	1	2	2	2	2	3	2	3	2	3	1	1	2	1	1	2
	Jan.	1	2	2	2	2	3	2	3	2	3	1	1	2	2	1	2
	Feb.	1	2	1	2	2	3	2	3	2	3	1	1	2	2	1	2
	Mar.	1	2	2	2	2	3	2	3	2	3	1	1	2	2	1	2
2015	Apr.	1	2	2	2	2	3	2	3	2	1	1	1	2	2	1	2
	May	1	2	2	2	2	3	2	3	2	1	1	1	2	2	1	2
	Jun.	1	2	2	2	2	3	2	3	2	3	1	1	2	2	1	2
	Jul.	1	2	2	2	2	3	2	3	2	1	1	1	2	2	1	2

Year	Month	B	Ca	Cl	E. coli	EC	HCO_3^-	K	Mg	Na	NH_4^+	NO_3^-	NO_2^-	pH	SAR	SO_4^{2-}	TN
	Aug.	1	2	2	2	2	3	2	3	2	3	1	1	2	1	1	2
	Sep.	1	2	2	2	2	3	3	3	2	1	1	1	2	2	1	2
	Oct.	1	2	2	2	2	3	2	3	2	1	1	1	2	2	1	2
	Nov.	1	2	2	2	2	3	2	3	2	3	1	1	2	2	1	2
	Dec.	1	2	2	2	2	3	2	3	2	1	1	1	2	2	1	2
2016	Jan.	1	2	2	2	1	3	2	3	2	1	1	1	2	2	1	2
	Feb.	1	1	2	2	1	3	2	3	2	3	1	1	3	2	1	2
	Mar.	1	2	2	2	1	3	2	3	2	1	1	1	2	2	1	2
	Apr.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	May	1	2	2	2	1	3	2	3	2	1	1	1	3	2	1	2
	Jun.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Jul.	1	1	2	2	1	3	2	2	2	1	1	1	3	2	1	2
	Aug.	1	1	2	2	1	3	2	3	2	1	1	1	3	2	1	2
	Sep.	1	1	2	2	1	3	2	3	2	1	1	1	3	2	1	2
	Oct.	1	1	2	2	1	3	2	3	2	3	1	1	3	2	1	2
	Nov.	1	1	2	2	1	3	2	3	2	1	1	1	3	2	1	2
	Dec.	1	2	2	2	1	3	2	3	1	1	1	1	3	1	1	2

Table B 8.3 JV1 - all parameters. 0: No data; 1: Low; 2: Medium; 3: High.

Year	Month	B	Ca	Cl	E. coli	EC	HCO_3^-	K	Mg	Na	NH_4^+	NO_3^-	NO_2^-	pH	SAR	SO_4^{2-}	TN
2008	Jan.	2	2	2	0	2	3	2	3	2	1	1	0	3	1	1	0
	Feb.	1	2	2	0	2	3	2	3	2	1	1	0	3	1	1	0
	Mar.	1	2	2	0	2	3	2	3	2	1	1	0	3	1	1	0
	Apr.	1	2	2	0	2	3	2	3	2	1	1	0	2	1	1	0
	May	1	2	2	0	2	3	2	3	2	1	1	0	3	2	1	0
	Jun.	1	2	2	0	2	3	3	3	2	1	1	0	2	2	1	0
	Jul.	1	2	2	0	2	3	2	3	2	1	1	0	2	2	1	0
	Aug.	1	2	2	0	2	3	2	3	2	1	1	0	2	2	1	0
	Sep.	1	2	2	0	2	3	2	3	2	1	1	0	2	1	1	0
	Oct.	1	2	2	0	2	3	2	3	2	1	1	0	2	1	1	0
	Nov.	1	2	2	0	2	3	2	3	2	1	1	0	2	1	1	0
	Dec.	2	2	2	0	2	3	2	3	2	1	1	0	3	1	1	0
2009	Jan.	2	2	2	2	2	3	2	3	2	1	1	1	3	1	1	0
	Feb.	0	0	0	0	0	0	0	0	2	1	1	0	0	0	0	0
	Mar.	1	1	2	3	2	3	2	3	2	1	1	1	3	1	1	0
	Apr.	1	1	2	2	2	3	2	3	2	1	1	1	3	2	1	0
	May	1	1	2	2	2	3	2	3	2	1	1	1	2	2	1	0
	Jun.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Jul.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Aug.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Sep.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Oct.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

	Nov.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Dec.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2010	Jan.	1	2	2	2	2	3	2	3	2	1	1	1	2	2	1	0
	Feb.	1	2	2	2	2	3	2	3	1	1	1	1	2	1	1	0
	Mar.	1	2	1	3	1	3	2	2	1	1	1	1	2	2	1	0
	Apr.	1	2	2	2	2	3	2	3	2	1	1	1	2	1	1	0
	May	1	2	2	2	2	1	2	2	2	1	1	1	0	1	1	0
	Jun.	1	2	2	1	2	3	0	3	2	1	1	1	2	1	1	0
	Jul.	1	2	2	2	2	3	2	3	2	1	1	1	2	2	1	0
	Aug.	1	2	3	3	2	3	2	3	2	1	1	1	3	2	1	0
	Sep.	1	2	3	2	2	3	2	3	2	1	1	1	2	2	1	0
	Oct.	1	2	2	2	2	3	2	3	2	1	1	1	2	2	1	0
	Nov.	1	2	2	2	2	3	2	3	2	3	1	1	2	1	1	0
	Dec.	1	2	2	2	2	3	2	3	2	1	1	1	3	1	1	0
2011	Jan.	1	2	2	2	2	3	0	3	2	1	1	1	2	1	1	0
	Feb.	1	2	2	2	1	3	0	3	1	1	1	1	3	1	0	0
	Mar.	1	2	2	2	2	3	0	3	2	1	1	1	3	2	0	0
	Apr.	1	2	2	2	2	3	0	3	2	1	1	1	2	1	0	0
	May	1	2	2	3	2	3	0	3	2	1	1	1	2	2	0	0
	Jun.	1	2	2	2	2	3	0	3	2	1	1	1	2	2	0	0
	Jul.	1	2	2	2	2	3	0	3	2	1	1	1	2	2	0	0
	Aug.	1	2	2	2	2	3	0	3	2	1	1	1	2	2	1	0
	Sep.	2	2	2	2	2	3	0	3	2	1	1	1	2	2	0	0
	Oct.	1	2	2	2	2	3	0	3	2	1	1	1	2	2	0	0

	Nov.	1	2	2	2	2	3	0	3	2	1	1	1	2	2	0	0
	Dec.	1	2	2	2	2	3	2	3	2	1	1	1	2	1	0	0
2012	Jan.	0	0	0	0	0	0	0	0	0	1	1	1	2	0	0	0
	Feb.	1	2	1	3	1	3	1	2	1	1	1	1	2	1	0	0
	Mar.	1	2	2	2	1	3	1	3	1	1	1	1	2	1	0	0
	Apr.	1	2	2	2	2	3	2	3	2	1	1	1	2	1	0	0
	May	1	2	2	2	2	3	2	3	2	1	1	1	2	1	0	0
	Jun.	1	2	2	2	2	3	2	3	2	1	1	1	0	1	0	0
	Jul.	2	2	2	2	2	3	2	3	2	1	1	1	0	2	0	0
	Aug.	2	2	3	2	2	3	2	3	2	1	1	1	2	2	1	0
	Sep.	2	2	2	2	2	3	2	3	2	3	1	1	2	2	0	0
	Oct.	1	2	2	2	2	3	2	3	2	3	1	1	3	2	0	0
	Nov.	2	2	2	2	2	3	2	3	2	1	1	1	3	1	0	0
	Dec.	1	2	2	2	2	3	2	3	2	1	1	1	2	1	0	0
2013	Jan.	1	2	1	2	1	3	1	2	1	3	1	1	2	1	0	0
	Feb.	1	2	1	2	1	3	1	3	1	1	1	1	2	1	1	2
	Mar.	1	2	2	2	2	3	2	3	1	1	1	1	2	1	1	2
	Apr.	1	2	2	2	2	3	2	3	2	3	1	1	2	1	1	2
	May	1	2	2	2	2	3	2	3	2	1	1	1	2	1	1	2
	Jun.	1	2	2	2	2	3	2	3	2	1	1	1	2	1	1	2
	Jul.	1	2	2	2	2	3	2	3	1	3	1	1	3	1	1	2
	Aug.	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Sep.	0	2	2	2	2	3	2	3	2	1	1	1	2	1	1	2
	Oct.	1	2	2	2	2	3	2	3	2	1	1	1	2	1	1	2

	Nov.	1	2	2	2	2	3	2	3	2	1	1	1	2	1	1	2
	Dec.	1	2	2	2	2	3	2	3	2	1	1	1	2	1	1	2
2014	Jan.	1	2	2	2	2	3	2	3	2	1	1	1	2	1	1	2
	Feb.	2	2	2	2	2	3	2	3	2	1	1	1	3	1	1	2
	Mar.	1	2	2	2	2	3	2	3	2	1	1	1	2	1	1	2
	Apr.	1	2	2	2	2	3	2	3	2	1	1	1	2	1	1	2
	May	2	2	2	2	2	3	2	3	2	1	1	1	2	1	1	2
	Jun.	1	2	2	2	2	3	2	3	2	1	1	1	2	1	1	2
	Jul.	1	2	2	2	2	3	2	3	2	1	1	1	2	1	1	2
	Aug.	1	2	2	2	2	3	2	3	2	1	1	1	3	2	1	2
	Sep.	2	2	2	2	2	3	2	3	2	1	1	1	2	2	1	1
	Oct.	1	2	2	3	2	3	2	3	2	1	1	1	2	1	1	1
	Nov.	1	2	2	2	2	3	2	3	2	3	1	1	2	1	1	1
	Dec.	1	2	2	2	1	3	2	3	2	1	1	1	2	1	1	1
2015	Jan.	1	2	2	2	2	3	2	3	2	1	1	1	2	1	1	2
	Feb.	1	2	2	2	2	3	2	3	2	1	1	1	2	1	1	2
	Mar.	1	2	2	3	2	3	2	3	2	3	1	1	2	1	1	2
	Apr.	1	2	2	2	2	3	2	3	2	1	1	1	2	2	1	2
	May	1	2	2	2	2	3	2	3	2	1	1	1	2	2	1	2
	Jun.	1	2	2	2	2	3	2	3	2	1	1	1	2	2	1	2
	Jul.	1	2	3	3	2	3	2	3	2	1	1	1	2	2	1	2
	Aug.	1	2	2	2	2	3	3	3	2	3	1	1	2	1	1	2
	Sep.	1	2	2	2	2	3	2	3	2	3	1	1	2	2	1	2
	Oct.	1	2	2	3	2	3	2	3	2	1	1	1	2	2	1	2

	Nov.	1	2	3	2	2	3	2	3	2	1	1	1	2	2	1	2
	Dec.	1	2	2	2	2	3	2	3	2	1	1	1	2	2	1	2
2016	Jan.	1	2	2	2	2	3	2	3	2	1	1	1	2	2	1	2
	Feb.	1	2	2	2	2	3	2	3	2	1	1	1	2	2	1	2
	Mar.	1	2	2	3	1	1	2	2	2	3	1	1	2	1	1	2
	Apr.	2	2	2	3	2	3	2	3	2	1	1	1	2	2	1	2
	May	1	2	2	2	2	3	2	0	2	1	1	1	2	2	1	1
	Jun.	1	2	2	2	2	3	2	3	2	1	1	1	2	2	1	2
	Jul.	1	2	1	2	2	3	2	3	2	1	1	1	2	2	1	2
	Aug.	1	2	2	3	2	3	2	3	2	1	1	1	2	2	1	2
	Sep.	1	2	2	3	2	3	2	3	2	1	1	1	2	2	1	2
	Oct.	1	2	2	2	2	3	2	3	2	1	1	1	2	2	1	2
	Nov.	1	2	2	2	2	3	1	3	2	1	1	1	2	2	1	2
	Dec.	1	2	2	2	2	3	2	3	2	1	1	1	2	2	1	2

B9 Supplemental data

This section provides supplemental tables, charts and maps compiled by the authors from the numerous sources indicated.

Figure B 9.1 Difference between the hydrological basin (used in this study) and (Syrian) administrative basins. *Source*: Authors, based on multiple sources listed in the text.

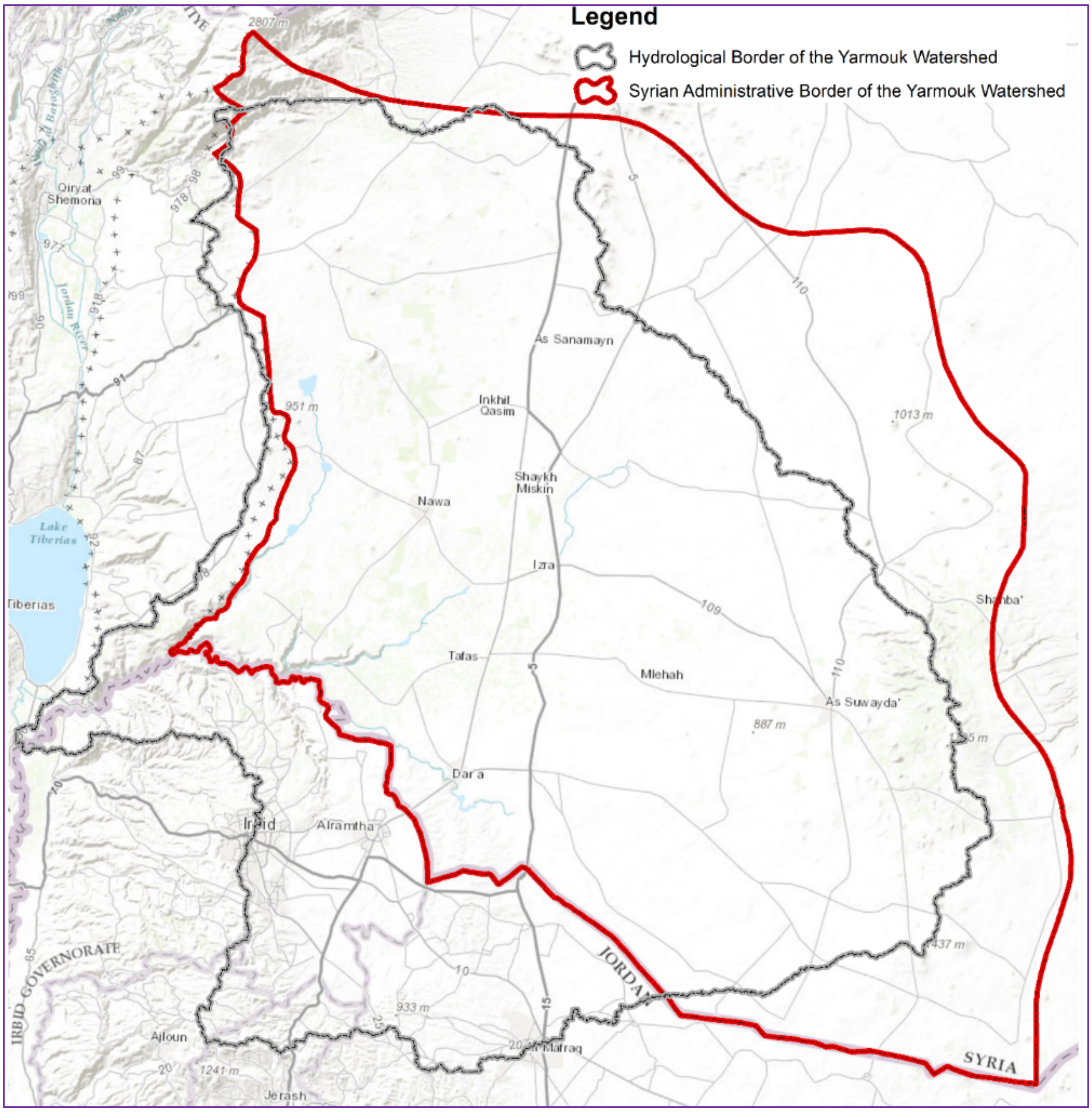


Table B 9.1 Compilation of estimates or measurements of the area of the Yarmouk tributary basin.

	Surface of basin (km²)				
Reference	**Total**	**Syria**	**Jordan**	**Golan**	**Israel**
(Ionides, 1939)	7,250		1,410		
(Burdon, 1954)	7,584				
(Baker and Harza, 1955)	6,800	5,000	1,800		
(Energoprojekt, 1964)	6,790				
(Swarieh and Sahawneh, 1998)	6,790				
(Al-Droubee, 2000)		5,700			
(Abu-Rukah and Ghrefat, 2001)	6,790				
(Agha and Deeb, 2005)	6,721	5,367			
(Al-Husein, 2007)	6,944	5,387	1,507		50
(Al-Ghraibeh, 2008)	6,700		1,514		
(Hammouri 2009)	6,790				
(Awawdeh, 2010)	7,242		1,424		
(Orient, 2010)	6,721				
(Orient, 2011)	6,717		1,402		
(Comair et al., 2012)	6,975				
(Husein, 2012)	6,724				
(Al Manaseer, 2012)	8,378	5,367	2,217		794
(Mourad and Berndtsson, 2012)		5,764			
(UN-ESCWA/BGR, 2013)	6,968	5,365 (77%)	1,533 (22%)		70 (1%)
(Etana, 2015)	7,584				
(Alhusban, 2016)	6,790				
(Al Qusaym, 2016)	6,944	5,387	1,507	1,150	
(Al-Fares 2016)	6,730		1,000		
(Hoff, n.d.)	6,721				

Table B 9.2 Compilation of different lengths of the Yarmouk tributary from the literature.

	Length of river (km)			
Reference	**Total**	**Syria**	**Jordan**	**Israel**
(Agha and Deeb, 2005)	60	45		
(Al-Hmoud, 2012)	80			
(Al Manaseer, 2012)	40	23	14	3
(UN-ESCWA/BGR, 2013)	143			
(Etana, 2015)	57	47	10	

Figure B 9.2 Population growth in the Syrian part of the Yarmouk tributary basin. Source: Authors' compilation based on Atlas Gildas and CBS data.

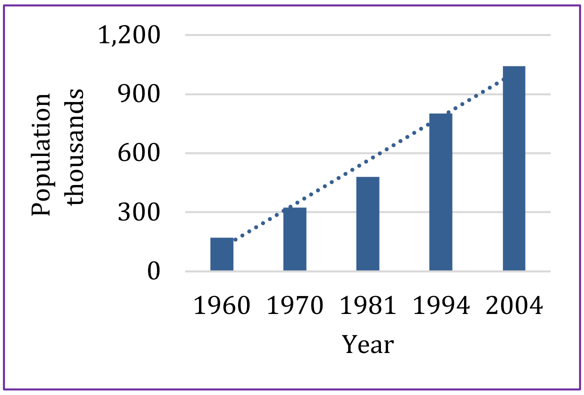


Figure B 9.3 Population growth in the Jordanian part of the Yarmouk tributary basin. Source: Authors' compilation based on DOS 2004 and 2015 censuses.

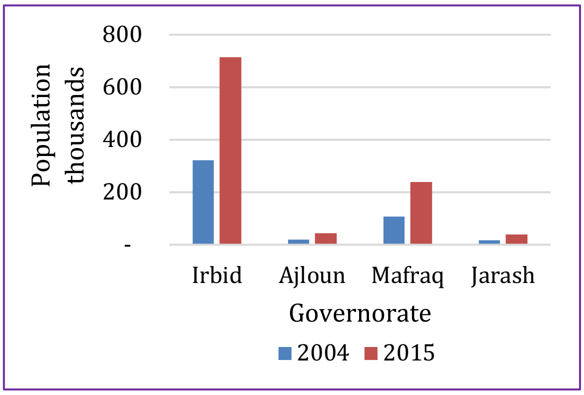


Figure B 9.4 Syrian refugees in Irbid. Source: UNHCR, 2017.

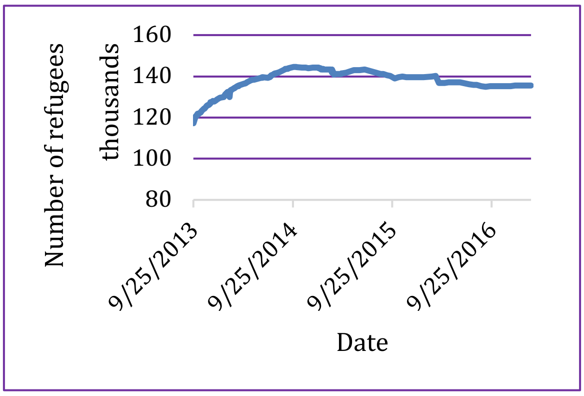


Figure B 9.5 Syrian refugees in Mafraq. Source: UNHCR, 2017.

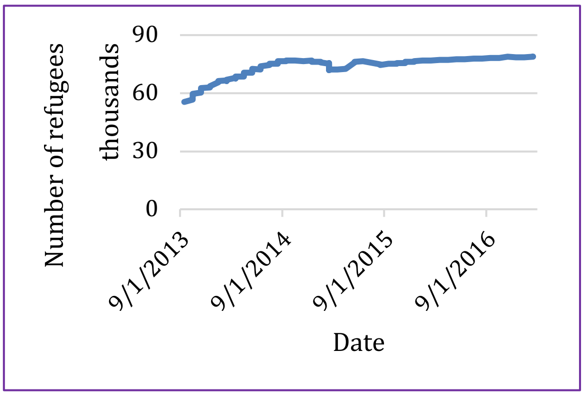


Table B 9.3 List of Landsat 5 and 8 bands employed. *Source*: Authors, based on multiple sources listed in the text.

Landsat 5		**Landsat 8**	
Band 1	Blue	**Band 1**	Ultra-blue (coastal/aerosol)
Band 2	Green	**Band 2**	Blue
Band 3	Red	**Band 3**	Green
Band 4	Near Infrared (NIR)	**Band 4**	Red
Band 5	Shortwave Infrared (SWIR) 1	**Band 5**	Near Infrared (NIR)
Band 6	Thermal	**Band 6**	Shortwave Infrared (SWIR) 1
Band 7	Shortwave Infrared (SWIR) 2	**Band 7**	Shortwave Infrared (SWIR) 2
		Band 8	Panchromatic
		Band 9	Cirrus
		Band 10	Thermal Infrared (TIRS) 1
		Band 11	Thermal Infrared (TIRS) 2

Table B 9.4 List of Landsat images used for climate characteristics analysis. *Source*: Authors, based on multiple sources listed in the text.

Year	Entity Identification	Acquisition Date	Year	Entity Identification	Acquisition Date
1985	LT51740371985060AAA03	1985/03/01	**2014**	LC81740372014092LGN00	2014/04/02
	LT51740381985060AAA03	1985/03/01		LC81740382014092LGN00	2014/04/02
	LT51730371985085XXX04	1985/03/26		LC81730372014101LGN00	2014/04/11
	LT51730381985085XXX04	1985/03/26		LC81730382014101LGN00	2014/04/11
1986	LT51740381986095XXX01	1986/04/05	**2015**	LC81740382015095LGN00	2015/04/05
	LT51740371986095XXX01	1986/04/05		LC81740372015095LGN00	2015/04/05
	LT51730371986136XXX03	1986/05/16		LC81730372015120LGN00	2015/04/30
	LT51730381986136XXX01	1986/05/16		LC81730382015120LGN00	2015/04/30
1987	LT51730371987091AAA02	1987/04/01	**2016**	LC81740382016098LGN00	2016/04/07
	LT51730381987091AAA02	1987/04/01		LC81740372016098LGN00	2016/04/07
	LT51740381987098AAA02	1987/04/08		LC81730382016107LGN00	2016/04/16
	LT51740371987098AAA02	1987/04/08		LC81730372016107LGN00	2016/04/16

Figure B 9.6 NDVI in the Yarmouk tributary basin for studied periods. *Source*: Authors, based on multiple sources listed in the text.

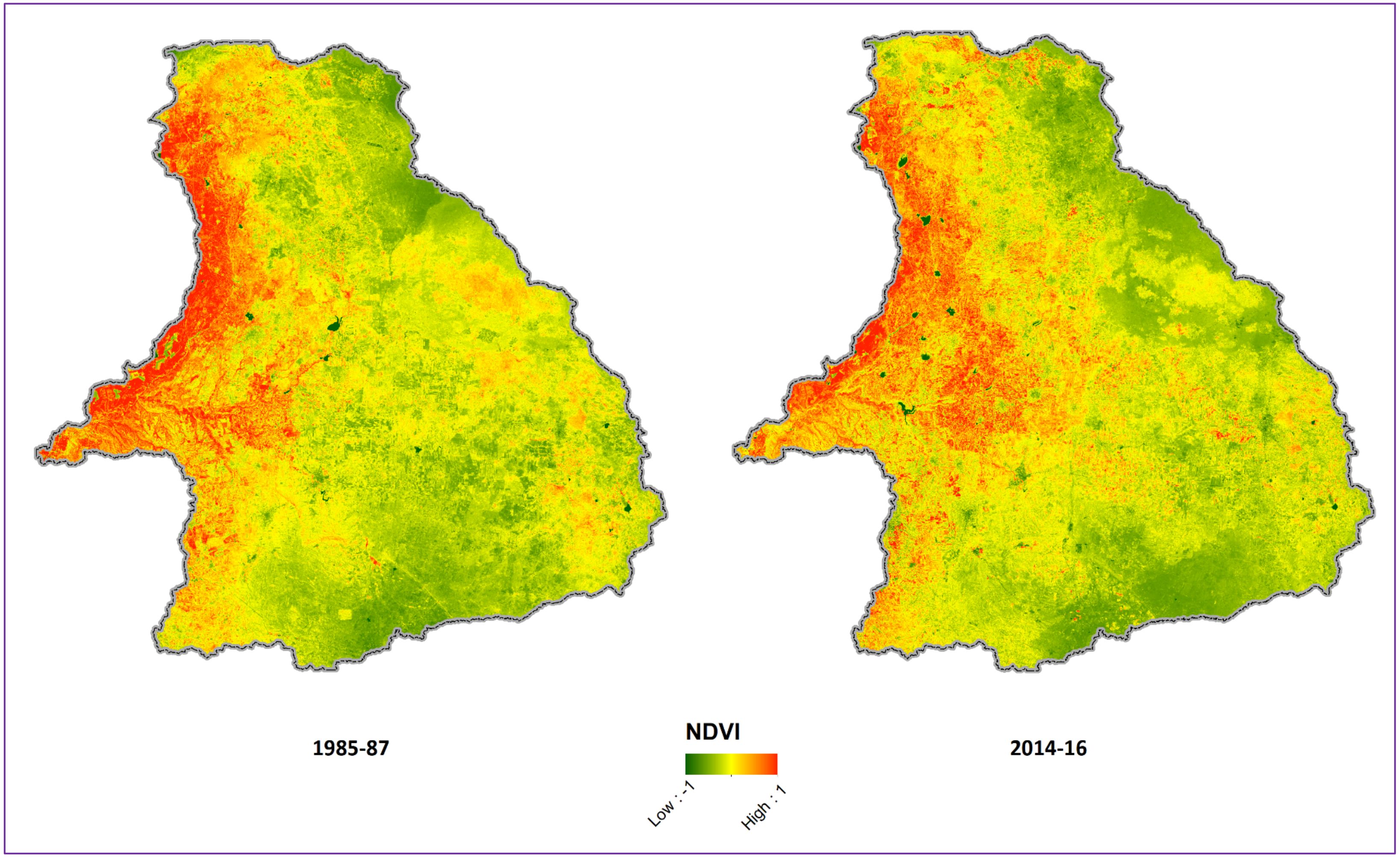


Figure B 9.7 Intra-annual ET_0 values across the Yarmouk tributary basin. *Source*: Authors, based on multiple sources listed in the text.

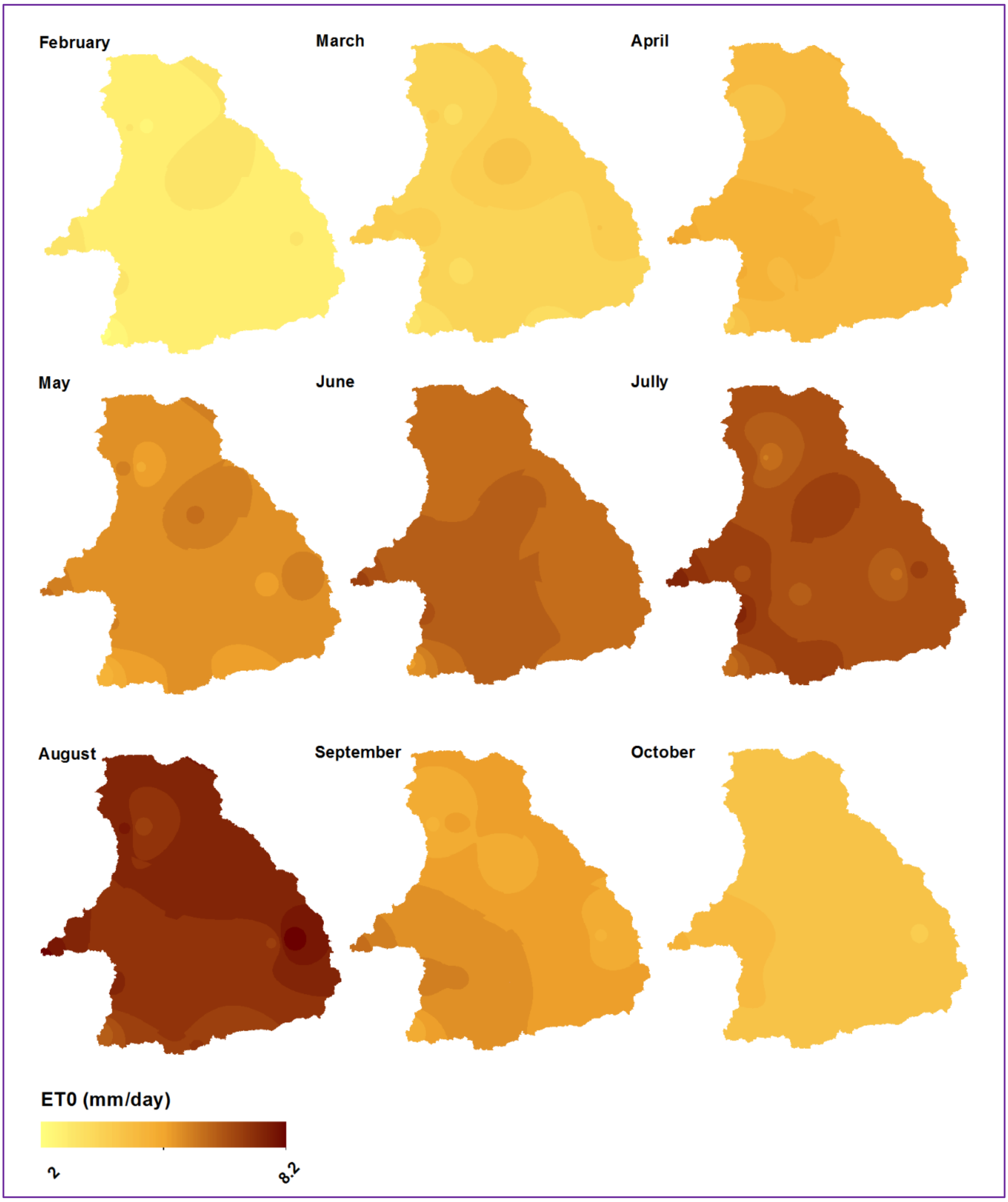


Table B 9.5 Drought classification per SPI. *Source*: Authors, based on multiple sources listed in the text.

St: stations, EW: Extremely Wet; VW: Very Wet; MW: Moderately Wet; N: Normal; MD: Moderately Dry; SD: Severely Dry; ED: Extremely Dry.

	3 Months									12 Months								
	St	EW	VW	MW	N	MD	SD	ED	Class	St	EW	VW	MW	N	MD	SD	ED	Class
1958	7				2			5	ED									
1959	9				9				N	7				3	3	1		SD
1960	9				6	3			MD	9					3	6		
1961	9				5	4				9				7	2			
1962	9				6	2	1			9				9				N
1963	9				9				N	9				9				
1964	9				9					9				9				
1965	10				8	2			MD	10				10				
1966	14				12	2				10				10				
1967	14				12	2				14				14				
1968	14				5	5	4		SD	14				12	1	1		
1969	14				11	3			MD	14				14				
1970	14				11	3				14				12	2			
1971	14			1	12	1			N	14				14				
1972	16				15		1			14				13	1			
1973	18				10	8			MD	16				12	4			MD
1974	18				18				N	18				18				N
1975	19				18	1				18				15	3			
1976	19				19					19				15	3			
1977	19				19					19				15	3			
1978	19				14	5			MD	19				17	2			
1979	21				11	6	3	1	ED	19				5	2	12		SD
1980	21				21				N	21				21				N
1981	21				17	4				21				20	1			
1982	21				20	1				21				14	7			MD
1983	21				21					21				21				N
1984	21				21					21				20	1			
1985	21				19	2				21				19	2			
1986	21				19	2				21				9	11	1		MD
1987	21				19	2				21				21				N
1988	21				18	1	1	1		21				19	1	1		
1989	21				2	5	4	10	ED	21				9	11			MD
1990	21				19	2			N	21				18	3			N
1991	21			1	17	3				21				19	2			
1992	21		1	2	16	2			VW	21		1	4	16				MW
1993	20				11	6	1	2	ED	20			1	19				N

1994	19				17	2			N	19				16	2	1		
1995	19				16	3				19				19				
1996	18				15	2		1		18				15	3			
1997	18				18					18				16	2			
1998	18				16		2			18				17	1			
1999	18				5	6	7		SD	18				4	4	9		SD
2000	18				11	6	1			18				12	3	3		
2001	18				10	6	2			18				12	4	2		
2002	15				15				N	15				13	2			MD
2003	15		1	2	7	2	1	1		15				12	2		1	
2004	13				9	3	1		SD	13				10	3			
2005	12				11	1			N	12				10	2			N
2006	11				10	1				11				10	1			
2007	10				8	1		1	ED	10				8	2			MD
2008	10				2	3	3	2		10				3	5	2		SD
2009	7				7				N	7				6	1			N
2010	5				3	1		1	ED	5				4	1			MD

Figure B 9.8 Salinity in the Basalt and A7/B2 Aquifers. TDS = Total Dissolved Solids. *Source*: Authors, based on multiple sources listed in the text.

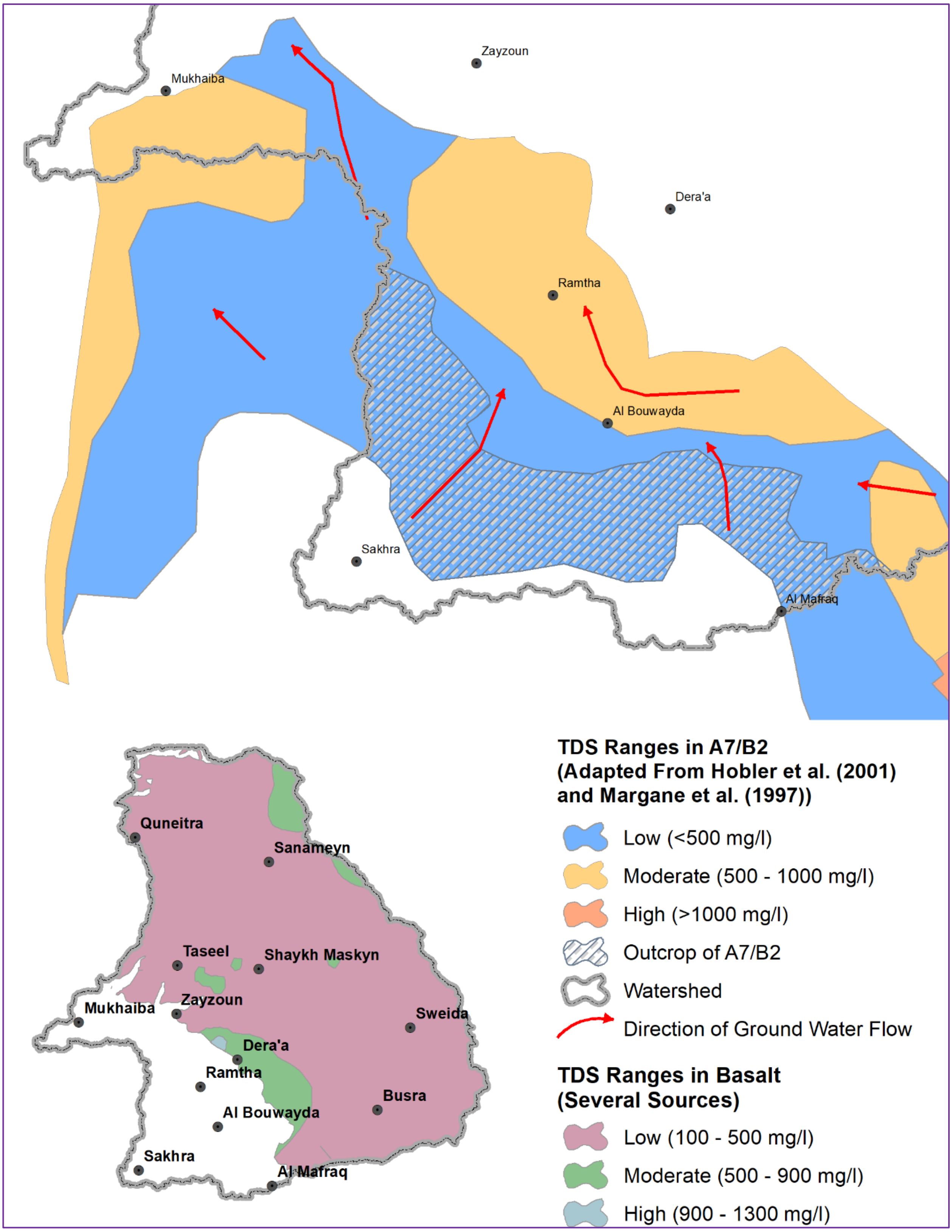


Figure B 9.9 Groundwater depth and Effective Thickness of the Basalt Aquifer in Syria. *Source*: Authors, based on multiple sources listed in the text.

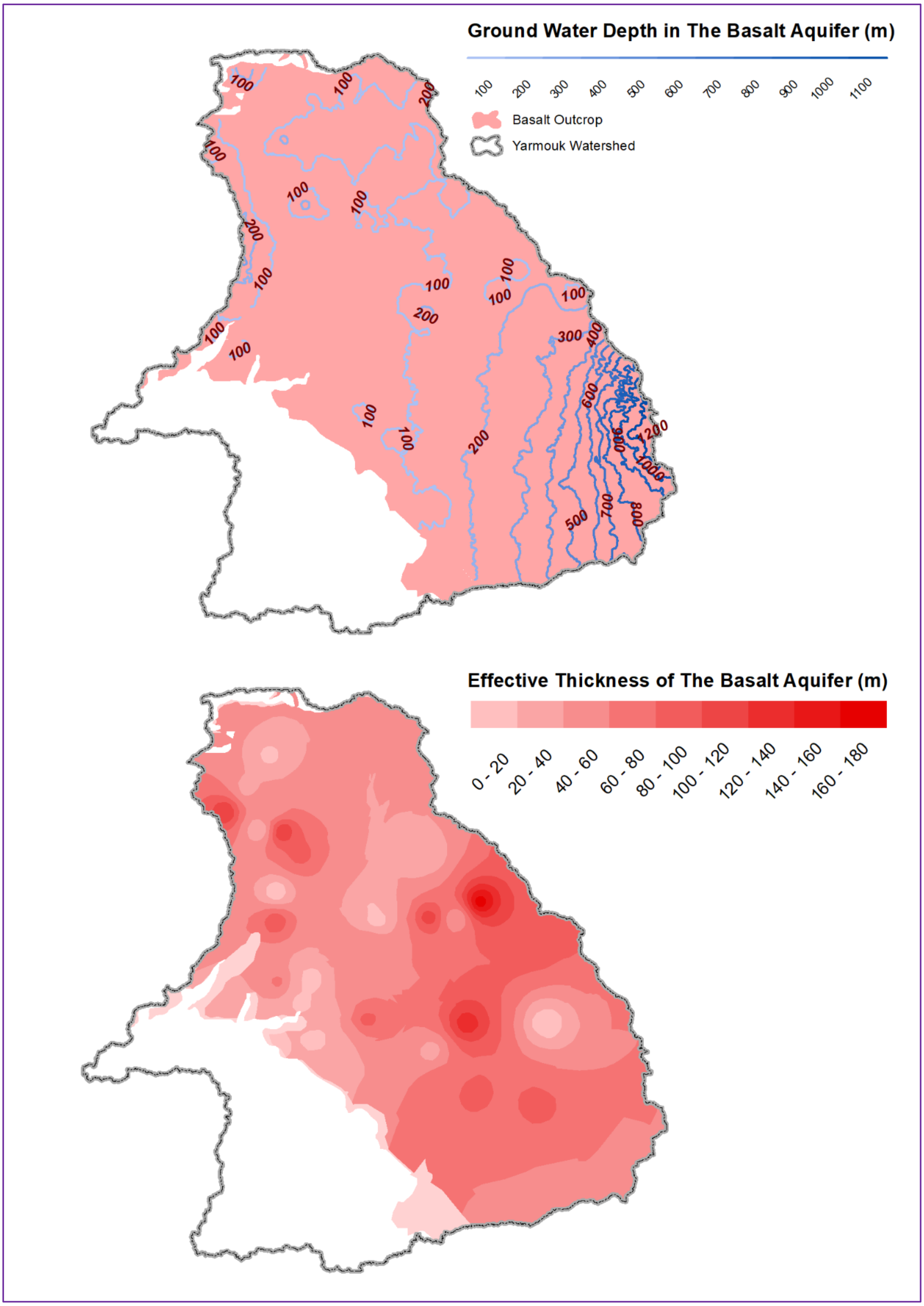


Figure B 9.10 Estimation of the age of groundwater in the Basalt Aquifer. *Source*: Authors, based on multiple sources listed in the text.

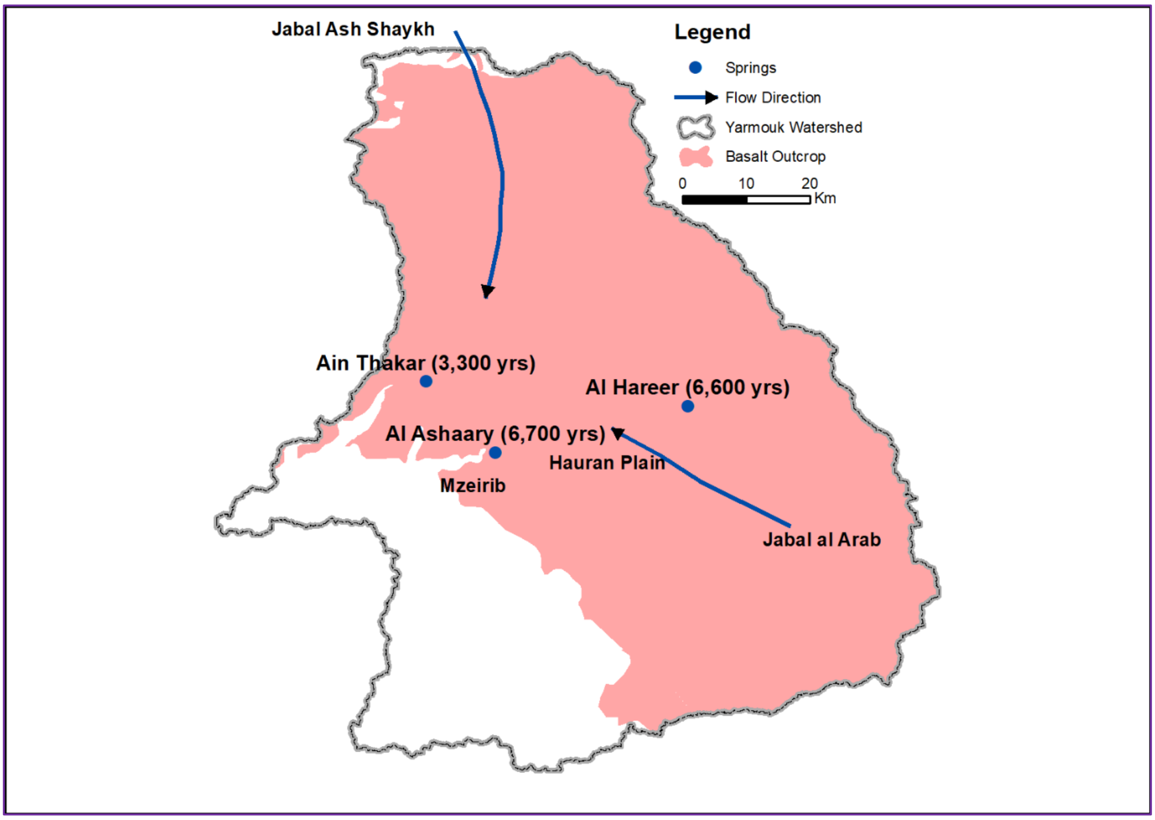


Table B 9.6 List of Landsat images used for calculation of volume retention of dams. *Source*: Authors, based on multiple sources listed in the text.

Image name	Landsat	Year	Month	Day
n_land851	L4	1985	April	
LT51740371985204AAA08_B41	L5	1985	July	23
n_land861	L4	1986	April	
LT51740371986255XXX01_B41	L5	1986	September	12
n_land871	L4	1987	April	
LT51740371987194XXX02_B41	L5	1987	July	13
LT51740371998096AAA03_B41	L5	1998	April	6
LT51740371999115AAA03_B41	L5	1999	April	25
LE71740372000094SGS02_B41	L7	2000	April	4
L5174037_03720001004_B40	L5	2000	October	4
LE71740372001112FUI00_B41	L7	2001	November	12
LE71740372002099SGS00_B41	L7	2002	April	9
L71174037_03720021018_B401	L7	2002	October	18
LE71740372003118ASN00_B41	L7	2003	April	28
L5174037_03720031013_B40	L5	2003	October	13
LE71740372004105ASN01_B41	L7	2004	April	15
L71174037_03720060607_B401	L7	2006	June	7
LE71740372008100ASN00_B41	L7	2008	April	10
L71174037_03720080714_B401	L7	2008	July	14
L71174037_03720091106_B401	L7	2009	November	6
L71174037_03720101109_B401	L7	2010	November	9
LE71740372011284ASN00_B41	L7	2011	October	11
LE71740372012095ASN00_B41	L7	2012	April	5
LE71740372012287ASN00_B41	L7	2012	October	14
LC81740372013080LGN01_B41	L8	2013	March	21
LC81740372014108LGN00_B41	L8	2014	April	18
LC81740372014236LGN00_B41	L8	2014	August	24
LC81740372015111LGN00_B41	L8	2015	April	21
LC81740372015239LGN00_B41	L8	2015	August	27
LC81740372016114LGN00_B41	L8	2016	April	24
LC81740372016242LGN00_B41	L8	2016	August	30

Table B 9.7 Volume of water used for irrigation from dams. *Source*: Authors, based on multiple sources listed in the text.

Dam	V Spring	V Summer	Total losses	Losses by ET	Water used for irrigation
			1985		
Abeedeen	0.00	0.00	0.00	0.00	0.00
Abta' al Kabeer	3.58	2.94	0.64	0.64	0.00
Adwan	0.11	0.05	0.06	0.02	0.04
Al ‘Allan	0.04	0.01	0.03	0.01	0.03
Al Bouwayda	1.62	0.01	1.61	0.03	1.57
Al Ghariyah al Sharqiyah	0.70	0.28	0.42	0.27	0.15
Al Sheikh Maskin	15.09	13.32	1.76	1.76	0.00
Der'a al Sharqi	9.98	7.94	2.04	0.87	1.17
Ghadir al Abyad	1.15	0.13	1.02	0.27	0.74
Ghadir al Bustan	0.93	0.22	0.72	0.23	0.49
Gharbi Tafs	1.92	1.41	0.50	0.45	0.06
Kudnah	0.00	0.00	0.00	0.00	0.00
Saham al Golan	0.00	0.00	0.00	0.00	0.00
Sama al Sarhan	1.70	0.83	0.87	0.21	0.66
Taseel	6.63	6.15	0.48	0.48	0.00
Total	**44.38**	**33.34**	**11.04**	**5.25**	**5.78**
			1986		
Abeedeen	0.00	0.00	0.00	0.00	0.00
Abta' al Kabeer	0.92	0.57	0.35	0.22	0.14
Adwan	0.09	0.07	0.02	0.02	0.00
Al Bouwayda	0.35	0.04	0.31	0.01	0.30
Al Ghariyah al Sharqiyah	0.16	0.09	0.06	0.06	0.00
Al Sheikh Maskin	11.59	7.85	3.74	2.23	1.51
Der'a al Sharqi	3.17	1.33	1.84	0.33	1.51
Ghadir al Abyad	0.04	0.01	0.04	0.01	0.02
Ghadir al Bustan	0.05	0.05	0.00	0.00	0.00
Gharbi Tafs	1.04	0.69	0.36	0.20	0.16
Kudnah	0.00	0.00	0.00	0.00	0.00
Saham al Golan	0.00	0.00	0.00	0.00	0.00
Sama al Sarhan	1.70	0.04	1.66	0.00	1.66
Taseel	5.89	4.52	1.37	1.37	0.00
Total	**25.01**	**15.26**	**9.75**	**4.65**	**5.10**
			1987		
Abeedeen	0.00	0.00	0.00	0.00	0.00

Dam	V Spring	V Summer	Total losses	Losses by ET	Water used for irrigation
Abta' al Kabeer	3.56	2.16	1.40	0.83	0.57
Adwan	3.25	2.64	0.60	0.60	0.00
Al Bouwayda	1.18	0.96	0.22	0.05	0.17
Al Ghariyah al Sharqiyah	1.76	0.42	1.35	0.60	0.75
Al Sheikh Maskin	14.94	13.44	1.51	1.51	0.00
‘Allan-Al Ghar	0.00	0.00	0.00	0.00	0.00
Der'a al Sharqi	9.50	4.85	4.65	0.70	3.95
Ghadir al Abyad	0.54	0.13	0.41	0.14	0.27
Ghadir al Bustan	8.52	7.60	0.93	0.93	0.00
Gharbi Tafs	2.47	1.72	0.75	0.48	0.27
Kudnah	0.00	0.00	0.00	0.00	0.00
Saham al Golan	0.00	0.00	0.00	0.00	0.00
Sama al Sarhan	1.70	0.08	1.62	0.10	1.52
Taseel	6.63	5.53	1.10	1.10	0.00
Total	**54.05**	**39.51**	**14.54**	**7.14**	**7.40**
2009					
Abeedeen	0.33	0.29	0.05	0.04	0.00
Abta'a al Kabeer	1.40	1.40	0.00	0.00	0.00
Adwan	4.57	0.77	3.81	0.90	2.91
Al ‘Allan	4.59	1.68	2.91	0.89	2.02
Al Bouwayda	0.40	0.27	0.14	0.01	0.12
Al Ghariyah al Sharqiyah	0.34	0.04	0.30	0.10	0.21
Al Mantara	21.13	19.75	1.38	0.83	0.55
Al Sheikh Maskin	2.57	0.35	2.21	0.30	1.92
Wehdeh	20.50	14.73	5.77	1.14	4.63
Dera'a al Sharqi	12.27	7.21	5.05	1.05	4.00
Ghadir al Abyad	0.87	0.05	0.82	0.19	0.63
Ghadir al Bustan	0.51	0.51	0.00	0.00	0.00
Gharbi Tafs	2.35	0.90	1.45	0.38	1.07
Hebran	2.04	1.38	0.66	0.14	0.52
Kudnah	5.02	4.97	0.05	0.05	0.00
Qanawat	0.59	0.10	0.49	0.04	0.45
Saham al Golan	1.62	0.10	1.53	0.12	1.41
Sama al Sarhan	1.05	0.68	0.37	0.03	0.34
Taseel	5.89	1.23	4.66	0.99	3.67
Total	**88.05**	**56.39**	**31.66**	**8.33**	**23.33**
2014					

Dam	V Spring	V Summer	Total losses	Losses by ET	Water used for irrigation
Abeedeen	0.35	0.05	0.31	0.05	0.26
Abta' al Kabeer	0.49	0.61	-0.12	0.00	0.00
Adwan	0.29	0.03	0.26	0.04	0.22
Al ‘Allan	1.76	1.00	0.76	0.34	0.42
Al Bouwayda	0.33	0.33	0.00	0.00	0.00
Al Ghariyah al Sharqiyah	0.00	0.00	0.00	0.00	0.00
Al Mantara	15.96	13.47	2.49	1.39	1.11
Al Sheikh Maskin	1.40	1.31	0.09	0.09	0.00
Wehdeh	65.88	60.13	5.75	1.00	4.75
Der'a al Sharqi	2.90	2.20	0.70	0.37	0.33
Ghadir al Abyad	0.08	0.00	0.08	0.00	0.08
Ghadir al Bustan	4.76	1.61	3.15	0.48	2.67
Gharbi Tafs	0.57	0.15	0.42	0.08	0.33
Hebran	0.80	0.80	0.00	0.00	0.00
Kudnah	21.93	12.05	9.88	1.84	8.03
Qanawat	0.07	0.03	0.04	0.01	0.04
Saham al Golan	10.07	1.05	9.02	0.77	8.24
Sama al Sarhan	0.54	0.08	0.46	0.00	0.46
Taseel	5.80	2.50	3.30	1.52	1.78
Total	**133.99**	**97.40**	**36.59**	**7.98**	**28.61**
2015					
Abeedeen	2.60	0.04	2.56	0.35	2.21
Abta' al Kabeer	0.75	0.02	0.73	0.11	0.62
Adwan	0.67	0.01	0.66	0.09	0.57
Al ‘Allan	2.04	1.00	1.04	0.38	0.66
Al Bouwayda	0.10	0.03	0.07	0.00	0.07
Al Mantara	19.23	14.79	4.44	1.60	2.84
Al Sheikh Maskin	1.23	2.09	-0.85	0.00	0.00
Wehdeh	85.65	78.23	7.42	3.12	4.30
Der'a al Sharqi	3.30	1.00	2.30	0.32	1.98
Ghadir al Bustan	6.75	2.77	3.98	0.71	3.27
Gharbi Tafs	1.11	0.02	1.09	0.13	0.96
Kudnah	19.20	5.68	13.52	1.35	12.17
Qanawat	0.05	0.05	0.00	0.00	0.00
Saham al Golan	2.30	0.07	2.23	0.19	2.04
Taseel	6.49	2.72	3.77	1.53	2.24
Total	**151.48**	**108.52**	**42.97**	**9.88**	**33.08**

Dam	V Spring	V Summer	Total losses	Losses by ET	Water used for irrigation
2016					
Adwan	0.26	0.25	0.01	0.01	0.00
Al ‘Allan	0.00	0.00	0.00	0.00	0.00
Al Bouwayda	0.43	0.17	0.26	0.01	0.24
Al Mantara	13.42	8.21	5.21	1.02	4.19
Al Sheikh Maskin	0.12	0.01	0.11	0.02	0.10
Wehdeh	71.72	64.24	7.48	0.22	7.26
Ghadir al Bustan	4.50	1.54	2.96	0.00	2.96
Gharbi Tafs	0.47	0.42	0.05	0.05	0.00
Hebran	0.60	0.57	0.03	0.03	0.00
Kudnah	2.83	2.60	0.23	0.23	0.00
Qanawat	0.05	0.02	0.03	0.00	0.02
Taseel	3.48	0.01	3.47	0.00	3.47
Total	**97.89**	**78.05**	**19.84**	**1.60**	**18.24**

Table B 9.8 Compilation of published data on water budgets in the Syrian part of the Yarmouk tributary basin.

SW: Surface Water; GW: Ground water; Av.: Available water resources; UWR: Unconventional water resources; TWR: Total water resources; Ev. SW: Evaporation demands from Surface Water; AD: Agricultural demand; IDD: Industrial and Domestic Demand; TWR: Total Water Requirements.

Reference	Resources (MCM)					Demands (MCM)				Balance (MCM)
	SW	GW	Av.	UWR	TWR	Ev. SW	AD	IDD	TWR	
(Youmans, 2016)					337				405	-68
(Al Qusaym, 2016)	180	267	380	104	484	31	400	96	527	-43
(CPC, 2017)	90	195	267	87	354	20	253	153	426	-72
(Hoff, n.d.)	180	267			447	31	329	106	527	-43
(Issa 2013)			359	88	443				466	-23
(Meselmanee 2008)			355	95	450	31	329	91	452	-2
(Mourad and Berndtsson, 2012)	24	170		82	276		205	150	355	-79
(Salman, *et al.*)					500		360	80	440	-60
(Varela-Ortega, *et al.* 2001)	88	131	186	86	272	31	360	87	478	-206

Table B 9.9 Morphometric characteristics of the main tributaries of the Yarmouk mainstream. *Source*: Authors, based on multiple sources listed in the text.

LT: Length of tributary; Pn: Path n; A: Area of sub-basin; SG: Slope Gradient; LS: total length of the streams; P: Perimeter; NS: Number of streams; Dd: Degree of development; KG: Gravelius shape index

Tributary/Sub-basin	LT (km)	A (km^2)	LS (km)	P (km)	NS	Dd (km/km^2)	KG
Al ‘Allan	98.67	310	323.73	178.26	213	1.04	2.83
Hareer or Arram	Path 1: 173.80	3,021	2947.8	492.48	2344	0.78	2.51
	Path 2: 144.08						
	Path 3: 105.52						
Yarmouk Mainstream	51.13	351	311.2	185.58	267	0.76	2.77
Raqqad	93.77	549	559.16	250.2	438	0.80	2.99
Shallala	94.32	449	419.64	182.52	315	0.70	2.41
Thahab	Path 1: 123.52	721	729.6	256.62	514	0.71	2.68
	Path 2: 123.28						
Zeidi	Path 1: 95.45	1,982	1933.32	415.74	1686	0.85	2.61
	Path 2: 143.74						
	Path 3: 97.10						
All Yarmouk (Total)		7,385	7224.48	708.84	4,790	0.65	2.31

Table B 9.10 Drainage network properties for the Yarmouk tributary and its sub-basins. *Source*: Authors, based on multiple sources listed in the text.

SN: Stream Number; SL: Stream Length; BR: Bifurcation Ratio.

Order	**1**			**2**			**3**			**4**			**5**			**6**			**7**		
Characteristics	**SN**	**SL**	**BR**	**SN**	**SL**	**BR**	**SN**	**SL**	**BR**	**SN**	**SL**	**BR**	**SN**	**SL**	**BR**	**SN**	**SL**	**BR**	**SN**	**SL**	**BR**
Al ‘Allan	110	144	0.4	45	78	0.6	26	38	1.1	29	58	0.1	3	5							
Hareer	113.7	1415	0.6	671	764	0.4	265	375	0.7	186	270	0.3	55	68		30	56				
Yarmouk Mainstream	139	142	0.5	64	100	0.2	14	17	0.0				2	0	1.5	3	2	15.0	45	49	
Raqqad	230	284	0.4	99	155	0.5	51	53	0.4	19	24	2.1	39	44							
Shallala	168	171	0.5	78	140	0.4	34	54	0.4	14	29	1.4	19	26		2	1				
Thahab	281	328	0.4	112	215	0.6	66	111	0.3	18	29	2.1	37	47							
Zeidi	882	879	0.4	368	491	0.6	232	318	0.5	114	130	0.4	41	54		49	61				
Total	2947	3363	0.5	1437	1943	0.5	688	967	0.6	380	539	0.5	196	243	0.4	84	120	0.5	45	49	

Table B 9.11 CHIRPS and bias correction of ground gauges. *Source*: Authors, based on multiple sources listed in the text.

Station	Station Name	Country	N	RMSE (mm)	MAE (mm)	ME (mm)	BIAS (%)	Remark
AD0019	Mafraq Airport	Jordan	22	32	27	-2	-1	Good Fit
AD0413	Mseifrah	Syria	22	42	50	-25	-10	Good Fit
AD0414	Busra Al Sham	Syria	23	45	48	-23	-10	Good Fit
AD0412	Dera'a	Syria	23	47	49	25	10	Good Fit
AD0005	Umm Qais	Jordan	21	55	49	15	4	Good Fit
AD0403	Sanameyn	Syria	22	56	62	32	13	Good Fit
AD0013	Khanasiri	Jordan	23	58	53	52	29	Good Fit
AD0003	Kufr Saum	Jordan	22	59	52	-19	-4	Moderate Fit
AD0002	Hartha	Jordan	22	62	57	7	2	Moderate Fit
AD0409	Al Suweida	Syria	22	65	86	-61	-19	Moderate Fit
AD0010	Husun	Jordan	22	68	59	36	10	Moderate Fit
AD0012	Ramtha Boys School	Jordan	22	71	62	56	22	Moderate Fit
AD0400	Izra'	Syria	21	74	63	26	10	Moderate Fit
AE0001	Irbid Met.	Jordan	23	79	65	49	11	Poor Fit
AD0401	Nawa	Syria	23	80	64	-47	-13	Poor Fit
AD0008	Kharja	Jordan	24	81	71	-13	-3	Poor Fit
AD0009	Hawwara	Jordan	25	82	71	51	14	Poor Fit
AD0023	Jaber Mughayyir	Jordan	28	100	89	84	63	Ex of inaccurate gauge data
AD0022	Hosha	Jordan	26	110	107	107	72	Poor Fit
AD0011	En Nueiyime	Jordan	25	113	106	106	37	Poor Fit
F-S1	Salkhad	Syria	24	114	92	-83	-26	Poor Fit

AD0018	Ibbin	Jordan	23	124	100	38	11	Very Poor Fit
AD0405	Shahba	Syria	22	130	143	-123	-31	Very Poor Fit
AD0021	Turra	Jordan	27	131	112	44	17	Very Poor Fit
AD0408	Tell Shehab	Syria	24	134	126	8	2	Very Poor Fit
AL0050	Qafqafa	Jordan	26	174	150	-149	-47	Very Poor Fit
AL0059	Umm el Jum	Jordan	27	205	201	201	181	Ex of inaccurate gauge data
AH0003	Ras Muneef	Jordan	27	214	158	-148	-27	Ex of underestimation of the 1992 rainfall

Table B 9.12 Calculation of ET_0. *Source*: Authors, based on multiple sources listed in the text.

Z: Elevation of Station ASL; J: Julian Day; RS: Relative Humidity; Rs: Mean Daily Solar Radiation; Uh: Wind speed; H: Elevation above ground.

Station	**Irbid-1-**	**Irbid -2-**	**Mafraq -2-**	**Ramtha**	**AH003**	**AL0059**	**AD0034**	**Al Baqura AGR0001**	**Ras Muneef AYNP0011**	**Dera'a**	**Suwaida**	**Quneitra**	**Dera'a_G**	**Suweida_G**	**Quneitra_G**	**Irbid_G**	**Mafraq_G**
February																	
T min	8.0	5.1	2.9	4.2	3.5	5.0	5.0	8.8	3.2	4.2	4.2	3.1	3.0	5.0	6.0	5.0	7.0
T max	19.7	14.2	14.2	13.9	9.0	19.0	16.0	19.7	9.2	15.0	13.0	11.6	20.0	20.0	20.0	25.0	23.0
Z	277.0	277.0	694.0	534.0	573.0	645.0	205.0	-119.0	679.0	511.0	1038.0	812.0	580.0	1025.0	850.0	576.0	703.0
J	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0
Latitude	32.6	32.6	32.3	32.6	32.4	32.3	32.7	32.6	32.3	32.6	32.7	33.1	32.9	32.7	33.1	32.6	32.3
Longitude	35.8	35.8	36.2	36.0	35.8	36.3	35.9	35.6	36.4	36.1	36.5	35.9	36.2	36.6	35.9	35.8	36.2
RH_{max} (%)	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0
RH_{min} (%)	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0
Rs	11.8	11.8	11.8	11.8	11.	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8	11.8

Station	Irbid-1-	Irbid -2-	Mafraq -2-	Ramtha	AH003	AL0059	AD0034	Al Baqura AGR0001	Ras Muneef AYNP0011	Dera'a	Suwaida	Quneitra	Dera'a_G	Suweida_G	Quneitra_G	Irbid_G	Mafraq_G
Uh (m/s)	3.0	3.0	3.0	3.0	3.1	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
H	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7
ET_0	**2.7**	**2.3**	**2.3**	**2.3**	**1.9**	**2.6**	**2.4**	**2.7**	**2.0**	**2.3**	**2.2**	**2.1**	**2.7**	**2.7**	**2.7**	**3.1**	**3.0**
March																	
T min	10.0	7.5	5.1	5.5	5.5	11.6	10.1	10.4	5.0	6.2	6.7	5.4	5.0	6.0	7.0	7.0	6.0
T max	22.9	17.0	17.9	16.4	12.3	19.6	20.9	22.9	12.3	18.4	17.2	15.7	28.0	23.0	23.0	27.0	27.0
Z	277.0	277.0	694.0	534.0	573.0	645.0	205.0	-119.0	679.0	511.0	1038.0	812.0	580.0	1025.0	850.0	576.0	703.0
J	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0
Latitude	32.6	32.6	32.3	32.6	32.4	32.3	32.7	32.6	32.3	32.6	32.7	33.1	32.9	32.7	33.1	32.6	32.3
Long.	35.8	35.8	36.2	36.0	35.8	36.3	35.9	35.6	36.4	36.1	36.5	35.9	36.2	36.6	35.9	35.8	36.2
RH_{max} (%)	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0	75.0
RH_{min} (%)	55.0	55.0	55.0	55.0	55.0	55.0	55.0	55.0	55.0	55.0	55.0	55.0	55.0	55.0	55.0	55.0	55.0
Rs	16.6	16.6	16.6	16.6	16.6	16.6	16.6	16.6	16.6	16.6	16.6	16.6	16.6	16.6	16.6	16.6	16.6
Uh (m/s)	3.1	3.1	3.1	3.1	3.0	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.0	3.0
H	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7
ET_0	**3.6**	**3.1**	**3.1**	**3.0**	**2.6**	**3.4**	**3.5**	**3.6**	**2.6**	**3.2**	**3.1**	**2.9**	**4.1**	**3.6**	**3.6**	**4.0**	**4.0**
April																	
T min	13.0	10.9	8.6	8.0	8.9	12.1	12.1	13.4	8.8	9.4	9.7	8.6	10.0	15.0	8.0	10.0	9.0
T max	28.1	22.2	23.0	23.0	17.4	25.6	25.0	28.0	17.6	23.7	22.0	20.1	30.0	27.0	27.0	30.0	27.0
Z	277.0	277.0	694.0	534.0	573.0	645.0	205.0	-119.0	679.0	511.0	1038.0	812.0	580.0	1025.0	850.0	576.0	703.0

Station	Irbid-1-	Irbid - 2-	Mafra q -2-	Ramth a	AH00 3	AL0059	AD003 4	Al Baqura AGR0001	Ras Muneef AYNP0011	Dera'a	Suwaida	Queneit ra	Dera'a_ G	Suweida _G	Quneitra _G	Irbid_ G	Mafraq _G
J	105.0	105.0	105.0	105.0	105.0	105.0	105.0	105.0	105.0	105.0	105.0	105.0	105.0	105.0	105.0	75.0	75.0
Latitude	32.6	32.6	32.3	32.6	32.4	32.3	32.7	32.6	32.3	32.6	32.7	33.1	32.9	32.7	33.1	32.6	32.3
Long.	35.8	35.8	36.2	36.0	35.8	36.3	35.9	35.6	36.4	36.1	36.5	35.9	36.2	36.6	35.9	35.8	36.2
RH_{max} (%)	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0
RH_{min} (%)	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0
Rs	20.7	20.7	20.7	20.7	20.7	20.7	20.7	20.7	20.7	20.7	20.7	20.7	20.7	20.7	20.7	20.7	20.7
Uh (m/s)	3.1	3.1	3.1	3.1	2.8	3.5	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1	3.1
H	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7
ET_0	**4.9**	**4.2**	**4.2**	**4.2**	**3.6**	**4.7**	**4.5**	**4.9**	**3.7**	**4.3**	**4.2**	**3.9**	**5.1**	**4.8**	**4.6**	**5.1**	**4.7**
May																	
T min	16.8	14.5	11.9	11.0	12.0	12.0	14.0	16.0	12.3	12.2	12.0	11.7	12.0	18.0	9.0	13.0	11.0
T max	32.2	26.8	28.5	28.6	22.0	30.0	28.4	32.8	22.1	28.3	26.4	24.6	35.0	36.0	25.0	35.0	30.0
Z	277.0	277.0	694.0	534.0	573.0	645.0	205.0	-119.0	679.0	511.0	1038.0	812.0	580.0	1025.0	850.0	576.0	703.0
J	135.0	135.0	135.0	135.0	135.0	135.0	135.0	135.0	135.0	135.0	135.0	135.0	135.0	135.0	135.0	135.0	135.0
Latitude	32.6	32.6	32.3	32.6	32.4	32.3	32.7	32.6	32.3	32.6	32.7	33.1	32.9	32.7	33.1	32.6	32.3
Longitu de	35.8	35.8	36.2	36.0	35.8	36.3	35.9	35.6	36.4	36.1	36.5	35.9	36.2	36.6	35.9	35.8	36.2
RH_{max} (%)	65.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0
RH_{min} (%)	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0	45.0
Rs	25.3	25.3	25.3	25.3	25.3	25.3	25.3	25.3	25.3	25.3	25.3	25.3	25.3	25.3	25.3	25.3	25.3

Station	Irbid-1-	Irbid -2-	Mafraq -2-	Ramtha	AH003	AL0059	AD0034	Al Baqura AGR0001	Ras Muneef AYNP0011	Dera'a	Suwaida	Quneitra	Dera'a_G	Suweida_G	Quneitra_G	Irbid_G	Mafraq_G
Uh (m/s)	2.4	2.4	2.4	2.4	1.9	2.9	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4
H	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7
ET_0	**5.8**	**5.1**	**5.2**	**5.2**	**4.3**	**5.7**	**5.2**	**5.8**	**4.6**	**5.2**	**5.0**	**4.8**	**6.0**	**6.3**	**4.7**	**6.1**	**5.4**
June																	
T min	20.3	17.5	14.1	15.4	15.0	13.0	17.0	20.3	14.4	15.0	15.5	15.4	17.0	15.0	15.0	15.0	13.0
T max	35.7	29.5	31.3	30.4	25.5	33.5	30.0	35.7	24.8	31.0	30.0	28.0	32.0	36.0	35.0	36.0	38.0
Z	277.0	277.0	694.0	534.0	573.0	645.0	205.0	-119.0	679.0	511.0	1038.0	812.0	580.0	1025.0	850.0	576.0	703.0
J	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0	165.0
Latitude	32.6	32.6	32.3	32.6	32.4	32.3	32.7	32.6	32.3	32.6	32.7	33.1	32.9	32.7	33.1	32.6	32.3
Longitude	35.8	35.8	36.2	36.0	35.8	36.3	35.9	35.6	36.4	36.1	36.5	35.9	36.2	36.6	35.9	35.8	36.2
RH_{max} (%)	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0
RH_{min} (%)	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
Rs	28.7	28.7	28.7	28.7	28.7	28.7	28.7	28.7	28.7	28.7	28.7	28.7	28.7	28.7	28.7	28.7	28.7
Uh (m/s)	2.0	2.0	2.0	2.0	1.5	2.5	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
H	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7
ET_0	**6.8**	**6.0**	**6.2**	**6.1**	**5.1**	**7.0**	**6.1**	**6.9**	**5.5**	**6.1**	**6.0**	**5.8**	**6.3**	**6.8**	**6.6**	**6.8**	**7.0**
July																	
T min	22.9	19.0	16.0	15.4	15.0	13.0	17.0	20.3	14.4	12.2	12.0	11.7	15.0	25.0	13.0	17.0	13.0
T max	37.0	31.0	32.8	30.4	25.5	33.5	30.0	35.7	24.8	28.3	26.4	24.6	37.0	35.0	31.0	35.0	37.0

Station	Irbid-1-	Irbid -2-	Mafraq -2-	Ramtha	AH003	AL0059	AD0034	Al Baqura AGR0001	Ras Muneef AYNP0011	Dera'a	Suwaida	Queitra	Dera'a_G	Suweida_G	Quneitra_G	Irbid_G	Mafraq_G
Z	277.0	277.0	694.0	534.0	573.0	645.0	205.0	-119.0	679.0	511.0	1038.0	812.0	580.0	1025.0	850.0	576.0	703.0
J	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0	195.0
Latitude	32.6	32.6	32.3	32.6	32.4	32.3	32.7	32.6	32.3	32.6	32.7	33.1	32.9	32.7	33.1	32.6	32.3
Long.	35.8	35.8	36.2	36.0	35.8	36.3	35.9	35.6	36.4	36.1	36.5	35.9	36.2	36.6	35.9	35.8	36.2
RH_{max} (%)	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0
RH_{min} (%)	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
Rs	27.9	27.9	27.9	27.9	27.9	27.9	27.9	27.9	27.9	27.9	27.9	27.9	27.9	27.9	27.9	27.9	27.9
Uh (m/s)	2.6	2.6	2.6	2.6	2.4	2.8	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.6
H	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7
ET_0	7.8	6.8	7.0	6.6	5.8	7.3	6.6	7.5	5.9	6.3	6.0	5.7	7.6	7.5	6.7	7.0	
August																	
T min	23.4	19.8	16.0	24.0	16.1	11.2	21.0	23.4	16.1	18.6	17.4	18.1	19.0	13.0	13.0	17.0	12.0
T max	37.0	31.0	32.0	31.0	26.5	35.2	33.0	37.2	26.5	32.7	31.9	30.9	33.0	37.0	33.0	35.0	37.0
Z	277.0	277.0	694.0	534.0	573.0	645.0	205.0	-119.0	679.0	511.0	1038.0	812.0	580.0	1025.0	850.0	576.0	703.0
J	225.0	225.0	225.0	225.0	225.0	225.0	225.0	225.0	225.0	225.0	225.0	225.0	225.0	225.0	225.0	225.0	225.0
Latitude	32.6	32.6	32.3	32.6	32.4	32.3	32.7	32.6	32.3	32.6	32.7	33.1	32.9	32.7	33.1	32.6	32.3
Long.	35.8	35.8	36.2	36.0	35.8	36.3	35.9	35.6	36.4	36.1	36.5	35.9	36.2	36.6	35.9	35.8	36.2
RH_{max} (%)	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0
RH_{min} (%)	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0

Station	Irbid-1-	Irbid - 2-	Mafra q -2-	Ramth a	AH00 3	AL0059	AD003 4	Al Baqura AGR0001	Ras Muneef AYNP0011	Dera'a	Suwaida	Queit ra	Dera'a_ G	Suweida _G	Quneitra _G	Irbid_ G	Mafraq _G
Rs	25.3	25.3	25.3	25.3	25.3	25.3	25.3	25.3	25.3	25.3	25.3	25.3	25.3	25.3	25.3	25.3	25.3
Uh (m/s)	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9
H	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7
ET_0	**7.8**	**6.8**	**7.0**	**7.0**	**6.1**	**7.4**	**7.2**	**7.9**	**6.2**	**7.1**	**6.9**	**6.8**	**7.6**	**8.2**	**7.7**	**8.2**	
September																	
T min	21.7	18.5	14.7	24.0	15.7	11.7	18.0	21.7	15.3	16.5	15.6	15.6	13.0	13.0	15.0	16.0	13.0
T max	36.1	29.7	31.1	31.0	26.1	33.0	32.0	36.1	25.4	31.3	29.3	28.3	32.0	30.0	33.0	34.0	35.0
Z	277.0	277.0	694.0	534.0	573.0	645.0	205.0	-119.0	679.0	511.0	1038.0	812.0	580.0	1025.0	850.0	576.0	703.0
J	255.0	255.0	255.0	255.0	255.0	255.0	255.0	255.0	255.0	255.0	255.0	255.0	255.0	255.0	255.0	225.0	225.0
Latitude	32.6	32.6	32.3	32.6	32.4	32.3	32.7	32.6	32.3	32.6	32.7	33.1	32.9	32.7	33.1	32.6	32.3
Long.	35.8	35.8	36.2	36.0	35.8	36.3	35.9	35.6	36.4	36.1	36.5	35.9	36.2	36.6	35.9	35.8	36.2
RH_{max} (%)	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0
RH_{min} (%)	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
Rs	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0	21.0
Uh (m/s)	2.3	2.3	2.3	2.3	2.0	2.6	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3
H	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7
ET_0	**6.0**	**5.2**	**5.2**	**5.5**	**4.6**	**5.6**	**5.4**	**6.0**	**4.7**	**5.3**	**5.1**	**5.0**	**4.7**	**4.5**	**4.5**	**4.9**	
October																	
T min	4.4	15.4	11.5	13.0	15.7	11.0	15.8	18.0	13.3	12.7	13.4	12.6	10.0	14.0	13.0	14.0	15.0
T max	32.0	26.4	27.2	26.7	26.1	28.3	28.0	32.0	21.5	27.7	24.8	25.3	32.0	33.0	30.0	33.0	32.0

Station	Irbid-1-	Irbid -2-	Mafraq -2-	Ramtha	AH003	AL0059	AD0034	Al Baqura AGR0001	Ras Muneef AYNP0011	Dera'a	Suwaida	Queneitra	Dera'a_G	Suweida_G	Quneitra_G	Irbid_G	Mafraq_G
Z	277.0	277.0	694.0	534.0	573.0	645.0	205.0	-119.0	679.0	511.0	1038.0	812.0	580.0	1025.0	850.0	576.0	703.0
J	285.0	285.0	285.0	285.0	285.0	285.0	285.0	285.0	285.0	285.0	285.0	285.0	285.0	285.0	285.0	225.0	225.0
Latitude	32.6	32.6	32.3	32.6	32.4	32.3	32.7	32.6	32.3	32.6	32.7	33.1	32.9	32.7	33.1	32.6	32.3
Long.	35.8	35.8	36.2	36.0	35.8	36.3	35.9	35.6	36.4	36.1	36.5	35.9	36.2	36.6	35.9	35.8	36.2
RH_{max} (%)	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0
RH_{min} (%)	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0	50.0
Rs	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1
Uh (m/s)	2.3	2.3	2.3	2.3	2.0	2.6	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3
H	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7	2.7
ET_0	**4.4**	**3.9**	**3.9**	**3.9**	**3.7**	**4.1**	**4.0**	**4.4**	**3.5**	**3.9**	**3.7**	**3.7**	**3.7**	**3.7**	**3.7**	**3.8**	

Table B 9.13 Compilation of flow values from different studies.

Reference	Time interval	Location	Flow (MCM/y)	Notes
(Ionides, 1939)	1925-1938	Confluence with Jordan River	60 m^3/s	Average
	1928/29	Confluence with Jordan River	135 m^3/s	Maximum Flow
	1927/28	Confluence with Jordan River	38 m^3/s	Minimum Flow
			226	Surface Water (Flood Flow, Runoff)
			254	Groundwater Runoff
			480	Total Flow
(Burdon, 1954)	1926-1946	Confluence with Jordan River	487.3	Gauged Surface Flow
(Energoprojekt, 1964)		Yarmouk River Mouth	450	Total Water Balance at Yarmouk mainstream mouth 47 Diverted In Syria 403 Discharge available for irrigation in the Jordanian system
		Maqaren	275	Annual Discharge
(Ayeb, 1993)		Yarmouk to Jordan River	282	'Etiages' (Baseflow)
		Yarmouk to Jordan River	182	'Crues' (Flood flow)
	< const'n of East Ghor Canal	Confluence with Jordan River	400	Yield of Yarmouk to Jordan River
(Ayeb, 1998)		Yarmouk to Jordan River	218	Baseflow
		Yarmouk to Jordan River	182	Flood flow
		Yarmouk to Jordan River	400	Total Flow
		Yarmouk River	467	Average
		Addasiyeh	870	Maximum Flow
		Addasiyeh	250	Minimum Flow

Reference	Time interval	Location	Flow (MCM/y)	Notes
(Courcier, *et al.* 2004)	1927-1954	Yarmouk at the Confluence with Jordan River	440-470	Input of Yarmouk into Jordan River
(Agha and Deeb, 2005)		Yarmouk In Syria	180	Average surface water resources
		Yarmouk In Syria	267	Average groundwater resources
		Yarmouk In Syria	447	Average total water resources
		Maqaren	275.94	Discharge at Maqaren (8.75 m^3/s)
		Addasiyeh	475-525	Resources of Yarmouk In Addasiyeh
(Rosenberg, 2006)	1970-2000s	Maqaren	200	After Syrian abstractions
	< 1950	Yarmouk	480	Flow
	1950-1990	Yarmouk	190	Flow that Jordan could use at the end of the period
(FAO, 2008)		Inflow from Syria To Jordan	400	Natural flow from Syria to the Jordan
(Kout, 2008)		Yarmouk In Syria	180	Annual surface runoff
		Yarmouk In Syria	475	Total water resources
		Yarmouk In Syria	245	Yield of springs (base flow)
(Hoff, *et al.* 2011)		Yarmouk	495	Annual stream flow
(Orient, 2011)	< 1970	Maqaren	162.6	Mean flow
	> 1970	Maqaren	144	Mean flow
	< 1970	Addasiyeh	269.8	Mean flow
	> 1970	Addasiyeh	223.6	Mean flow
	1920-1940		500	Natural flow, before the development
	1995-2008	Maqaren	82.8	Observed mean annual flow
	1971-1995	Addasiyeh	264	Observed mean annual flow
	1995-2008	Addasiyeh	145	Observed mean annual flow

Reference	Time interval	Location	Flow (MCM/y)	Notes
(Al Manaseer, 2012)			180	Water used by Syria
			128	Water used by Jordan
			90	Water used By OSOI
		Yarmouk River	475	Average Annual Discharge
	2000	Yarmouk River	460	Average Discharge
	2010	Yarmouk River	470	Average Discharge
	1929	Yarmouk River	750	Highest Recorded Level of Discharge
	1933	Yarmouk River	150	Lowest Historic Level of Discharge
(Comair et al., 2012)		Yarmouk River	470	Annual Flow Average
(Husein, 2012)		Yarmouk In Syria	267	Groundwater Resources
		Yarmouk In Syria	180	Surface Water Resources
		Yarmouk In Syria	447	Total
(UN-ESCWA/BGR, 2013)	1950s	Yarmouk	450-500	Historic Flow
	1963-2006	Addasiya	272	Maximum Flow
	1963-2006	Maqaren	253	Maximum Flow
	1963-2006	Maqaren	152	Mean Annual Flow
	1963-2006	Addasiya	120	Mean Annual Flow
	1985-2006	Addasiya	35	Minimum Flow
	1985-2006	Maqaren	7.6	Minimum Flow
	recently	Yarmouk	83-99	Recent Flow
(Hadadin, 2015)		Yarmouk	166	Annual Discharge of Yarmouk Into Jordan River
			105	Long Term Average – Baseflow
			155	Long Term Average – Flood flow

Reference	Time interval	Location	Flow (MCM/y)	Notes
			260	Long Term Average - Total Flow
	1963-1981		40	Baseflow From Jordan - Pre- Development
	1997/98		35	Baseflow From Jordan - Today Estimates
(Al Qusaym, 2016)		Yarmouk In Syria	200-220	Groundwater Resources
		Yarmouk In Syria	180	Surface Water Resources
		Yarmouk Resources	400	Total Groundwater Resources
(Alhusban, 2016)		Yarmouk	203	Average Amount of Runoff
{(Cafiero 2016)		Yarmouk In Syria	131	Groundwater Resources
		Yarmouk In Syria	88	Surface Water Resources
		Yarmouk In Syria	219	Total Resources
(Youmans, 2016)		Yarmouk In Syria	355	Surface and Groundwater Resources In Yarmouk
		Yarmouk In Syria	64	Surface Water Resources
		Yarmouk In Syria	289	Groundwater Resources
		Yarmouk In Syria	253	Water Total Resources
(CPC, 2017)	2005-2013	Syria	90	Average Surface Water
	2007/08	Syria	24	Average Surface Water
	2012/13	Syria	160	Average Surface Water

Table B 9.14 Compilation of thickness of different geological formations.

Upper Aquifer System (Basalt and B4/B5 - Pg_2^2 / Pg_2^3)			
Basalts			
Study	**Basalt thickness (m)**		
(Dafny et al., 2003)	In the Golan area, near Al Quneitra: 700-750; At Yarmouk Gorge: 50		
(Bourgoin et al., 1948)	~300		
(Hobler et al., 2001)	Beneath Jabal al Arab: 1,500		
(Margane, 2015)	100 – 650		
(UN-ESCWA/BGR, 2013)	At the fringes of the basalt plateau: 100; At the foothills of Jabal al Arab: >700; Beneath Jabal al Arab: 1,500		
B4/B5 - Pg_2^2 / Pg_2^3			
Study	**B4 thickness (m)**	**B5 thickness (m)**	**B4/B5 thickness (m)**
(Awawdeh, 2010)			>200
Bender, 1968	Central Jordan: 20-40	S- and central Jordan: 20-40; Wadi Shallala area: 35 m; Yarmouk valley: 130-140	
(Youmans, 2017) - Paleogene in Syria			East: 100-200; West: 500-700; In the river bank of the Yarmouk: 200-350
(Margane, 2015)	0-310	0-550	
(Moh'd, 2000)	Wadi Shallala: 200	Irbid area: 150	
(Obeidat et al., 2012)			>200
(Smadi, 2000)	North of Husha: 90; Irbid area: 220; Jabal Umm Rijam: 73		

Aquitard of B3 - Pg_1-Pg_2[1]

Study	B3 thickness (m)
(Abu-Jaber and Kharabsheh, 2008)	80-320
(Awawdeh, 2010)	125-500
(Bandel and Salameh, 2013)	near Irbid: 100
(Burdon et al., 1954)	Varies but usually around 500
(Hobler et al., 1994)	Yarmouk: between 360 and >540; Ramtha: around 130
(Hobler et al., 2001)	Maximum around 300
(Margane, 2015)	80-320
(Moh'd, 2000)	near Maqaren: 100
(Obeidat et al., 2012)	125-500
(Smadi, 2000)	Mafraq: 80-90; North of Husha: 85; Muwaqqar area: 70; Irbid: 200-240
(UN-ESCWA/BGR, 2013)	0-220

The Middle Aquifer System: (A7/B2 - Cr2cn cp / Cr2m-d) and (A1/A6 - Cr2cm-t)

Study	A4 thickness (m)	A5/6 thickness (m)	A7 thickness (m)	B1 thickness (m)	B2 thickness (m)	A7/B2 thickness (m)
(Abu-Jaber and Kharabsheh, 2008)			>200	30-35	35-200	
Awawdeh, 2010						300-500
(Bandel and Salameh, 2013)		65	150 – 200	3-40 around Irbid	72-76 in Irbid	
(Burdon and Safadi, 1962) - Upper Cretaceous in Syria						around 900 in Syria

(Burdon et al., 1954) - Upper Cretaceous in Syria						1,000 in south-west Syria
Abu Qudaira (2005) in Hamdan (2016) (2016)	45-60	57-80	57-80	25-40	70	
(Hobler et al., 1994)		638 in Mukheibeh (Ajloun Group)		50		
Abdelhamid (1993, 1995) in Hamdan (2016)	40-50	55-70	70-220	30-35	60-70	
(Margane, 2015)	30-100	40-120	60-340	20-90	20-140	
(Moh'd, 2000)			296 in Qumein Borehole; 120 in Ishtafina; 110 in Tubna; 118 in Ramtha	35 in Wadi Arab; 33 in Qumeim; 39 in Ramtha	47 in west of Irbid; 60 m in Wadi al Arab	
(Obeidat et al., 2012)						300-500
(Smadi, 2000)	40-55 in Mafraq 41 in Wadi Ayn 40-50 in Jarash 65 in Wadi Shuayb 60 in Wadi Esh Shita 60 in Hummar area	50-60 in Mafraq 65 in Ajlun 55-70 in Jarash	41 in Tughrat Al Jub; 70 in Jarash 106 East of Asfor 150 South of Sakeb 220 South of Inba	12-15 in Mafraq; 25-30 in Jarash	95 in Mafraq 50-70 in Jarash	

Figure B 9.11 Monitoring wells in the Jordanian part of the basin. *Source*: Authors, based on JVA data.

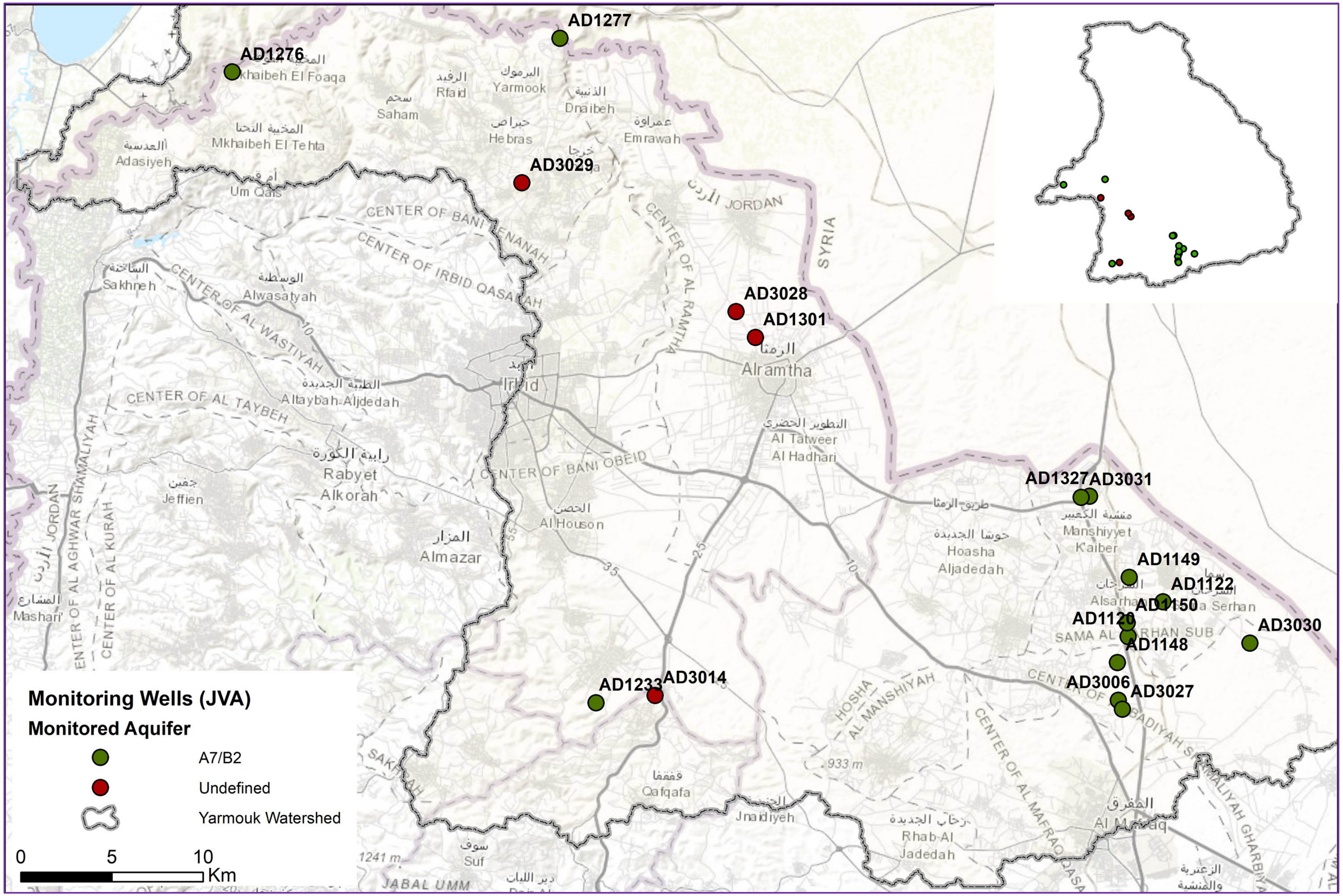
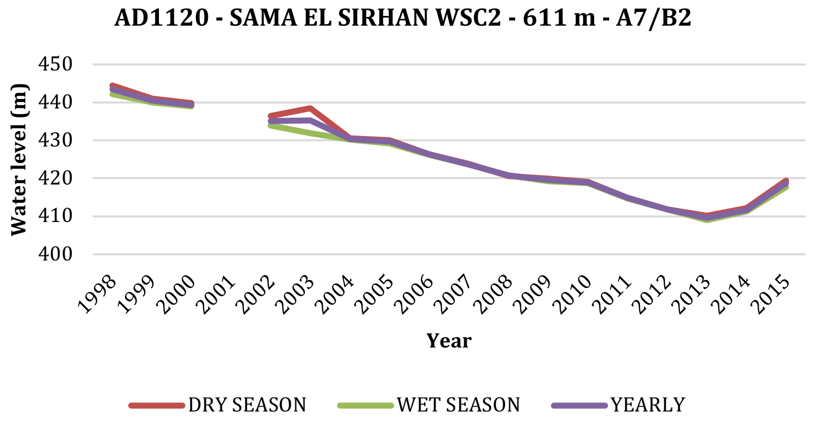
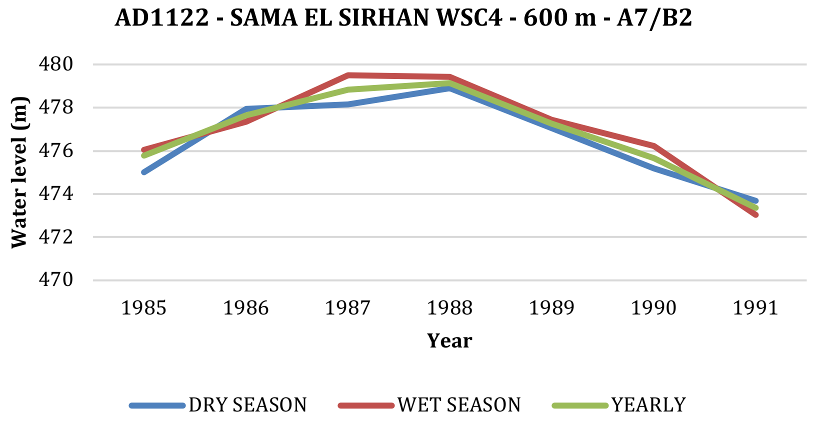


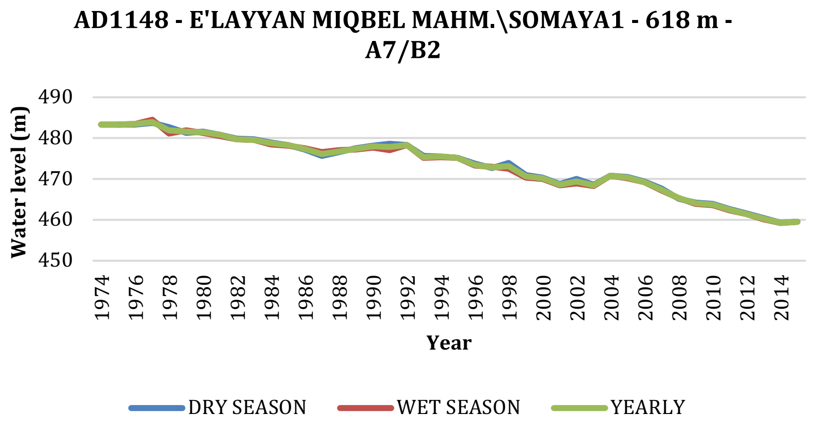
Table B 9.15 List of the monitoring wells and difference in water level between first and last year of recording. *Source*: JVA.

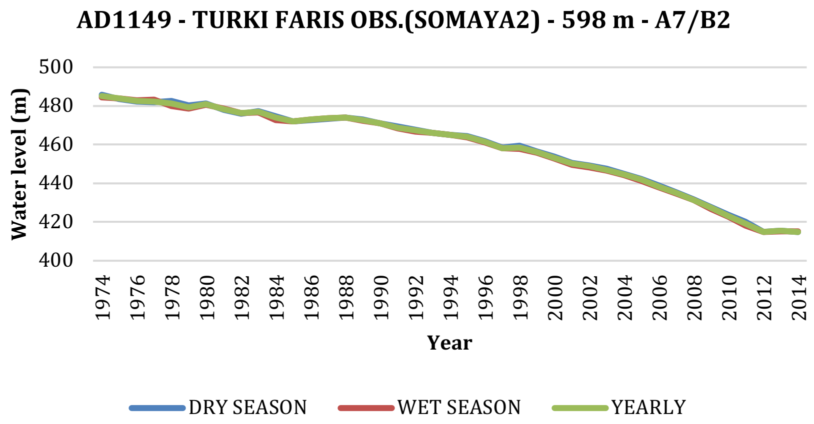
Station Code	Station name	X UTM37	Y UTM37	Altitude (m)	Average change (m/y)	First Year of Record	Last Year of Record
AD1120	SAMA EL SIRHAN WSC2 (PP 467)	238603	3592399	611	-1.37	1998	2015
AD1122	SAMA EL SIRHAN WSC4	240516	3594292	600	-0.40	1985	1991
AD1148	E'LAYYAN MIQBEL MAHM.\SOMAYA1	238012	3590969	618	-0.58	1974	2015
AD1149	TURKI FARIS OBS.(SOMAYA2)	238668	3595640	598	-1.75	1974	2014
AD1150	WARWEER HASHAL OBS	238554	3593141	608	-0.64	1974	2015
AD1233	YAMOUN EXP 1	209386	3588761	786	0.04	1999	2015
AD1276	MUKHEIBA (JRV1)	189408	3623339	-78	0.59	1982	1993
AD1277	MAQARIN 2	207398	3625186	98	-0.21	1986	2005
AD1301	MAHASI 8 (DEEP)	218130	3608795	489	-0.76	2003	2015
AD1327	JABER OBSERVATION 1	236484	3600082	586	-1.23	1988	1990
AD3006	MAFRAQ WASTEWATER OBSERV.1	238058	3588905	646	-0.78	1993	1999
AD3014	BALILA 2	212621	3589168	750	-0.64	1998	2015
AD3027	MAFRAQ WASTEWATER MONITORING	238286	3588407	654	0.60	1998	2015
AD3028	RAMTHA WASTEWATER MONITORING	217074	3610210	481	-0.08	2003	2015
AD3029	A'ZREET OBSERVATION	205312	3617262	488	0.00	1997	2015
AD3030	UMM ESRAB OBSERVATION 1	245294	3592034	663	-2.01	2001	2012
AD3031	JABER MONITORING	236022	3600022	589	-1.86	1997	2005

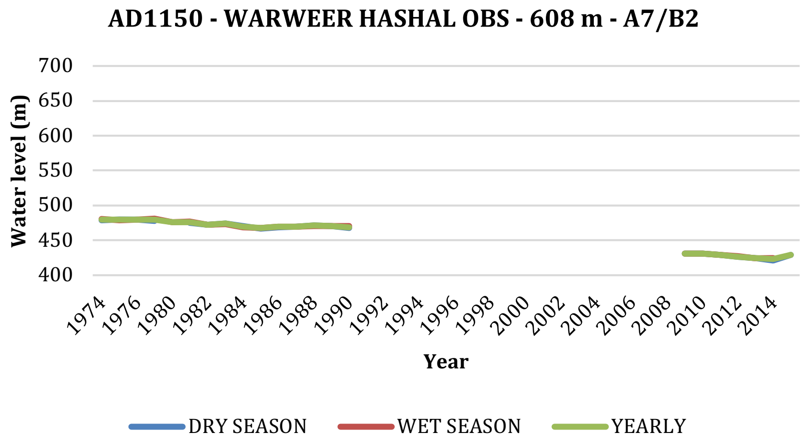
Figure B 9.12 Fluctuation of water levels in monitoring wells in Jordan. *Source*: Authors, based on JVA data.

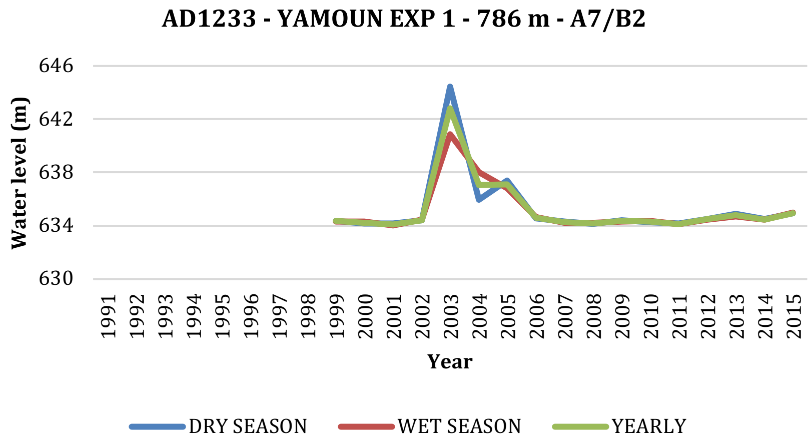


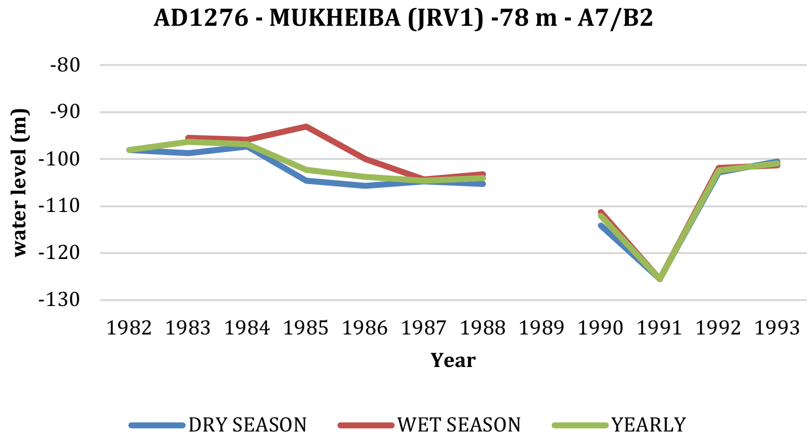


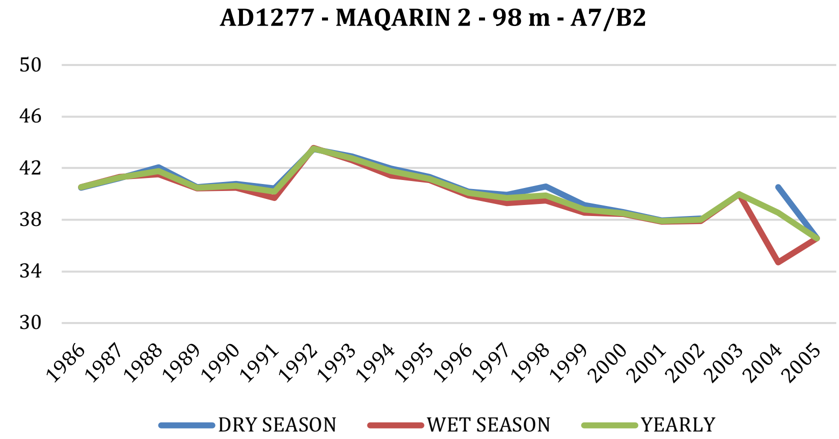


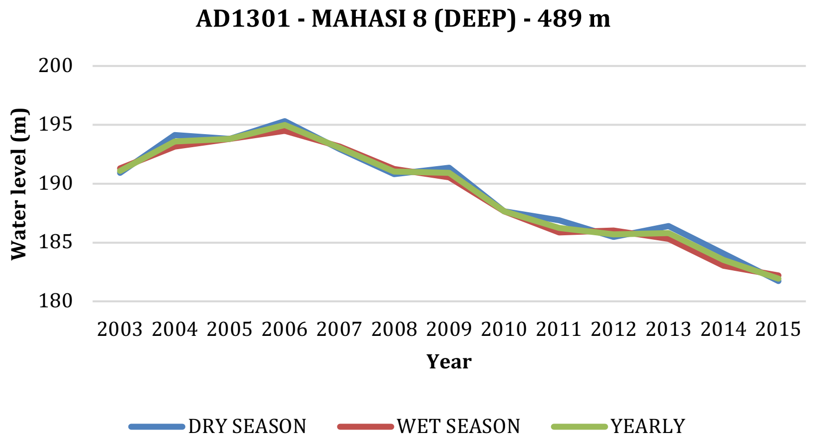


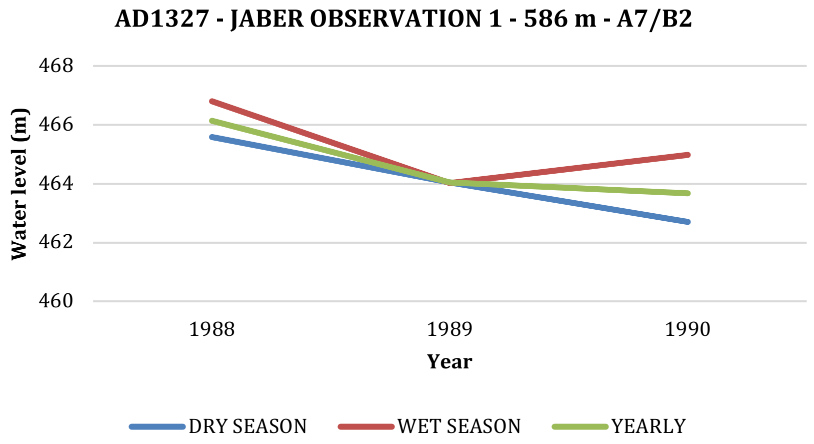

AD1150 - WARWEER HASHAL OBS - 608 m - A7/B2
Water level (m)
700
650
600
550
500
450
400
1974 1976 1980 1982 1984 1986 1988 1990 1992 1994 1996 1998 2000 2002 2004 2006 2008 2010 2012 2014
Year
DRY SEASON
WET SEASON
YEARLY

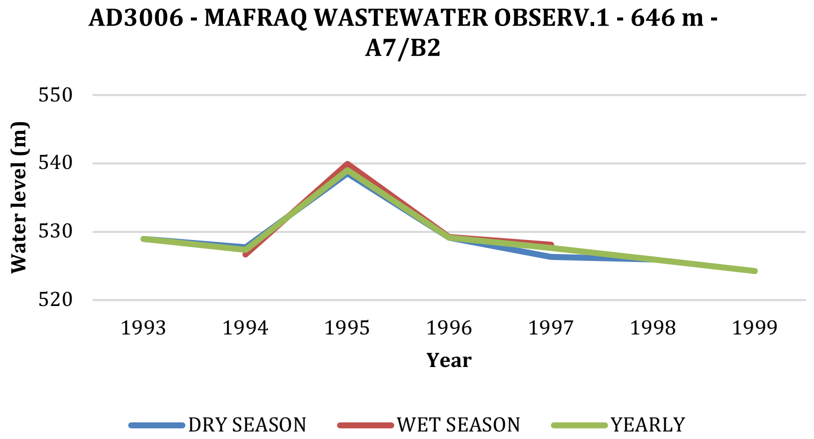

AD1233 - YAMOUN EXP 1 - 786 m - A7/B2
Water level (m)
646
642
638
634
630
1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015
Year
DRY SEASON
WET SEASON
YEARLY

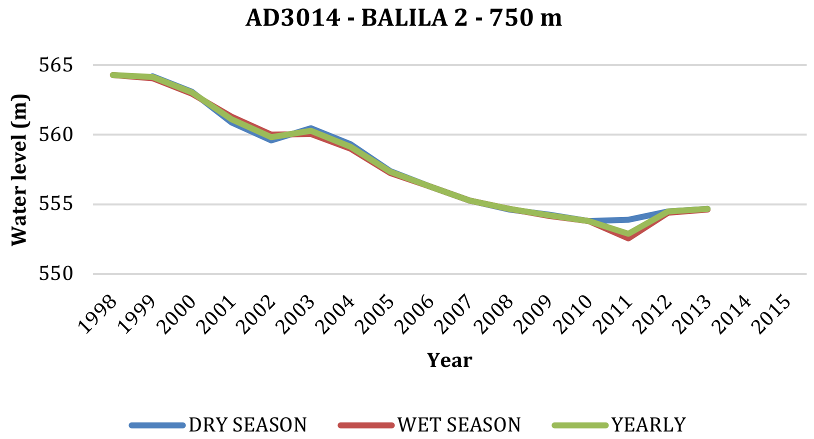

AD1276 - MUKHEIBA (JRV1) -78 m - A7/B2
water level (m)
-80
-90
-100
-110
-120
-130
1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993
Year
DRY SEASON
WET SEASON
YEARLY

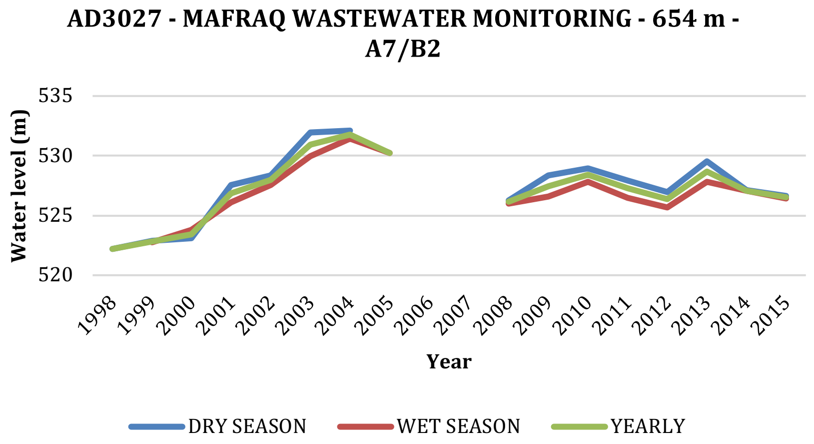

AD1277 - MAQARIN 2 - 98 m - A7/B2
50
46
42
38
34
30
1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005
DRY SEASON
WET SEASON
YEARLY

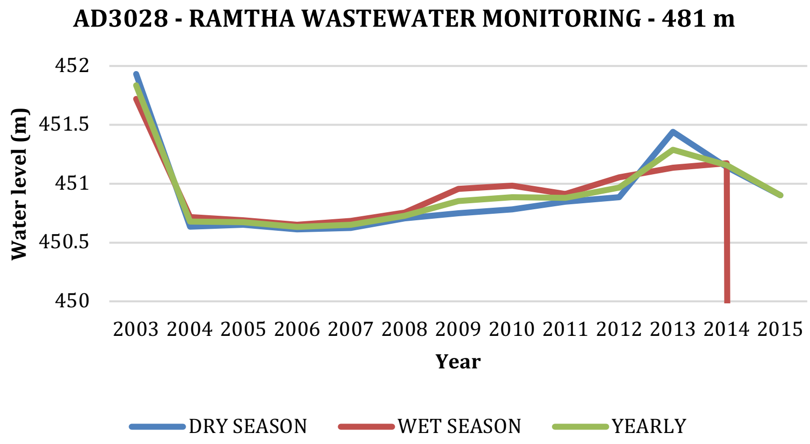

AD1301 - MAHASI 8 (DEEP) - 489 m
Water level (m)
200
195
190
185
180
2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015
Year
DRY SEASON
WET SEASON
YEARLY

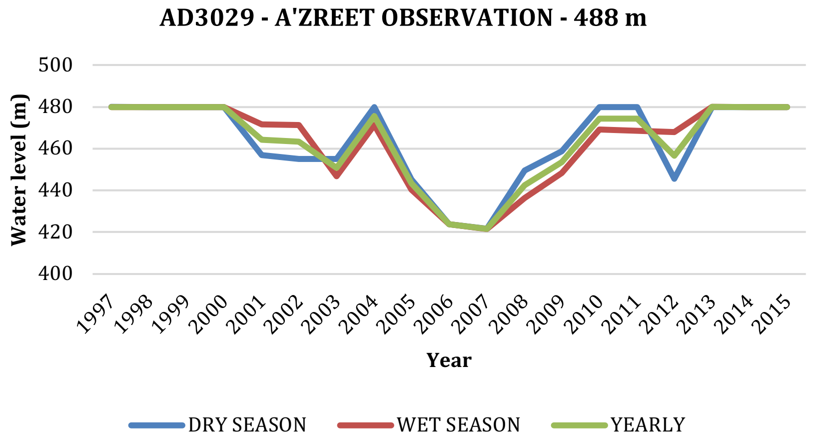

AD1327 - JABER OBSERVATION 1 - 586 m - A7/B2
Water level (m)
468
466
464
462
460
1988
1989
1990
Year
DRY SEASON
WET SEASON
YEARLY

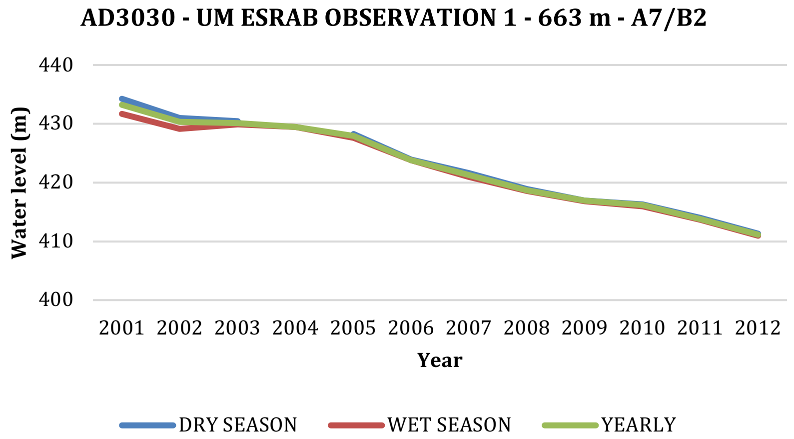

AD3006 - MAFRAQ WASTEWATER OBSERV.1 - 646 m - A7/B2
Water level (m)
550
540
530
520
1993 1994 1995 1996 1997 1998 1999
Year
DRY SEASON
WET SEASON
YEARLY


AD3014 - BALILA 2 - 750 m
Water level (m)
565
560
555
550
1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015
Year
DRY SEASON
WET SEASON
YEARLY


AD3027 - MAFRAQ WASTEWATER MONITORING - 654 m - A7/B2
Water level (m)
535
530
525
520
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
Year
DRY SEASON
WET SEASON
YEARLY


AD3028 - RAMTHA WASTEWATER MONITORING - 481 m
Water level (m)
452
451.5
451
450.5
450
2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015
Year
DRY SEASON
WET SEASON
YEARLY


AD3029 - A'ZREET OBSERVATION - 488 m
Water level (m)
500
480
460
440
420
400
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
Year
DRY SEASON
WET SEASON
YEARLY


AD3030 - UM ESRAB OBSERVATION 1 - 663 m - A7/B2
Water level (m)
440
430
420
410
400
2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012
Year
DRY SEASON
WET SEASON
YEARLY

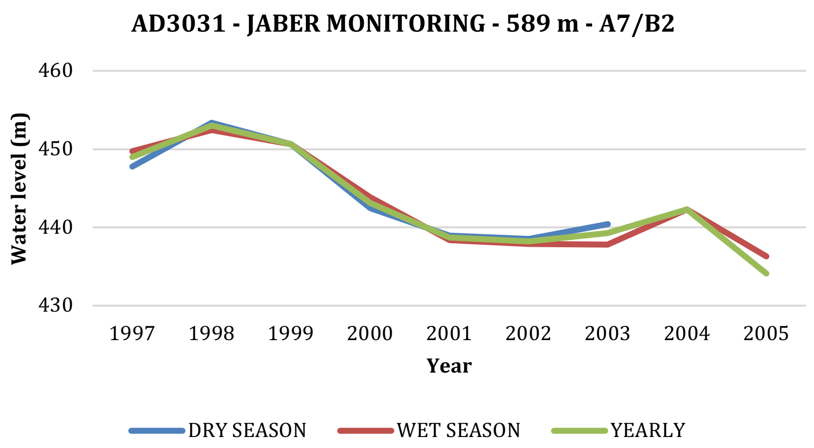
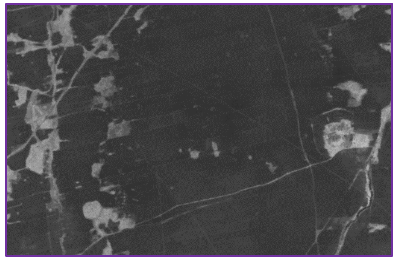
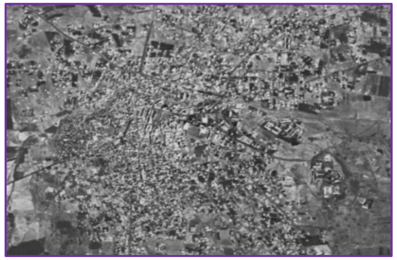


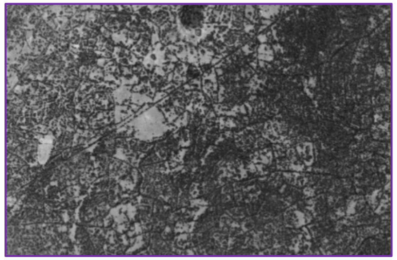
Figure B 9.13 Classes used in LUC (1966-67).



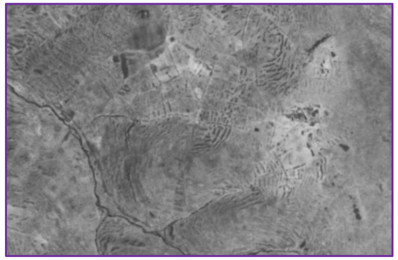
A – Crop



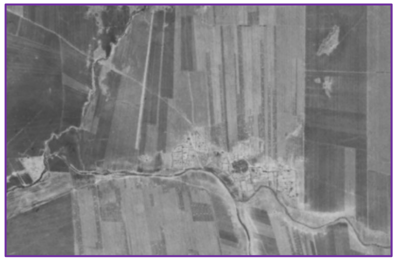
B – Urban zones



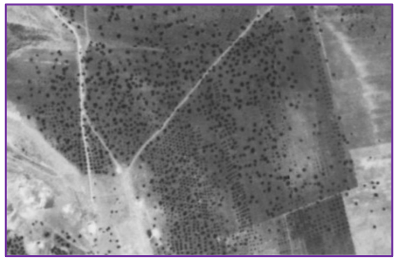
C – Forest



D – Bare lands



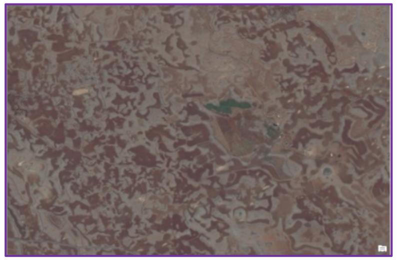
E – Water bodies



F – Fruit trees

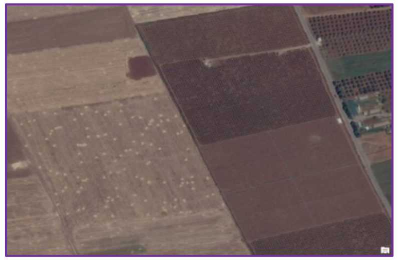
Figure B 9.14 Classes used in LUC (2011).

A – Bare Rock



B – Bare Rock/Soil

C – Bare Land



D – Vine

E – Fruit Tree

F – Olive

G – Green House

H – Forest

I – Urban Zone

J – Dams

K – Water Bodies

L – Surface Flow

M – Crop

Figure B 9.15 Land use in the Yarmouk tributary basin, by country (2011).

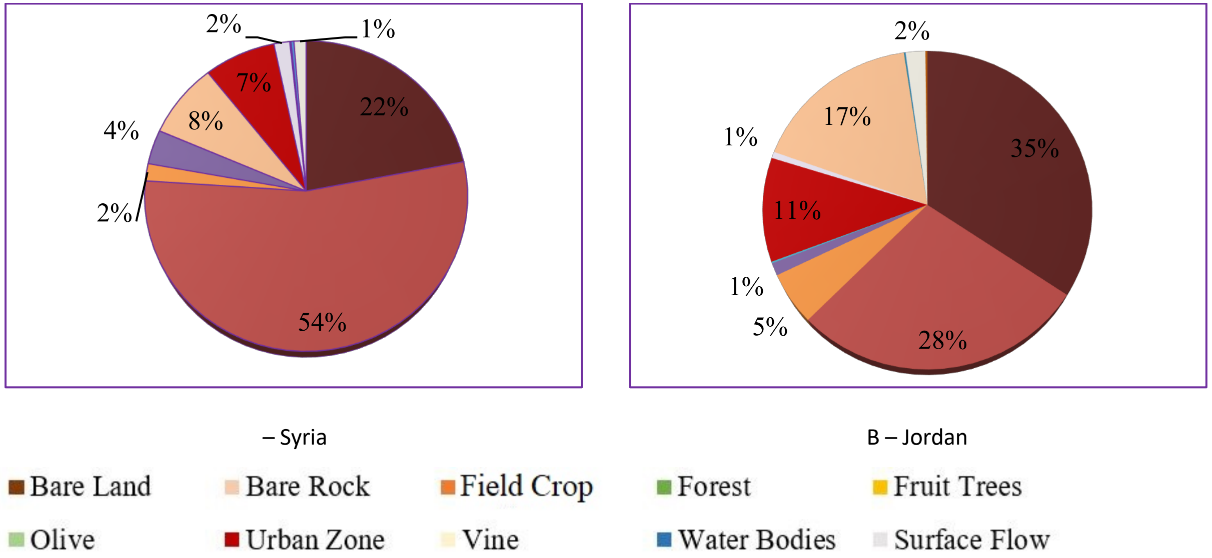


Figure B 9.16 LUC in Syria per governorate (2011).

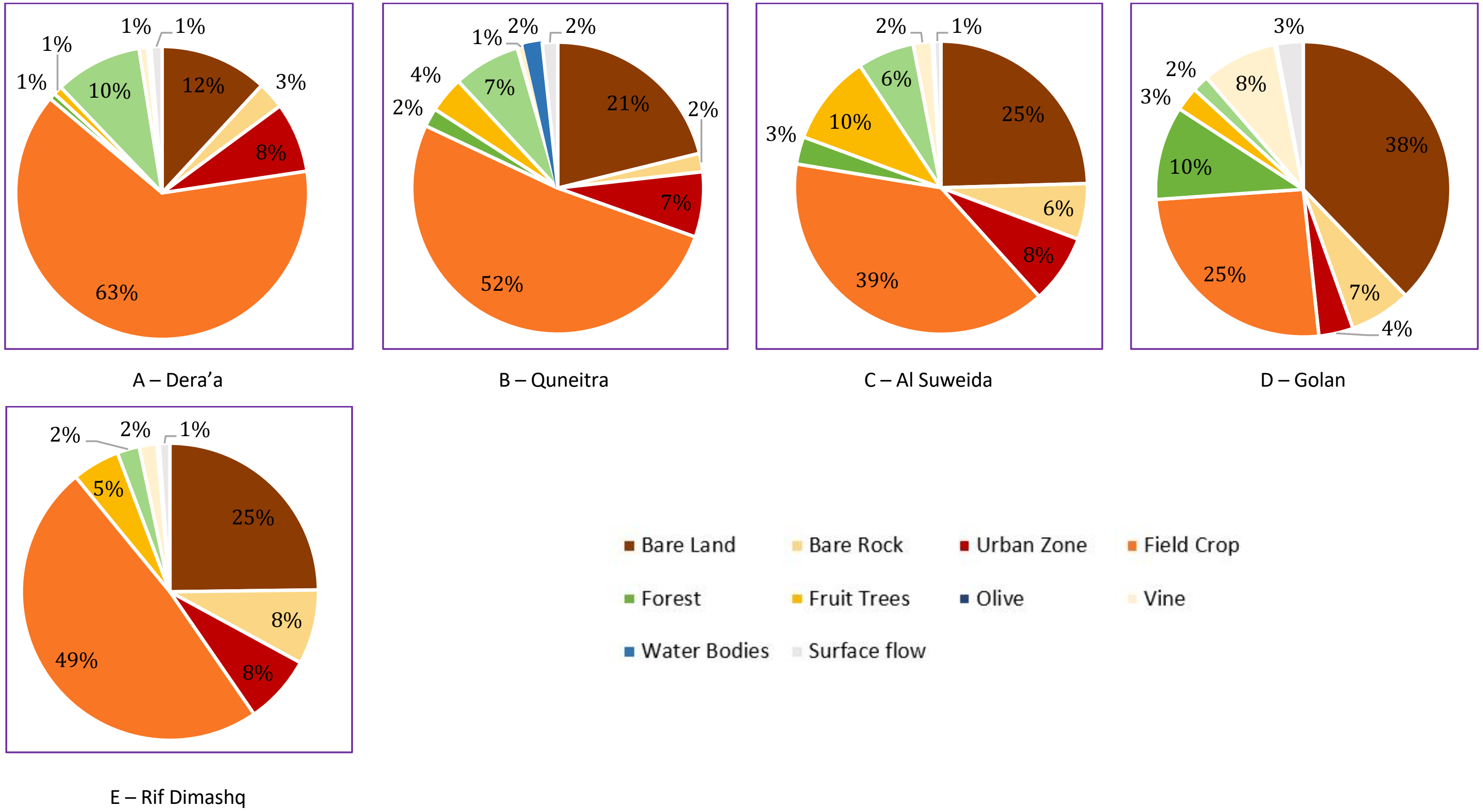


Figure B 9.17 LUC in Jordan per governorate (2011).

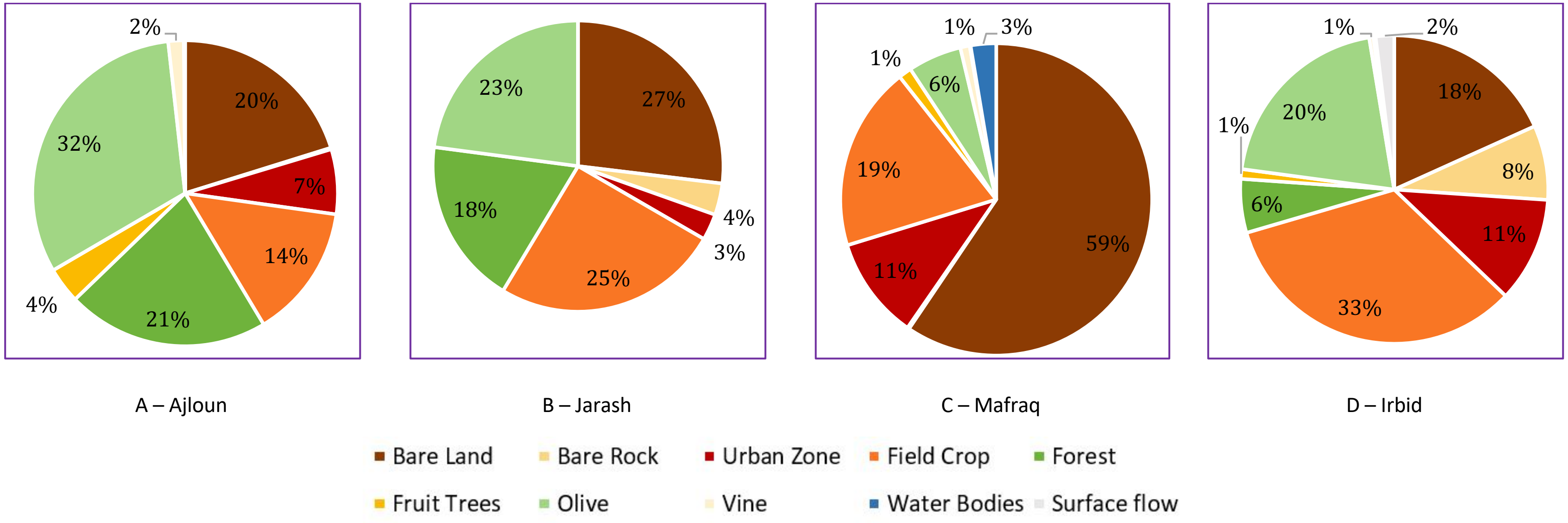
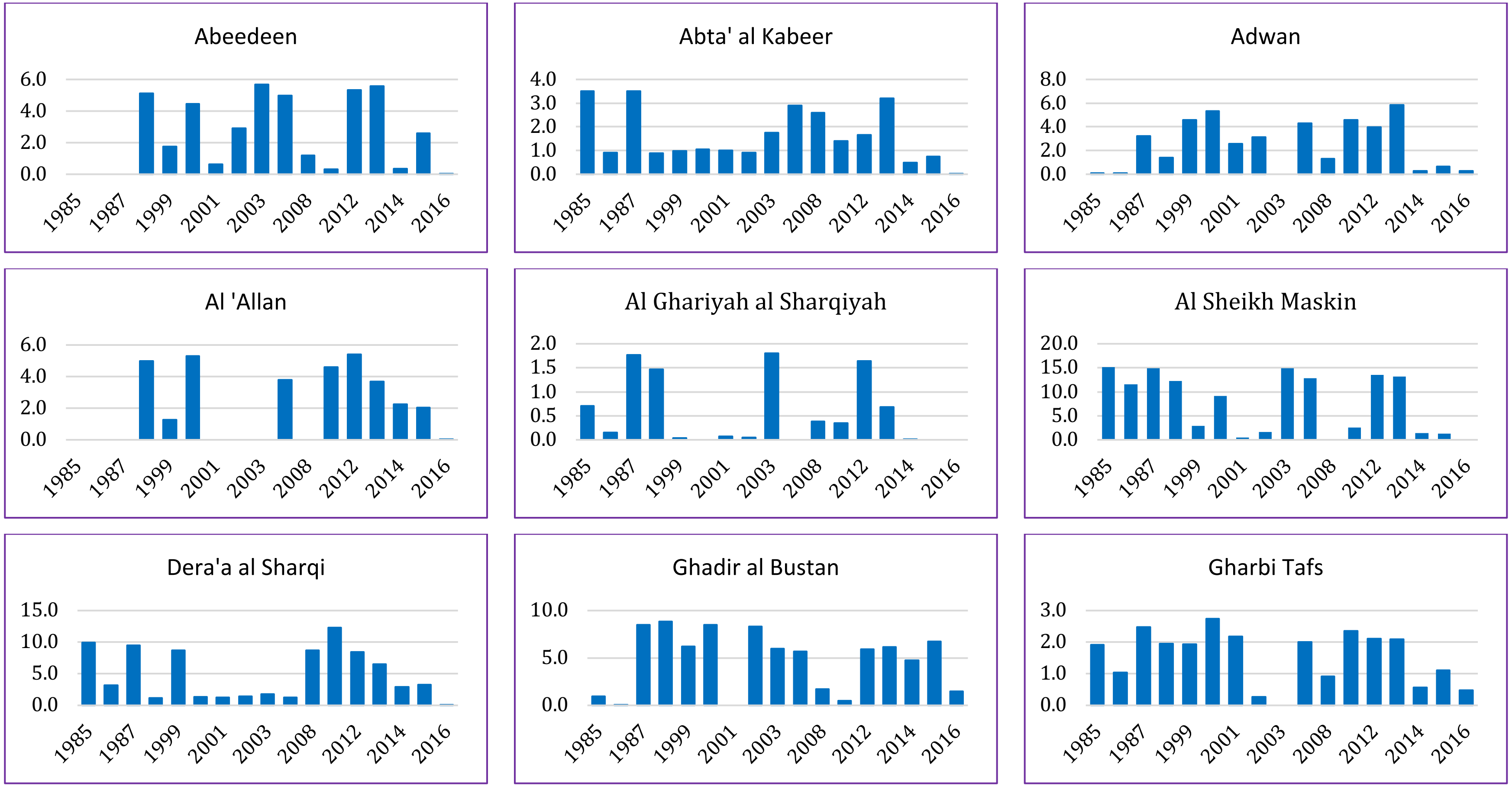
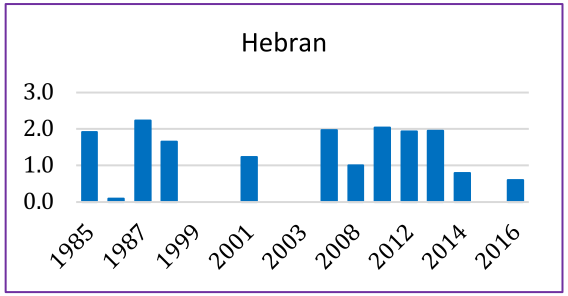
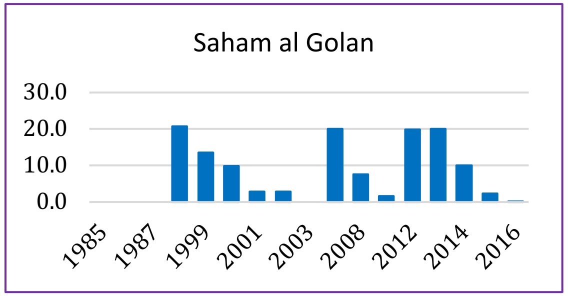
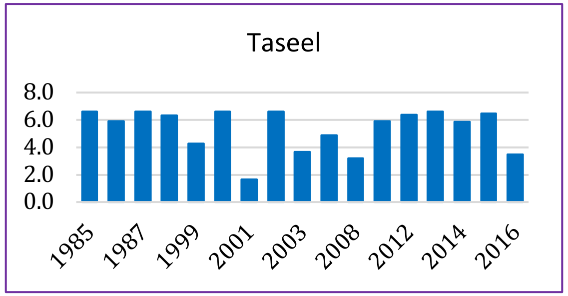


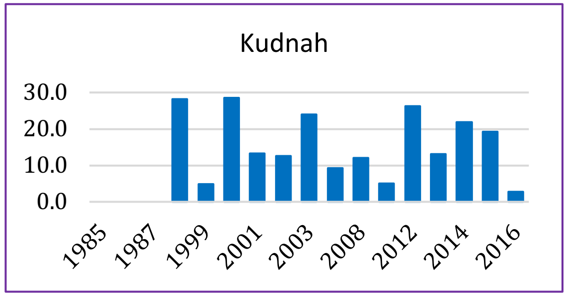
Figure B 9.18 Volumes of water (MCM) retained by dams in Spring (April).

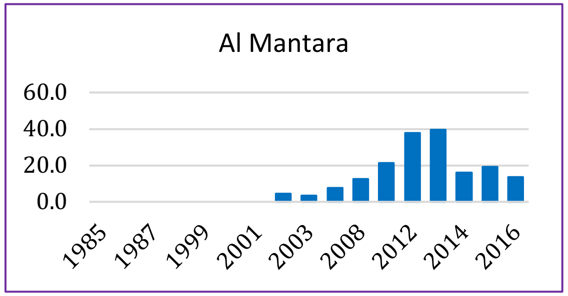


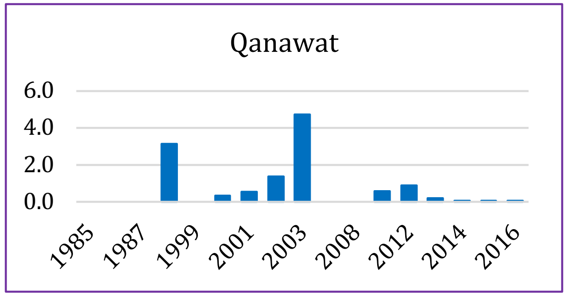

Hebran
3.0
2.0
1.0
0.0
1985
1987
1999
2001
2003
2008
2012
2014
2016

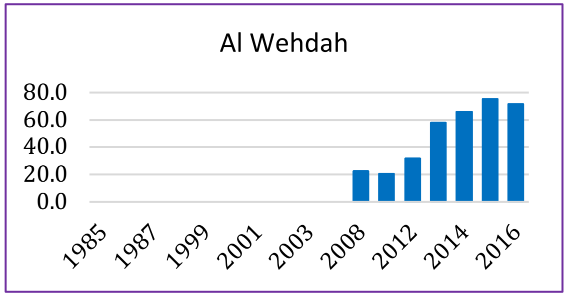

Saham al Golan
30.0
20.0
10.0
0.0
1985
1987
1999
2001
2003
2008
2012
2014
2016

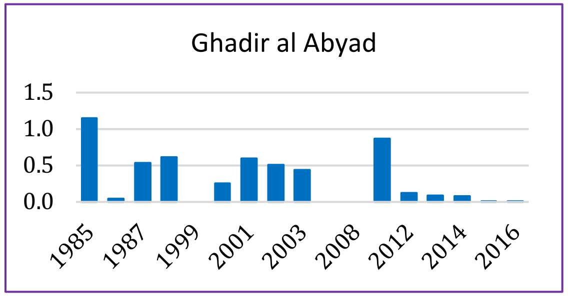

Taseel
8.0
6.0
4.0
2.0
0.0
1985
1987
1999
2001
2003
2008
2012
2014
2016

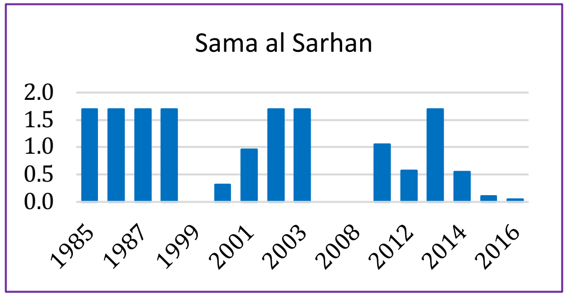

Kudnah
30.0
20.0
10.0
0.0
1985
1987
1999
2001
2003
2008
2012
2014
2016


Al Mantara
60.0
40.0
20.0
0.0
1985
1987
1999
2001
2003
2008
2012
2014
2016


Qanawat
6.0
4.0
2.0
0.0
1985
1987
1999
2001
2003
2008
2012
2014
2016


Al Wehdah
80.0
60.0
40.0
20.0
0.0
1985
1987
1999
2001
2003
2008
2012
2014
2016


Ghadir al Abyad
1.5
1.0
0.5
0.0
1985
1987
1999
2001
2003
2008
2012
2014
2016


Sama al Sarhan
2.0
1.5
1.0
0.5
0.0
1985
1987
1999
2001
2003
2008
2012
2014
2016

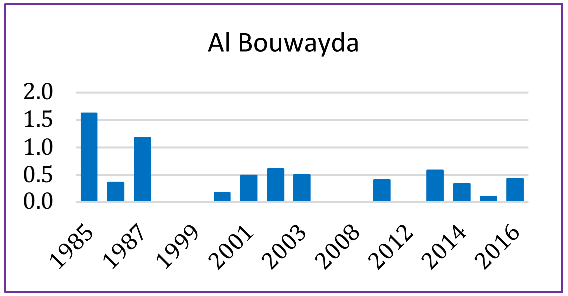

Al Bouwayda
2.0
1.5
1.0
0.5
0.0
1985
1987
1999
2001
2003
2008
2012
2014
2016

Figure B 9.19 Number of wells, and area irrigated from groundwater in Al Suweida, Dera'a and Al Quneitra Governorates. *Source*: (MoAAR, 2014)

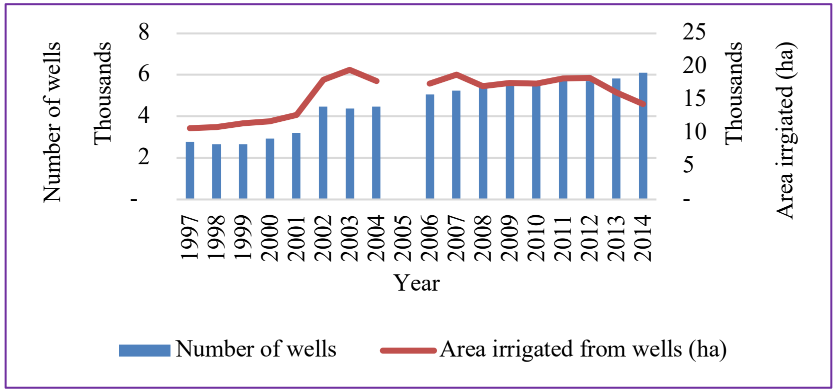


Figure B 9.20 Percentages of legal and unlicensed wells from 1997 to 2014. *Source*: (MoAAR, 2014)

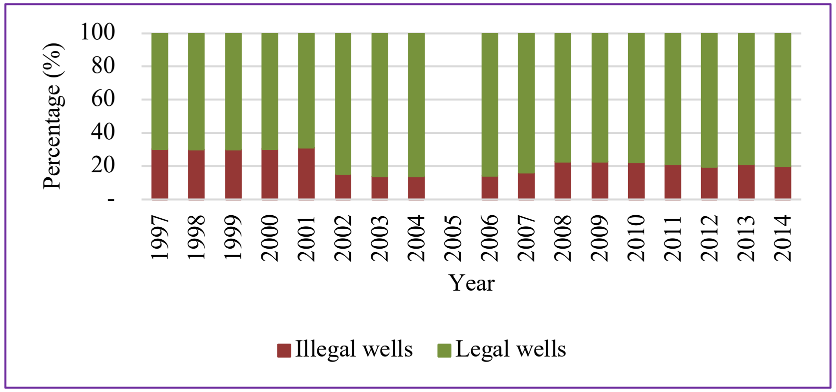


Figure B 9.21 Number of wells and amount of water abstracted in Jordan between 2009 and 2015. *Source*: JVA.

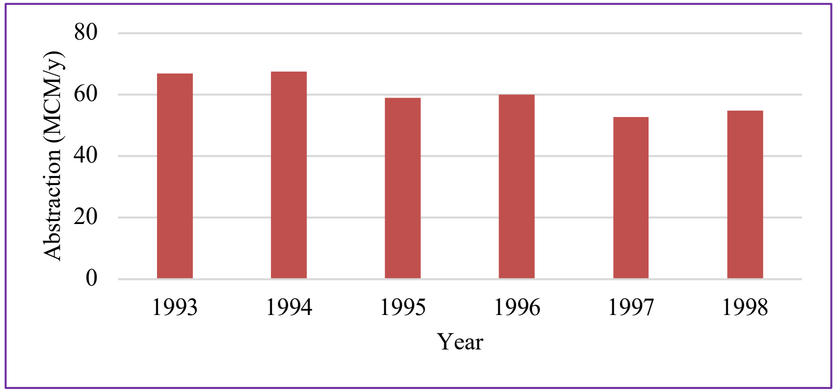


Figure B 9.22 Abstraction from wells in 1993 and 1994 from Yarmouk tributary basin in Jordan. *Source*: (Margane et al., 1995)

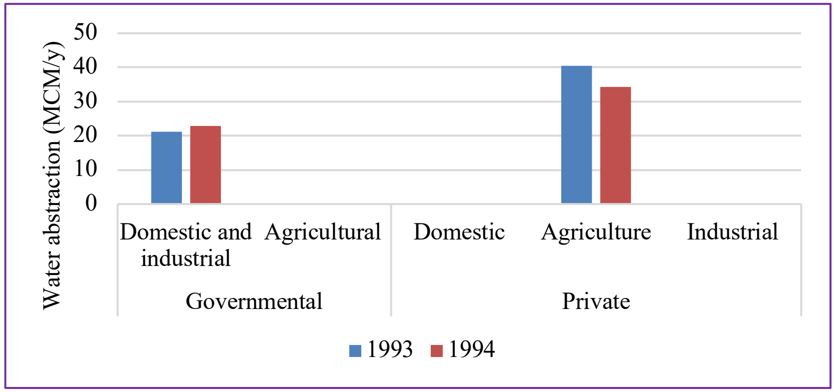


Figure B 9.23 Groundwater abstraction in Yarmouk and Wadi al Arab in Jordan between 1993 and 1998. *Source*: WAJ files in Hobler et al. (2001).

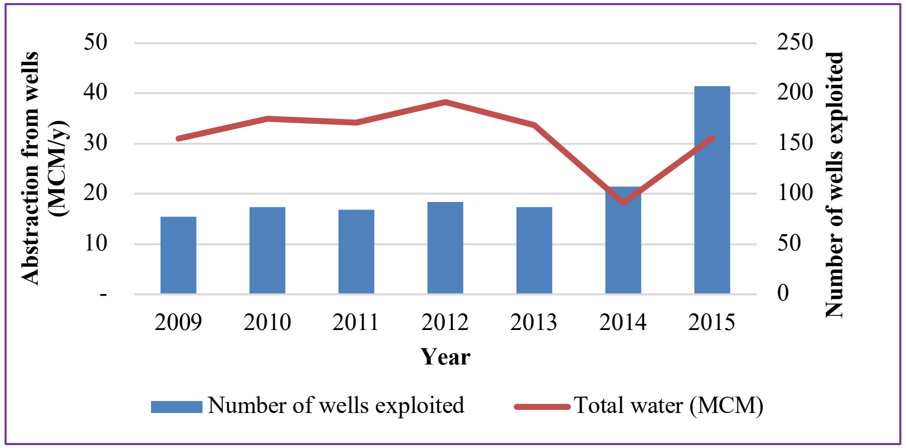


Table B 9.16 Summary of the resources used for water-quality parameters. Highlight denotes the parameters used effectively as thresholds. *Source*: Authors, based on multiple sources listed in the text.

		Drinking	**Irrigation**	
Parameter	**Unit**	**EU**	**IWG_1**	**IWG_2**
Ammonium	mg/l	0.3	Not mentioned	Not mentioned
Bicarbonate	mg/l	Not mentioned	< 120	Not mentioned
Boron	mg/l	1	0.2 - 0.8	< 0.5: Optimal 0.5-1: Crops very sensitive to B accumulate toxic levels (root uptake), they start to display symptoms of foliar injury and/or yield decreases.
Calcium	mg/l	Not Mentioned	40 - 120	Not mentioned
Chloride	mg/l	250	< 140	<100: Should prevent the accumulation of Cl to toxic levels in plants. <140: Should prevent the accumulation of Cl to toxic levels except the most sensitive plants 140 – 175: Slight problems with the accumulation of Cl to levels toxic to crops.
E. coli	MNP/100 ml	0	Not Mentioned	<1: Optimal, will not lead to spread of human pathogens 1-1000: Likelihood of contamination from vegetables and other. Fruit trees and grapes may be irrigated but fruits not wetted, crops and pastures not consumed raw can be irrigated and they should dry before harvesting. >1000: No contact is allowed to take place with humans, water can be used in irrigation to produce fodder, tree plantations, nurseries, parks ...
EC	us/cm = 640 ppm	Not Mentioned	<1.5 (960): desired range >1.5 (960): potential problem >3.0 (1920): will burn under certain conditions	Not mentioned
Magnesium	mg/l	30 if sulfate > 250. If less sulfate, up to 125 allowed	6 to 24	Not mentioned
Nitrate (NO3)	mg/l	50	Not mentioned	Not mentioned

		Drinking	Irrigation	
Parameter	**Unit**	**EU**	**IWG_1**	**IWG_2**
Nitrite (NO2)	mg/l	0.5	Not mentioned	Not mentioned
pH		Not Mentioned	5.5-6: Ideal >7: Can cause tank mix problems	< 6.5: Acidic, increasing problems with foliar damage when the crop foliage is wetted. Could give rise to yield reduction or decrease in the quality of marketable materials. Increasing problems with availability of several micro- and macro-nutrients in toxic concentrations over the long term. Increasing problems with corrosion of metal in irrigation equipment is experienced. 6.5 - 8.4: Optimal, should not cause damage. > 8.4: increasing problems with foliar damage affecting yield. In soil, nutrients can become unavailable. Problems at equipment with encrustation of irrigation pipes and clogging of drip irrigation systems.
Potassium	mg/l	Not mentioned	5 to 10	Not mentioned
SAR - Sodium Adsorption Ratio		250	< 400: good > 400: will acidify the soil	Not mentioned
Sodium	mg/l	200	0-50	< 70: Target number. Should prevent the accumulation of Na to toxic levels in all but the most sensitive plants. 70-115: Crops sensitive to foliar absorption accumulate toxic levels of Na when crop foliage is wetted. 115-230: Crops moderately sensitive to foliar absorption accumulate toxic levels of Na when crop foliage is wetted.
Sulfate	mg/l	250	< 400: good > 400: will acidify the soil	Not mentioned
Total Nitrogen	mg/l	Not Mentioned	Not mentioned	<5: Target number. Does not affect even the sensitive crops. 5-30: Sensitive crops increasingly likely to be affected, other crops remain largely unaffected in 1 concentration. > 30: Most crops are affected. Severe restrictions are placed on the utilisation of these waters.

REFERENCES

Please refer to the main text of the Yarmouk Hydropolitical Baseline study.