Delineation of Groundwater Protection Zones for Tanoor and Rasoon Springs

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Bundesanstalt für Geowissenschaften und Rohstoffe

On behalf of:

DEUTSCHE ZUSAMMENARBEIT

TECHNICAL REPORT

Delineation of Groundwater Protection Zones for Tanoor and Rasoon Springs

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Abbreviations

BGR	Bundesanstalt für Geowissenschaften und Rohstoffe (Federal Institute for Geosciences and Natural Resources), Hannover/Germany
BMZ	Bundesministerium für Wirtschaftliche Zusammenarbeit und Entwicklung (Federal Ministry for Economic Cooperation and Development), Bonn/Germany
COP	Flow **C**oncentration, **O**verlying layers, and **P**recipitation – Method for the definition of groundwater vulnerability
DoS	Department of Statistics, Jordan
E.C.	Electrical conductivity
E. Coli	Escherichia Coli
GIZ	Gesellschaft für Internationale Zusammenarbeit GmbH, Eschborn, Germany
GPS	Global Positioning System
LMWL	Local Meteoric Water Line
m.a.s.l	Meters above sea level
l/c/a	Liter per capita per year
MCM	Million Cubic Meters
MPN	Most Probable Number
MWI	Ministry of Water and Irrigation, Amman/Jordan
NRA	National Resource Authority, Amman/Jordan
RSCN	Royal Society for the Conservation of Nature, Jordan
TOC	Total Organic Carbon
USDA	United States Department of Agriculture
WAJ	Water Authority of Jordan, Amman/Jordan

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Summary

Authors: Florian Brückner, Mohammad Al Hyari, Tasneem Hiasat, Ayman Jaber, Adel Obaiat, Mohammad Qadi, Mathias Toll, Batool Beni-Mustafa

Title: Delineation of Groundwater Protection Zones for Tanoor and Rasoon Springs

Keywords: Jordan, Karstic Springs, Olive Mill Wastewater,

Tanoor and Rasoon springs in the northern highlands of Jordan are the main source for local water supply. They are frequently affected by pollution with coliform bacteria and wastewater from olive oil extraction. A monitoring system was installed to characterise spring chemistry and pollution in response to precipitation. This is the first time that the effect of olive oil wastewater has been studied in a high temporal resolution. The measurements show a fast response of spring water chemistry to precipitation as a result of the karstic nature of the aquifer.

1 Introduction

Due its importance for the local domestic water supply of the surrounding villages (they supply 20% of the population in the Ajloun governorate), Tanoor and Rasoon springs were selected by the technical cooperation project "Water Aspects in Land Use Planning", which is currently implemented by the Jordanian Ministry of Water and Irrigation (MWI) and the German Federal Institute for Geosciences and Natural Resources (BGR). The project focuses on the delineation of groundwater protection zones according to the Jordanian "Water Resources Protection Guideline", which has been issued in 2006 and updated in 2011.

The springs discharge from an Upper Cretaceous limestone, which is strongly karstified in the area. The karstic nature of the spring catchment increases its vulnerability to contamination significantly. The relatively high precipitation in the area is also an important factor that enhances the pollution risk in the springs especially in combination to the presence of the karstic features.

Frequent contamination events have been recorded in both springs during the last few years that obliged Water Authority of Jordan (WAJ) directorate in Ajloun to stop pumping water from the springs for periods between several days to a few weeks. The majority of the contamination events occurred during the rainy season, which usually extends from October to April.

Olive oil extraction represents one of the major agro-industries of Ajloun and the surrounding areas and the majority of agriculturally used lands in this area are olive groves. The oil production period extends from October to February. Olive oil extraction produces high amounts of wastewater as a by-product of the milling process. This wastewater, which is locally called "Zeebar", has a high pollution load, so it cannot be treated in conventional wastewater treatment facilities and requires collection in isolated pools and transportation to special disposal sites by tanker trucks.

Zeebar contains high amounts of toxic organic compounds (mainly Polyphenols), which endanger groundwater quality. Many visible pollution signs such as black colour, organic odour, and white foam were observed in Tanoor spring after some precipitation events, due to the contamination by Zeebar.

In Rasoon, bacteriological contamination with E. coli is the most frequent kind of contamination. It is highly correlated to precipitation and thus usually occurs during the rainy season. The most probable source for this kind of contamination are the cesspools of the houses in the surrounding villages, which are apparently not sealed properly and leak to the groundwater.

2 Description of the Working Area

2.1 Socio-Economic Conditions

The watershed of the springs lies almost entirely in Ajloun governorate, that comprises five municipalities: Ajloun Al-Kubrah, Kufranjah Jadedah, Janed, Shafa, and Al-Ayoun (Figure 1). The working area is located in Al-Ayoun municipality that consists of 9 villages, two of which are adjacent to the springs: Irjan at Tanoor spring and Rasoon at Rasoon spring.

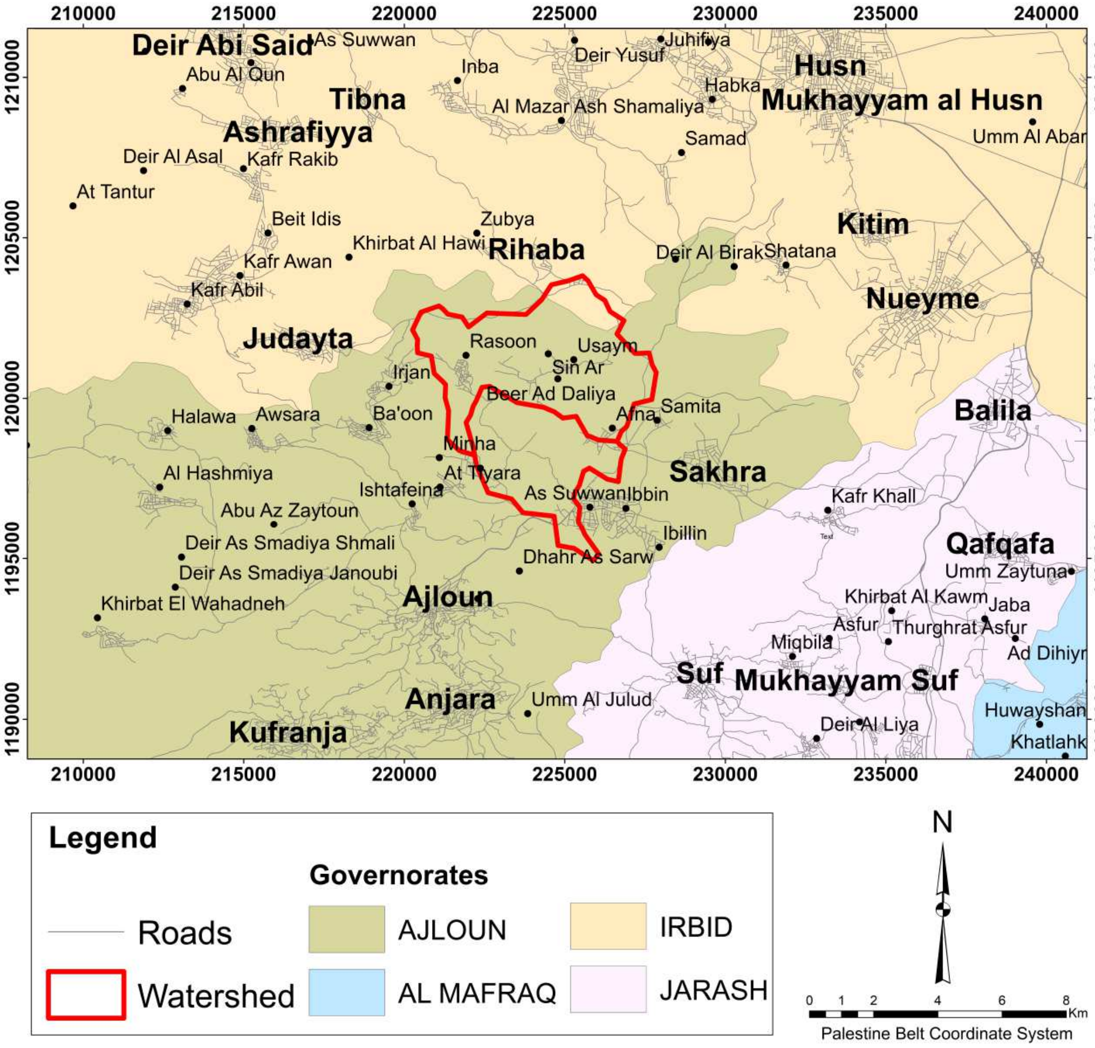


Figure 1 Administrative boundaries in the working area

According to 2014 Census by the Department of Statistics (DoS, 2015), the total population in Al-Ayoun municipality was 19,686. The nine villages of Al-Ayoun municipality and their population are shown in Table 1.

Table 1 Population of the Al-Ayoun municipality by villages and sex in 2014

	Village	Male	Female	Total
Al-Ayoun Municipility	Um El-Yanabie'	154	132	286
	Irjan	3,425	3,122	6,547
	Ba'oon	2,433	2,357	4,790
	Rasoon	1,376	1,308	2,684
	Awsara	1,128	1,018	2,146
	Sena'ar	467	435	902
	Merjam	752	677	1,429
	Asiem	331	293	624
	Bier Eddalyeh	148	130	278
	Total	**10,214**	**9,472**	**19,686**

Socioeconomic conditions in the communities close to the protection zones are an important factor for the effectiveness of the implementation of restrictions and the planning of awareness campaigns. The poverty rate in Ajloun Governorate in 2010 was 25.6% (DoS, 2006). Enrolment in elementary and secondary schools is high, decreasing to about 22.6 % for the age group 20 – 24 (Table 2).

Table 2 : Percentage of enrolled population by age in Ajloun governorate

Age Group	Percentage of enrolled population
5	14.5
6-9	99.1
10-14	98.9
15-19	74.0
20-24	22.6
Total	**72.4**

The population is mainly composed of the following tribes (DoS, 2013): Al-Qudah, Al-Share, Al-Zghoul, Al-Momani, Al-Smadi, Al-Shwayyat, Al-Freihat, and Al-Khatatbah.

Muslims make up the majority of Ajloun's population, but there are Christian minority groups especially in Ajloun City.

The area of the governorate is mainly rural and agriculture is the main occupation. The Ajloun Mountains are famous for their lush vegetation and thick green forests and a good place for hikes. Its highest mountain peaks reach up to 1,268 m.a.s.l. Ajloun forest reserve (Figure 2) was established in 1987 and is managed by RSCN. It comprises an area of 13 km^2 adjacent to the springs (RSCN, 2015) and is protected by a fence.

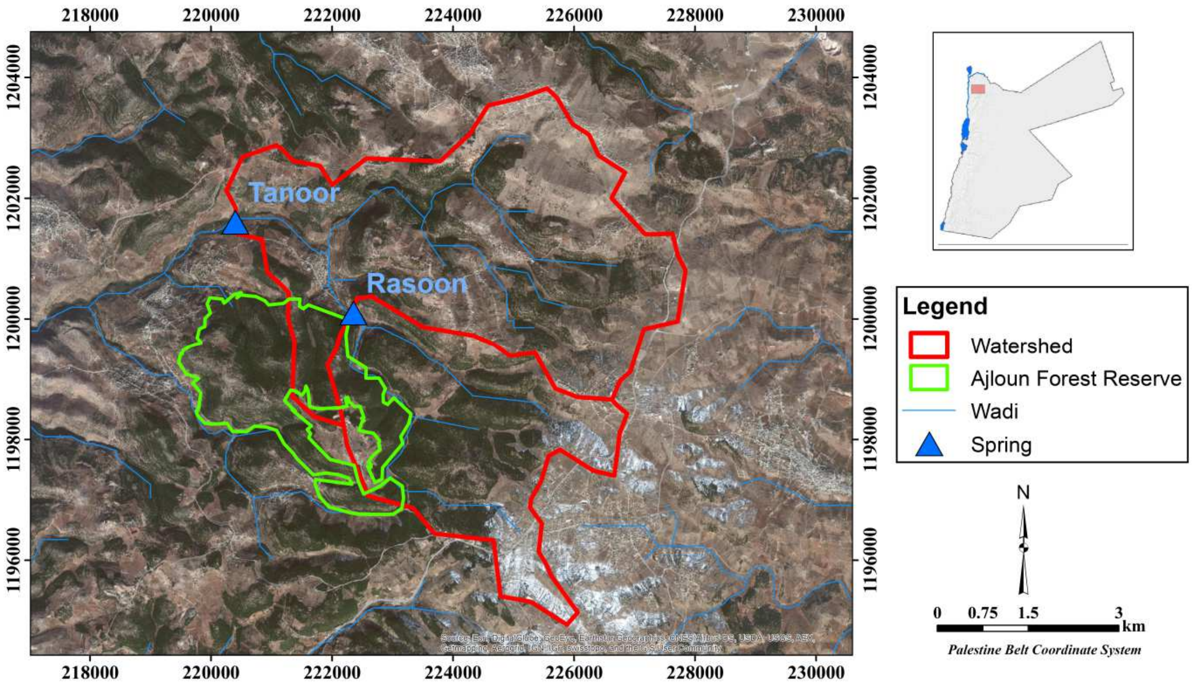


Figure 2 Location of Ajloun forest reserve

2.2 Topography

The working area is located between the major cities Jarash and Irbid and covers an area of 600 km^2, between the coordinates PBN 1190000 and 1210000 and PBE 210000 and 240000. It comprises three main physiographic regions: the upper part of the Jordan valley escarpment in the east, the mountainous Jordan highlands in the centre, and the Jordan plateau in the northeast. The transition from the Jordan Valley to the highlands is characterised by a pronounced topography with changes in elevation from around 50 m.a.s.l. to more than 1100 m.a.s.l. in the central working area (Figure 3). This structure is called Ajloun Dome and is deeply incised by wadis disposed in a radial pattern. This can be well observed on the slope map (Figure 4) which shows the steepest slopes at the wadi courses.

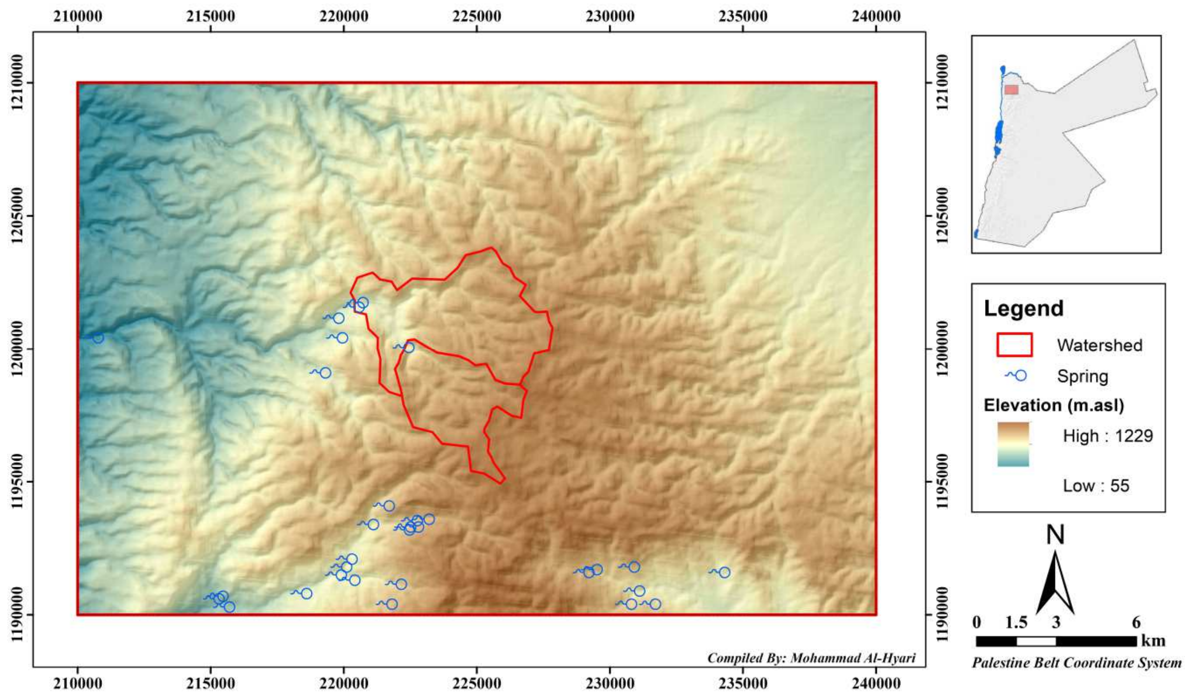


Figure 3 Topography of the working area

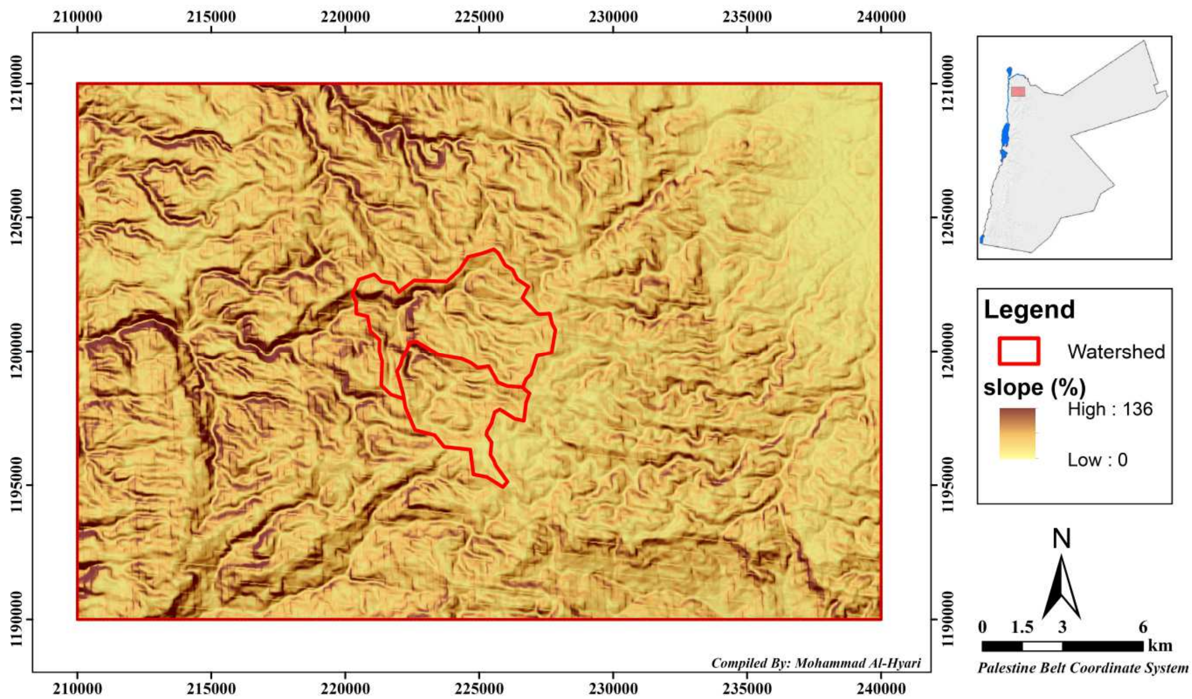


Figure 4 Slope map of the working area

2.3 Climate

The climate in the working area is of Mediterranean type, characterised by hot summers without any precipitation and wet, cool winters. The average monthly rainfall at Ras Mouneif station as well as average minimum and maximum temperatures are given in Figure 5. The northern highlands are one of the regions in Jordan that receive most rainfall with a long term average of 600 mm/a. Most precipitation falls during single storm events and snow is common in winter.

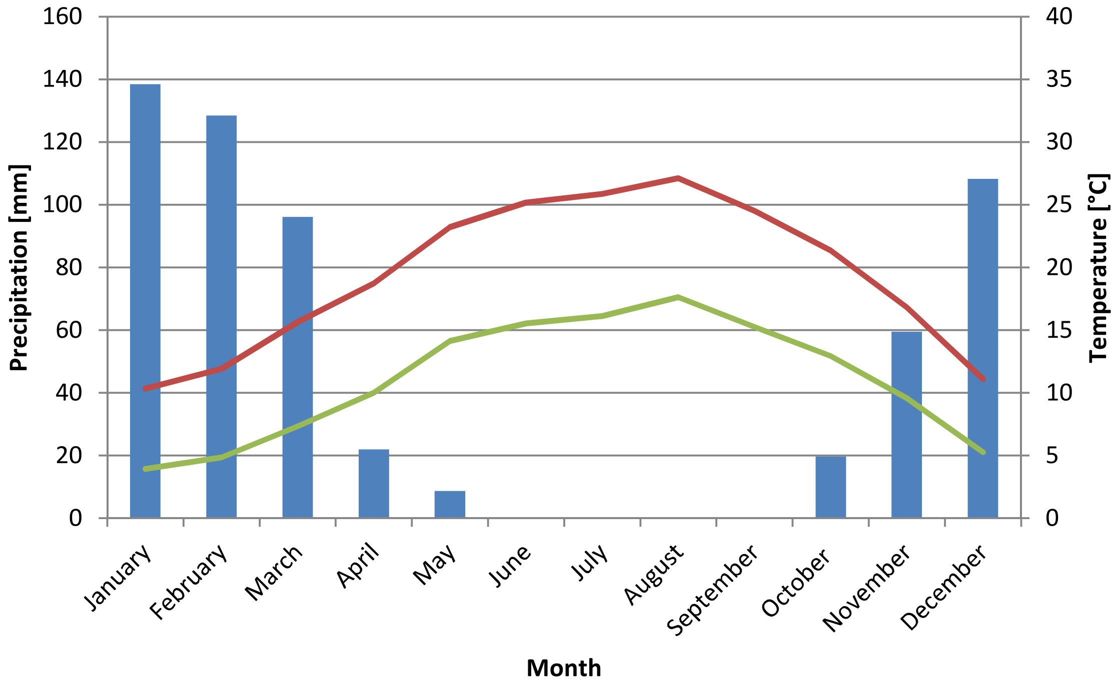


Figure 5 Average monthly precipitation as well as average maximum (red line) and average minimum (green line) temperatures at Ras Mouneif station 2012 – 2015.

There are 10 rainfall stations inside the working area and three close to the working area (Table 3). Several stations have been equipped with telemetry data transmission over the course of the last years (Table 3) and data is since recorded manually/semiautomatically and telemetrically at the same time. In this report, manual/semiautomatic data was used because of long term availability. The location of the rainfall stations is shown in Figure 6.

Table 3 Rainfall stations in the working area

Name	Records since	Records until
DEIR ABI SAID	29/10/1937	09/05/2014
KUFR AWAN	16/10/1937	08/05/2014
HUSN	22/11/1942	09/05/2014
EN NUEYME	27/10/1955	09/05/2014
RIHABA	03/01/1963	10/05/2014
IRJAN	09/11/2012	07/01/2013
QAFQAFA	17/11/1950	09/05/2014
KUFRINJA	14/11/1937	09/05/2014
AJLOUN POLICE POST	25/12/1937	09/05/2014
RAS MUNEIF EVAP. ST	22/10/1968	09/05/2014
ISHTAFEINA	11/11/1952	09/05/2014
IBBIN	08/11/1937	09/05/2014
KH.EL-WAHADNEH	21/10/1950	09/05/2014

Table 4 Stations equipped with telemetry

Name	Implementing Project	Start of measurement	Measurement frequency
DEIR ABI SAID	Tewaron 1	03/02/2011	hourly
HUSN	Tewaron 2	23/04/2012	daily
AJLOUN POLICE POST	Tewaron 2	23/04/2012	daily
RAS MUNEIF EVAP. ST	Tewaron 2	23/04/2012	daily
RIHABA	Tewaron 4	25/11/2015	daily
QAFQAFA	Tewaron 4	25/11/2013	daily
ISHTAFEINA		12/04/2015	daily
EN NUEYME	-	14/04/2015	hourly

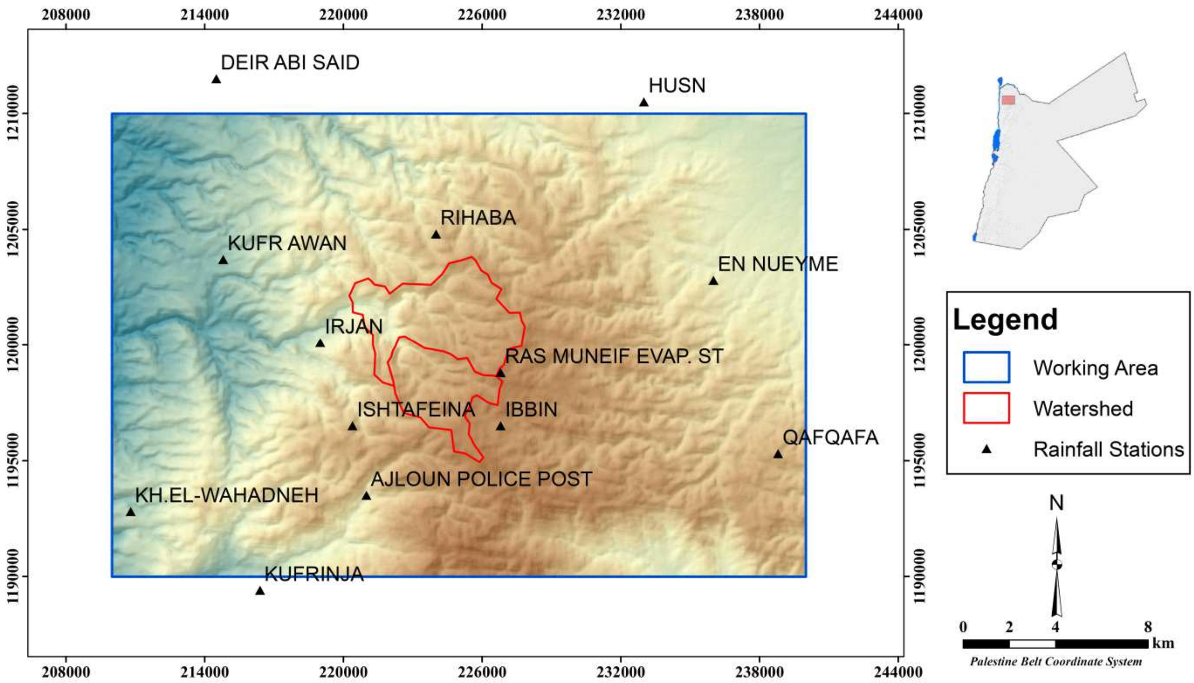


Figure 6 Distribution of rainfall stations in the working area

Rainfall in the area is highly variable with strong differences between dry and wet years. Figure 7 shows the long term rainfall record for Ras Mouneif station. The x-axis is on the 30 year average rainfall of 562 mm/a. Maximum precipitation was measured in 1991/1992 with 1151 mm. Minimum precipitation of 265 mm was measured in 1998/1999 and 2013/2014. In Jordan, there is no universal definition of wet and dry year. Therefore, in this report the definition used in the COP-method for groundwater vulnerability mapping (e.g. Vías et al., 2006) is adopted. There, a wet year is defined as a year with at least 115% percent of the long term average. Correspondingly, a dry year is a year with 85% of average precipitation or less. In the period 1984-2013, there were eight wet years (above the green line) and nine dry years (below the red line). The trend line (black line) shows a general decrease of precipitation over the last 30 years.

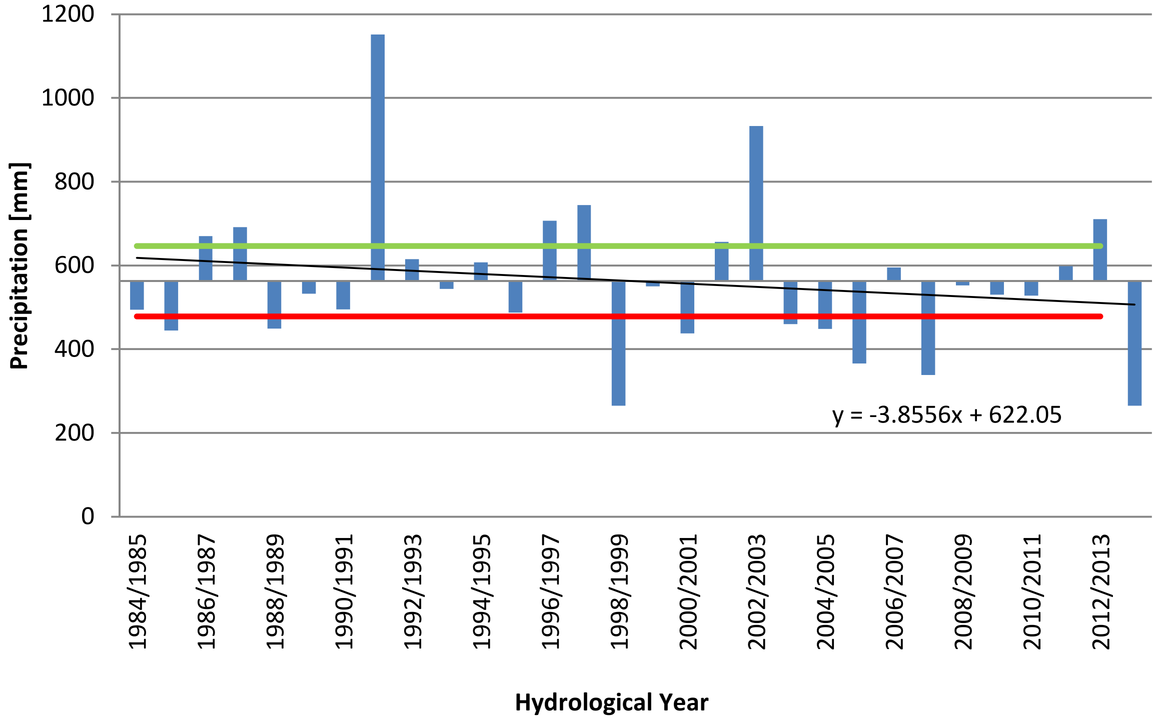


Figure 7 Long term rainfall record for Ras Mouneif evaporation station. Green line: wet year lower limit. Red line: dry year upper limit

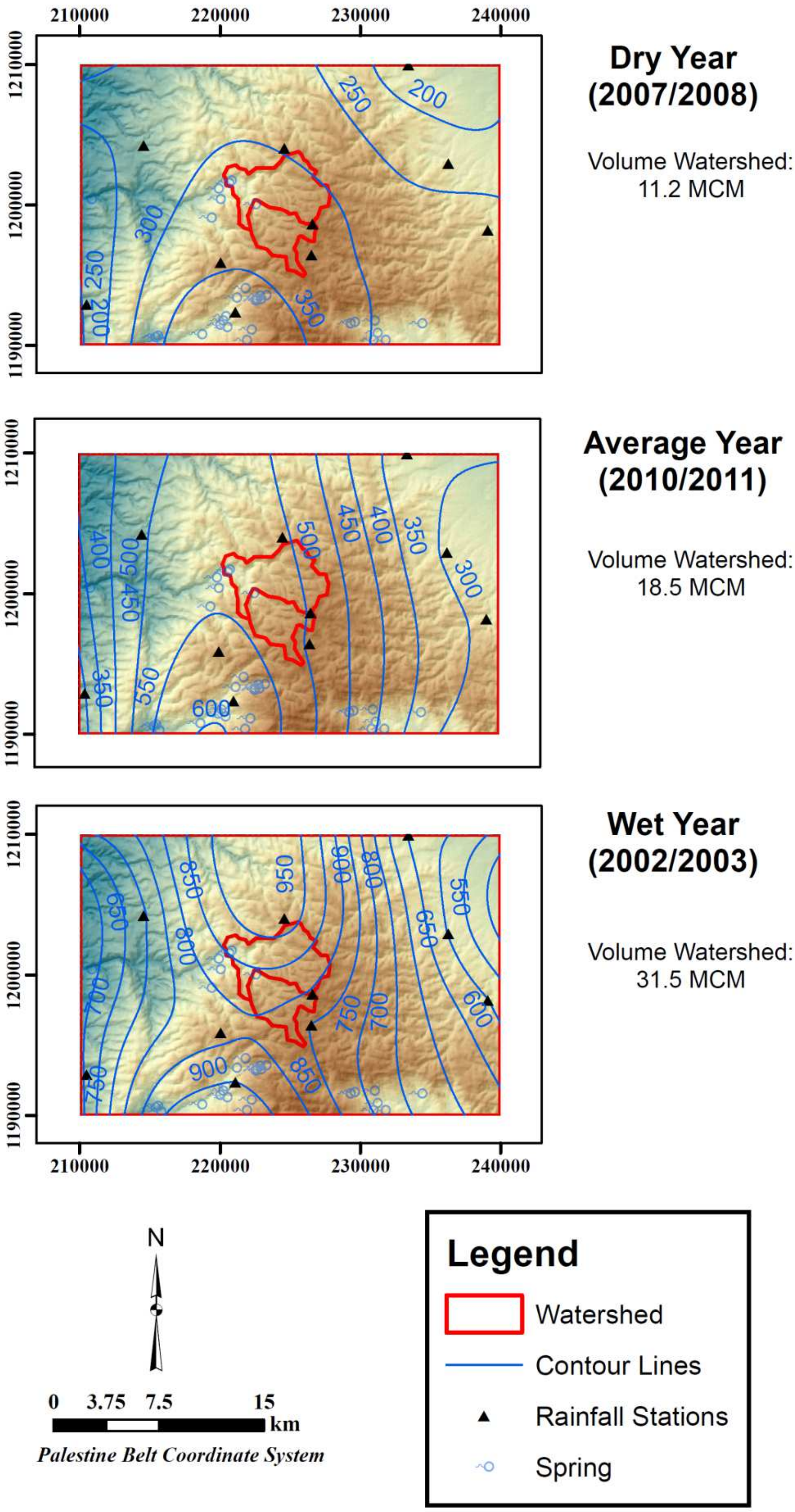


Figure 8 Rainfall contours [mm/a] for a dry, average and wet year

Figure 8 shows the rainfall distribution for a dry year, an average year and a wet year. In order to preserve precipitation patterns, examples for individual hydrological years are shown instead of average values. The variation of rainfall quantities is strong: in the exceptionally wet year 2002/2003, the precipitation was almost three times that of the dry year 2007/2008. Highest rainfalls are usually recorded at Ajloun police station in the southern centre of the working area. In general, precipitation amounts increase with elevation from west to east up to the Ajloun Mountains and then decrease further to the east due to the rain shadow of the mountains. For better interpolation results, data from the following precipitation stations outside of the study areas were used: Al-Tayibiba, Wadi Al-Yabis, Midwar, Kitta, Khanasira, Jarash, Hawwara and Deir Alla Agr. Station.

Other climatic parameters (Table 5) are available for two stations, Ras Mouneif and Deir Abi Said. Data for Ras Mouneif is available until 1973 and again from mid 2012 onwards, after the installation of a telemetric station. Records for Abi Said also started with the implementation of a telemetric station in mid 2011.

Table 5 Measured parameters at Ras Mouneif and Abi Said telemetric stations

Station	Ras Mouneif	Abi Said
Measurement frequency	daily	hourly
Barometric Pressure	x [mbar]	x [hPa]
Wind Speed [m/s]	x	x
Wind direction [degrees]	x	x
Total Solar Energy [MJ/m2]	x	-
Radiation [W/m2]	-	x
Air Temperature [°C]	x [Minimum/ Maximum]	x
Rain sum [mm]	x	x
Sunshine hours [h/day]	x	-
Evaporation [mm]	x (faulty data)	-

Reference evapotranspiration was calculated according to the Penman FAO 56 Method (Allen et al., 1998) that is considered to be the most physically sound method. Because this method needs a lot of input parameters that are rarely available in Jordan, two simplified and more empirical models were also used to check on their usability: Hargreaves (e.g. Hargreaves & Allen, 2003) and Turc (1961). The results are presented in Figure 9 for Abi Said and Ras Mouneif stations.

For Abi Said station the calculations according to Penman and Hargreaves agree fairly well, except in the summer months where there is some deviation. The calculation with the formula of Turc yields similar values in the winter months, but they are significantly lower in the summer months.

Evapotranspiration at Ras Mouneif station was only calculated following the Hargreaves method because of missing values for relative humidity necessary for

the Penman and Turc methods. The values are lower than at Abi Said station, due to lower temperatures caused by the difference in elevation. Monthly potential evapotranspiration varies from around 40 mm/month in winter to around 170 mm/month in summer.

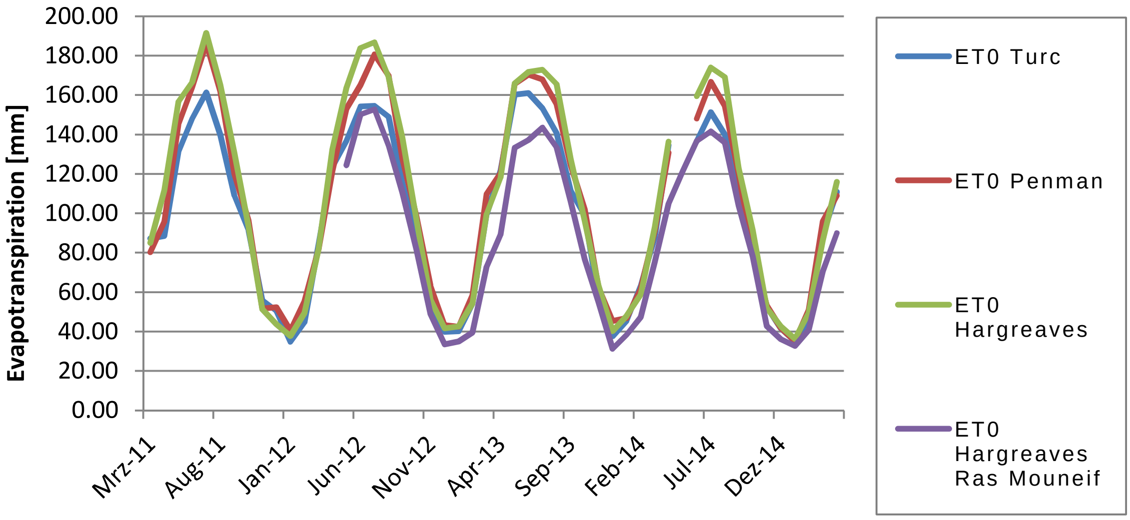


Figure 9 Evaporation at Ras Mouneif and Abi Said stations according to different calculation methods

2.4 Soils

The soil constitutes the natural protection for groundwater depending on its characteristics. Therefore, they need to be well known when it comes to the definition of groundwater protection zones. Several soil groups occur in the working area, as shown in Figure 10. The following paragraphs describe all groups that can be found in the working area according to the report of the Ministry of Agriculture (1993).

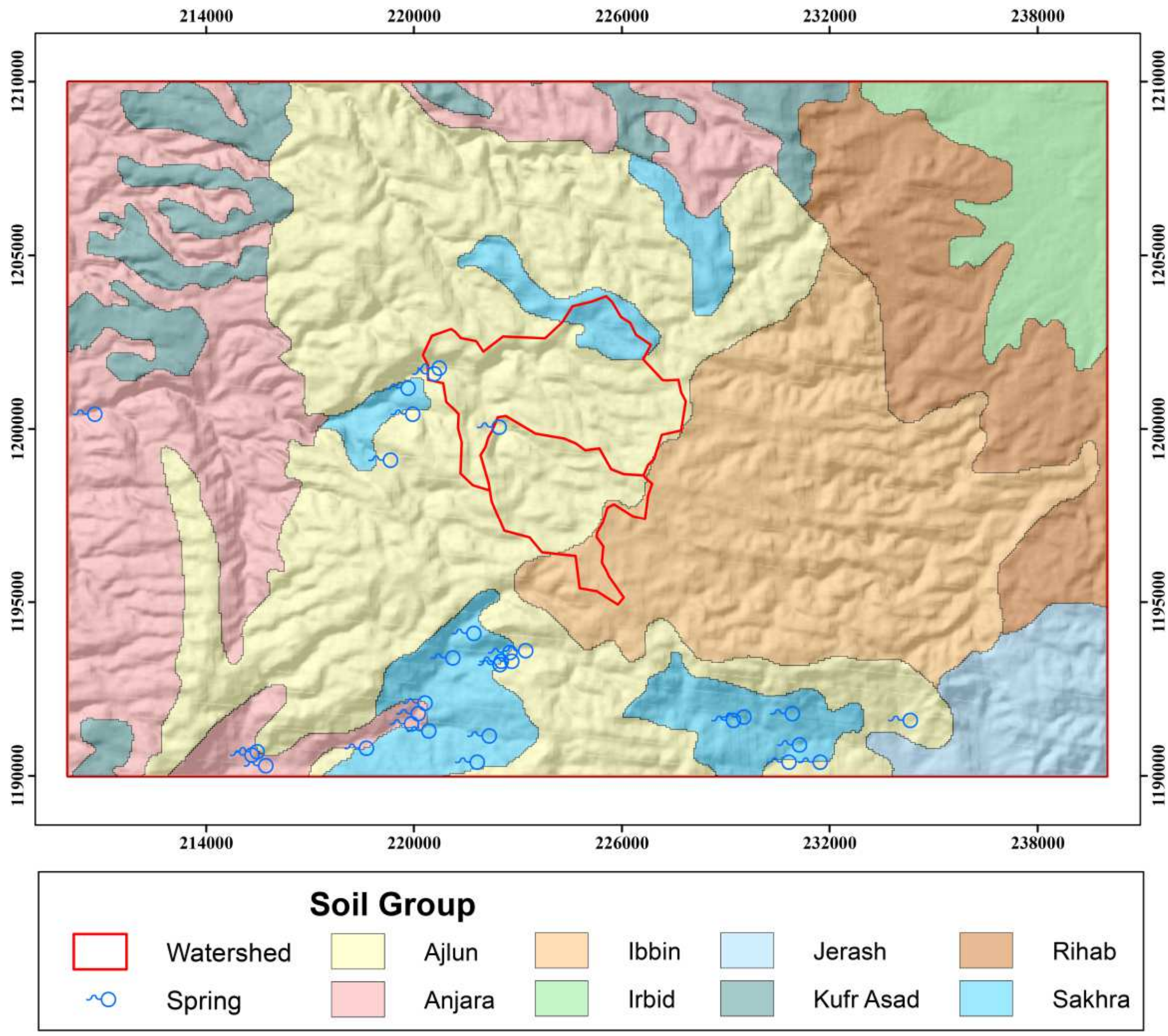


Figure 10 Distribution of soil groups within the working area

Ajloun (AJL)

Physiography: Deeply dissected limestone plateau on rocks of the Ajloun and Belqa Groups. Limestone pavements and rounded crests with karstic features; undulating, colluvially mantled plateau remnants, steeply sloping zone, and steep lower slopes with rock outcrops; the altitude is between 500 and 1200 m.

Taxonomy: Dark brown to dark yellowish brown, fine, mixed, thermic, stony, silty clay and clay. Moderate to coarse, prismatic and medium sub-angular blocky structure. Three main soils subgroups, classified according to USDA soil taxonomy (1975) are presented in the Table 6.

Table 6 Three main soils subgroups of AJL

Subgroup	Clay [%]	Silt/Clay Ratio	E.C. [mS/cm]	$CaCo_3$ [%]
Typic Xerochrept	34	1.90	0.94	19
Lithic Xerochrept	35	1.95	0.81	26
Calcixerollic Xerochrept	36	1.47	0.78	26

Anjara (ANJ)

Physiography: Deeply dissected uplands on Ajloun Group limestones, chalks and marls with narrow convex crests and long steep slopes. The altitude is between 0 and 800 m.

Taxonomy: Brown to reddish brown, fine, mixed, thermic, stony to very stony, silty clay and silty clay loam, moderate to strong medium sub angular blocky structure, moderately calcareous. Seven soil subgroups are presented in Table 7.

Table 7: Seven subgroups soils of ANJ

Subgroup	Clay [%]	Silt/Clay Ratio	E.C. [mS/cm]	$CaCo_3$ [%]
Typic Xerochrept	34	1.90	0.94	19
Lithic Xerochrept	35	1.95	0.81	26
Calcixerollic Xerochrept	36	1.47	0.78	26
Vertic Xerochrept	45	1.00	0.55	12
Typic Chromoxererts	48	0.93	0.63	12
Typic Haploxerolls	52	0.81	0.68	6
Lithic Xerorthent	33	1.68	0.88	26

Rihab (HAB)

Physiography: Moderately dissected limestone plateau on Ajloun and Belqa Group rocks. Convex crests on limestone with karst features, low rocky ridge. The altitude is between 800-950 m.

Taxonomy: Reddish brown to yellowish red, fine, mixed, montmorillonitic, thermic, silty clay and clay moderate to strong medium sub angular blocky structure, calcareous and non-saline with calcite horizon. Four soil subgroups are presented in Table 8.

Table 8: Four subgroups soils of HAB

Subgroup	Clay [%]	Silt/Clay Ratio	E.C. [mS/cm]	$CaCo_3$ [%]
Calcixerollic Xerochrept	36	1.47	0.78	26
Lithic Xerochrept	35	1.95	0.81	26
Vertic Xerochrept	45	1.00	0.55	12
Typic Chromoxererts	48	0.93	0.63	12

Ibbin (IBB)

Physiography: Undulating to rolling dissected plateau on limestone of the Ajloun and Belqa Groups including Wadi As Sir Limestone and Amman Silicified Chert Limestone. Rocky Plateau and crest with limestone pavement and convex crests from the highest part of the unit. Colluvially mantled plateau remnants are eroded and produce steep limestone-banded slopes towards incised wadis with alluvial infills in the wider wadis. The altitude is between 850 - 1100 m.

Taxonomy: Dark reddish brown to dark brown, fine, mixed, thermic, stony silty clay and clay, moderately to strong medium sub angular blocky structure, weakly and non-calcareous and non-saline. Five subgroups soils found presented in the Table 9.

Table 9: Five subgroups soils of IBB

Subgroup	Clay [%]	Silt/Clay Ratio	E.C. [mS/cm]	$CaCo_3$ [%]
Typic Xerochrept	34	1.90	0.94	19
Lithic Xerochrept	35	1.95	0.81	26
Lithic Xerorthent	33	1.68	0.88	26

Subgroup	Clay [%]	Silt/Clay Ratio	E.C. [mS/cm]	$CaCo_3$ [%]
Vertic Xerochrept	45	1.00	0.55	12
Typic Haploxerolls	52	0.81	0.68	6

Irbid (IRB)

Physiography: the Irbid soil consists of Quaternary alluvium, colluvium and loss overlying a gently undulating plain formed in Belqa Group limestone and Chart. Basalt outcrop locally near Irbid and the wadi Esh Shallala. Low hills capped by calcrete outcrop locally, the western margins include a moderately slop in colluvial plain. In the north, local areas of Quaternary deposits overly basalt. Calcrete hills outcrop in a few places and the plains are moderately incised by wadis. The altitude varies from 350 – 750 m with

Taxonomy: Dark reddish brown and dark brown to brown, fine, mixed, montmorillonitic, thermic, deeply and widely cracked soils with very well developed wedge shaped aggregates and major slickensides, weakly to strongly calcareous and non-saline. These soils represents the most fully developed of the Jordanian vertisol which occur predominantly on forest. Four subgroups soils found presented in the Table 10.

Table 10: Four subgroups soils for IRB

Subgroup	Clay [%]	Silt/Clay Ratio	E.C. [mS/cm]	$CaCo_3$ [%]
Typic Chromoxererts	48	0.93	0.63	12
Calcixerollic Xerochrept	36	1.47	0.78	26
Typic Xerochrept	34	1.90	0.94	19
Vertic Xerochrept	45	1.00	0.55	12

Jarash (JER)

Physiography: deeply dissected plateau within the Ajloun Group limestones with narrow rounded interfluve crests, long, steep slopes on upper and middle slopes with banded rocks outcrops, colluvial mantles of middle and lower slopes. The altitude varies from 350m- 1000m, with relative relief of up to 250m.

Taxonomy: Dark brown and reddish brown to brown, fine, mixed, clayey-skeletal, thermic, clay and silty clay, moderately to strong medium sub angular blocky structure, moderately calcareous and non-saline. Four subgroups soils found presented in the

Table 11.

Table 11: Four subgroups soils of JER

Subgroup	Clay [%]	Silt/Clay Ratio	E.C. [mS/cm]	$CaCo_3$ [%]
Typic Xerochrept	34	1.90	0.94	19
Calcixerollic Xerochrept	36	1.47	0.78	26
Lithic Xerorthent	33	1.68	0.88	26
Lithic Xerochrept	35	1.95	0.81	26

Kufr Asad (KUF)

Physiography: Dissected undulating limestone plateau remnant on Ajloun Group limestone and Quaternary basalt in the north. The unit consists of adulating limestone covered by fluvial and losses material, steep upper slopes to the Anjara unit, karstic features with colluvial pockets, undulating slopes on limestone with colluvium, occasionally with basalt admixture. The altitude is between 100 - 750 m.

Taxonomy: Dark brown to brown, fine, mixed, clayey-skeletal, thermic, clay and loam, moderate to weak medium and coarse sub angular blocky structure, has a stony surface and up to 25% stone content, weakly or non-calcareous and non-saline. Five subgroups soils found presented in the Table 12.

Table 12: Five subgroups soils of KUF

Subgroup	Clay [%]	Silt/Clay Ratio	E.C. [mS/cm]	$CaCo_3$ [%]
Typic Xerochrept	34	1.90	0.94	19
Lithic Xerochrept	35	1.95	0.81	26
Typic Chromoxererts	48	0.93	0.63	12
Calcixerollic xerochrept	36	1.47	0.78	26
Typic Haploxerolls	52	0.81	0.68	6

Sakhra (SAK)

Physiography: Bouldery, calcareous colluvium of major landslip zones, the colluvium has some sandstone admixture in the lowest part of the unit. The altitude is between 600 -1100 m

Taxonomy: Dark reddish Brown to strong brown, fine, mixed, thermic, stony silty clay and clay, moderately to medium sub angular blocky structure, moderately calcareous and non-saline. Four subgroups soils found presented in the Table 13.

Table 13: Four subgroups soils of SAK

Subgroup	Clay [%]	Silt/Clay Ratio	E.C. [mS/cm]	$CaCo_3$ [%]
Typic Xerochrept	34	1.90	0.94	19
Lithic Xerochrept	35	1.95	0.81	26
Calcixerollic Xerochrept	36	1.47	0.78	26
Vertic Xerochrept	45	1.00	0.55	12

In conclusion, all of the soils have a high clay content of more than 30% that generally decreases aquifer vulnerability. However, the soil thickness is highly variable and rock outcrops do occur. This means that in these areas contamination can bypass the protective soil cover.

2.5 Land Use

A land use map was derived from Pleiades satellite images with 50 cm resolution acquired in November 15th 2013 using image processing techniques (Figure 11). Seven classes were distinguished in the working area based on the reflectance values of the surface.

As the land use map shows (Figure 11), the working area is dominated by forests, followed by farms that are present in most parts of the area (mainly olive groves and to a lesser extent grapes). Shrubs mostly appear in the north-eastern part of the working area, while bare soil is generally located in the northern central part. Soil cover is distributed everywhere in the area and is predominantly used as agricultural land for seasonal vegetables, fruits or cereals.

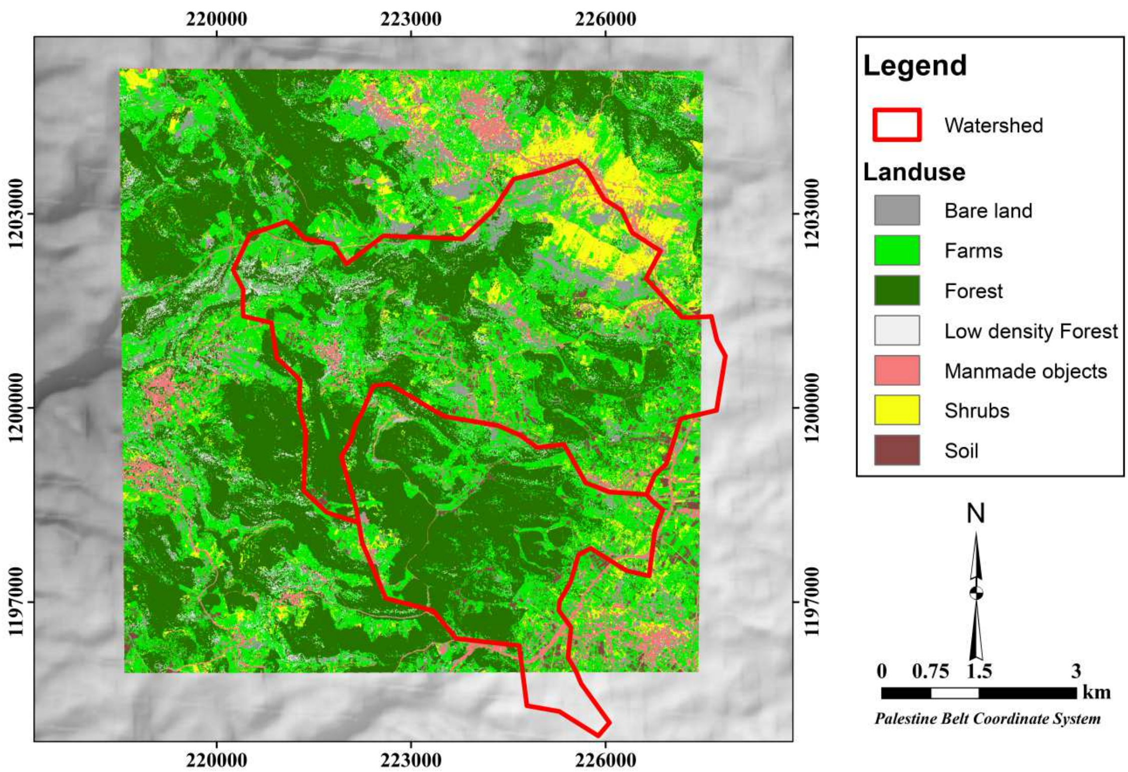


Figure 11 Distribution of land use classes in the watershed

Manmade objects (buildings and streets) appear as clusters (villages and towns) and sometimes as individual farm houses. Also several olive presses exist in the working area. The respective shares of the total area are summarized in (Table 14).

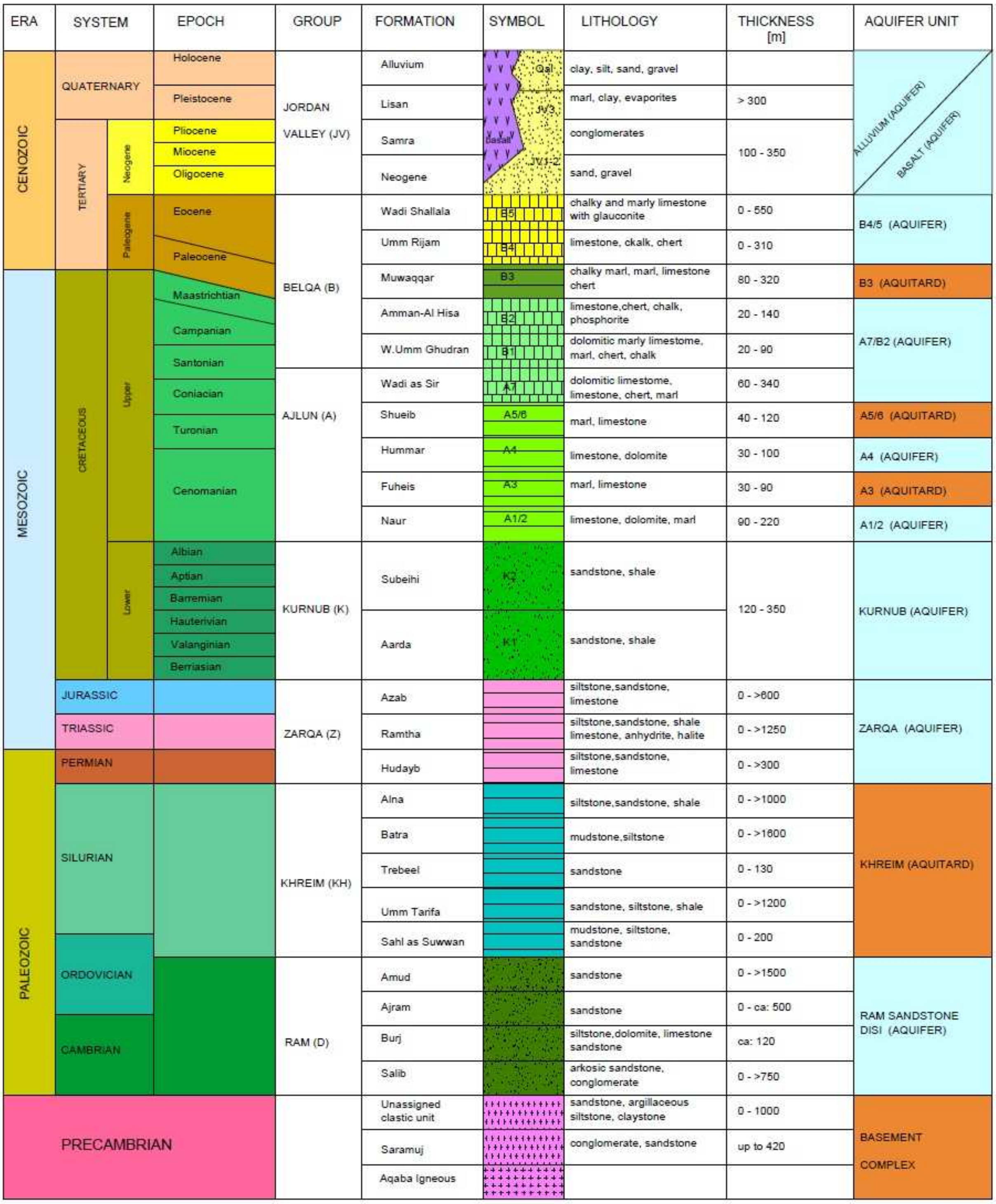
Table 14: Contribution of different land use classes in the working area

Land Use	Area (km²)	Percentage
Natural Forest	38.55	44.50%
Farms	26.16	30.20%
Manmade objects	7.06	8.14%
Shrubs	6.53	7.54%
Bare land	5.95	6.86%
Soil	2.07	2.39%
Shadow	0.31	0.36%
Total area	86.62	100%

3 Geology

3.1 Description of the Geological Units

The main lithologies on the surface are limestone and superficial deposits. Superficial deposits consist mostly of soil cover and alluvium of Quaternary age. Sedimentary rocks consist of limestone and chert of different facies and are of Upper Cretaceous age. The limestones are underlain by the sandstones of Kurnub formation. The stratigraphic chart (Figure 12) gives an overview of all formations in Jordan. It is based on Geological Bulletin No.30 of NRA that accompanies the geological map sheet of Jarash (Abdelhamid, 1995). A geological map was produced from NRA shapefiles (Figure 13).



ERA	SYSTEM		EPOCH	GROUP	FORMATION	SYMBOL	LITHOLOGY	THICKNESS [m]	AQUIFER UNIT
CENOZOIC	QUATERNARY		Holocene	JORDAN VALLEY (JV)	Alluvium	Qal	clay, silt, sand, gravel		ALLUVIUM (AQUIFER) / BASALT (AQUIFER)
			Pleistocene		Lisan	JV3	marl, clay, evaporites	> 300	
	TERTIARY	Neogene	Pliocene, Miocene		Samra	Basalt	conglomerates	100 - 350	
			Oligocene		Neogene	JV1-2	sand, gravel		
		Paleogene	Eocene	BELQA (B)	Wadi Shallala	B5	chalky and marly limestone with glauconite	0 - 550	B4/5 (AQUIFER)
			Paleocene		Umm Rijam	B4	limestone, ckalk, chert	0 - 310	
MESOZOIC	CRETACEOUS	Upper	Maastrichtian		Muwaqqar	B3	chalky marl, marl, limestone chert	80 - 320	B3 (AQUITARD)
			Campanian		Amman-Al Hisa	B2	limestone,chert, chalk, phosphorite	20 - 140	A7/B2 (AQUIFER)
			Santonian		W.Umm Ghudran	B1	dolomitic marly limestome, marl, chert, chalk	20 - 90	
			Coniacian	AJLUN (A)	Wadi as Sir	A7	dolomitic limestone, limestone, chert, marl	60 - 340	
			Turonian		Shueib	A5/6	marl, limestone	40 - 120	A5/6 (AQUITARD)
			Cenomanian		Hummar	A4	limestone, dolomite	30 - 100	A4 (AQUIFER)
					Fuheis	A3	marl, limestone	30 - 90	A3 (AQUITARD)
					Naur	A1/2	limestone, dolomite, marl	90 - 220	A1/2 (AQUIFER)
		Lower	Albian, Aptian, Barremian	KURNUB (K)	Subeihi	K2	sandstone, shale	120 - 350	KURNUB (AQUIFER)
			Hauterivian, Valanginian, Berriasian		Aarda	K1	sandstone, shale		
	JURASSIC			ZARQA (Z)	Azab		siltstone,sandstone, limestone	0 - >600	ZARQA (AQUIFER)
	TRIASSIC				Ramtha		siltstone,sandstone, shale limestone, anhydrite, halite	0 - >1250	
PALEOZOIC	PERMIAN				Hudayb		siltstone,sandstone, limestone	0 - >300	
	SILURIAN			KHREIM (KH)	Alna		siltstone,sandstone, shale	0 - >1000	KHREIM (AQUITARD)
					Batra		mudstone,siltstone	0 - >1600	
					Trebeel		sandstone	0 - 130	
					Umm Tarifa		sandstone, siltstone, shale	0 - >1200	
					Sahl as Suwwan		mudstone, siltstone, sandstone	0 - 200	
	ORDOVICIAN			RAM (D)	Amud		sandstone	0 - >1500	RAM SANDSTONE DISI (AQUIFER)
					Ajram		sandstone	0 - ca: 500	
	CAMBRIAN				Burj		siltstone,dolomite, limestone sandstone	ca: 120	
					Salib		arkosic sandstone, conglomerate	0 - >750	
PRECAMBRIAN					Unassigned clastic unit		sandstone, argillaceous siltstone, claystone	0 - 1000	BASEMENT COMPLEX
					Saramuj		conglomerate, sandstone	up to 420	
					Aqaba Igneous				

Figure 12 Chronostratigraphic chart of Jordan (Margane et al., 2009)

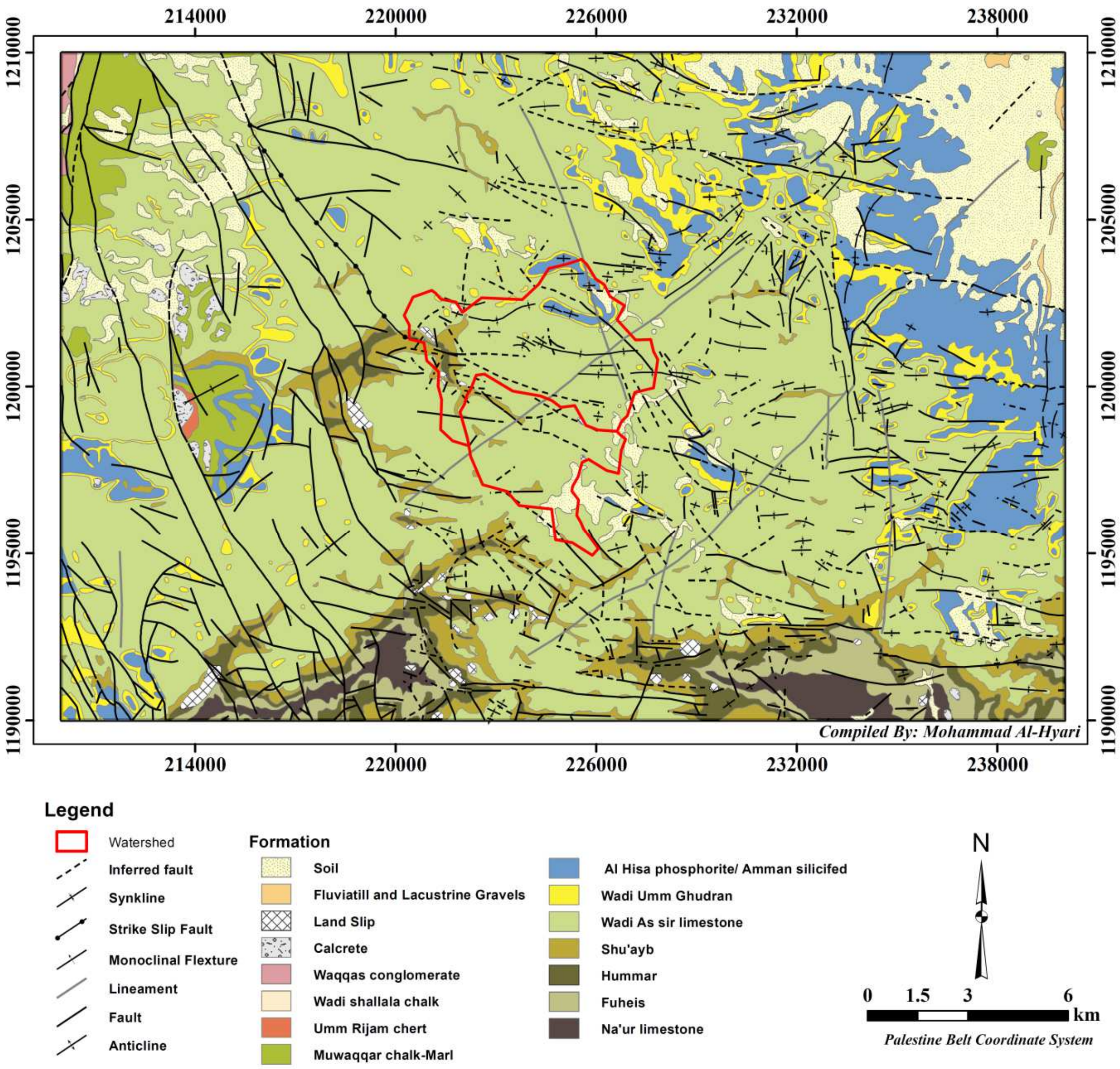


Figure 13 Geological map of the working area

The following paragraphs describe the geological units present in the study area, according to the geological map of Figure 13.

Kurnub Sandstone Group (K)

The Kurnub Group is of Albian to Aptian Age (Lower Cretaceous) and consists of fluvial, medium to coarse grained sandstone in south and central Jordan, with marine intercalations (dolomite and marl) in north-central and north Jordan (Bender, 1974). This unit is not exposed in the study area, but there are extensive outcrops along Zarqa River in the south, where complete sections can be seen. It forms massive yellowish to white grey and varicoloured cliffs separated by poorly exposed friable sandstone, siltstone and shale. It is characterized by gentle slopes and reaches. The thickness reaches up to 350 m.

Naur Limestone Formation (A 1/2)

This formation belongs to the Ajloun Group of Cenomanian age that discomfortably overlies the Kurnub Group. It consists of grey to yellow-grey limestone and dolomitic limestone towards the top of the formation. Medium to thick micritic beds are alternating with beds of marl. Thickness in the region is between 160 to 180 meters, but the formation is poorly exposed in the working area.

Fuheis Formation (A3)

Exposures of this formation are sparse. It crops out along deeply incised wadis and road cuts. The formation consists mainly of yellowish marl and marly nodular limestone. The thickness varies between 60 to 75 meters.

Hummar Formation (A4)

Exposures of this formation are present in central and southern parts of the working area. The formation has a distinctive grey to pink grey colour and vertical to sub vertical cliffs. It is composed of dolomitic to partly dolomitic, recrystallised to micritic limestone and fossiliferous in some places. Thickness of this formation ranges from about 40 to 50m. Elongated karstic solution cavities can be observed in the lower part of the formation.

Shuayb Formation (A5/6)

This soft – weathering formation is exposed in the southern and central parts of the working area. It forms distinctive yellow to yellow-grey gentle slopes. It consists mainly of thin to medium bedded marly limestone, frequently nodular and fossilferous. The thickness of the formation ranges from about 55 to 70m.

Wadi As Sir Limestone Formation (A7)

The Wadi As Sir limestone forms the most extensive outcrops in the working area .It is distinctive by thickly bedded to massive limestone with earthy to grey–weathering colours. It consists of thick beds of dolomite, dolomitic limestone with thin beds of marly limestone layers to thick beds of massive limestone layers. The rocks of the formation have dissolution cavities, dense fractures and minor faults. The thickness of the formation varies between 70 to 220 m.

Wadi Umm Ghudran Formation (B1)

This formation is the lowermost member of the Balqa Group. Outcrops occur in most of the working area above the A7 formation, forming gentle slopes of yellow to white grey fossiliferous chalky limestone, with layers of soft chalky marl. The thickness of this formation ranges from around 20 to 35m.

Amman Silicified Limestone/ Al Hisa Phosphorite Formations (B2)

This undifferentiated unit crops out in most of the working area. It consists of medium to thin bedded silicified limestone with limestone and phosphatic chert. It forms steep slopes with undulating striped tones. The thickness of formation ranges from 50 to 70m.

Muwaqqar Chalk Marl Formation (B3)

This formation has few exposures in the north-east and north-west of the working area. It consists mainly of chalk, marl and chalky marl. This formation is covered by recent sediments like soil, calcrete, and Pleistocene gravels.

3.2 Structural setting

The structural pattern of Jordan is dominated by Dead Sea Rift valley, which is the main structural element governing the geological structures in its adjacent areas. The strata are downthrown into the graben with a vertical displacement of more than 1000 m while the eastern marginal zone has been uplifted relatively so that the Upper Cretaceous rocks are now found in altitudes of more than 1200 m (a.s.l.) and gradually flattening out to the east (Bender, 1974). In the working area north-northeast direction of faults is dominant with major and minor faults parallel to the

Dead Sea rift. Other fault trends are in east – west direction. Most faults are strike–slip faults.

3.3 Karst

The karstic nature of the Ajloun group can be well observed on the surface and in spring hydrographs. Dissolution features are the most common manifestation of karst and occur over wide parts of the study area. Two examples are shown in Figure 14 and Figure 15.

Figure 14 Dissolution features on limestone

Figure 15 Panhole on A7/B2 limestone formation. Note GPS for scale.

While dolines have not been found in the field, there are some caves in the area. A maze cave located around three kilometres northeast of the watershed has been described by Kempe et al. (2009) and is the largest cave found so far in Jordan. A large chamber cave, located just 700 m southeast of Rasoon spring was found during field investigations. Frumkin & Fischhendler (2005) analysed isolated caves in the equivalent formations of the West Bank. They suggest hypogene formation for both types of caves with artesian groundwater conditions responsible for the formation of maze caves, whereas chamber caves are formed close to an unconfined water table. Due to the topographical position, lithology and morphology of the caves their formation is attributed to late Miocene. Some of them have been excavated by erosion following the uplift of the Jordan valley rift shoulders, while a great number is supposed to be still buried and undiscovered.

Just downstream of Tanoor spring, several karst channels have been excavated by the incision of wadi Irjan (Figure 16).

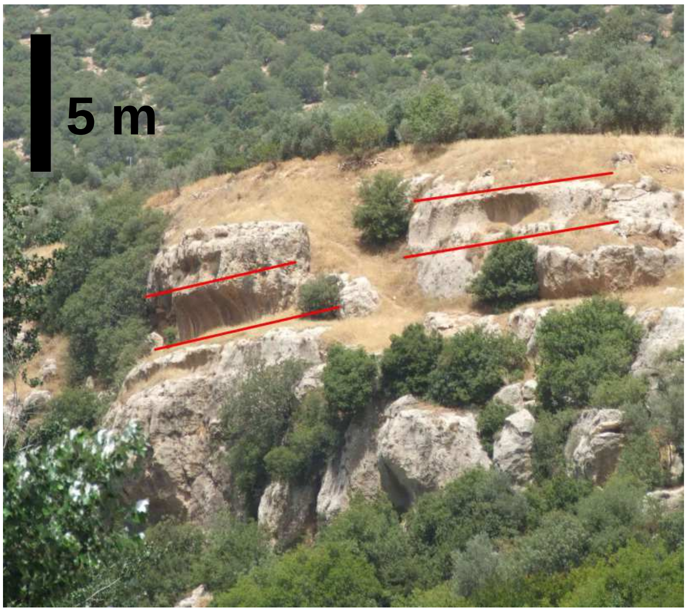


Figure 16 Karst channels downstream of Tanoor spring

4 Hydrology

In the working area, there are three main surface water basins (Figure 17): the Northern Rift Side basin, the Yarmouk basin, and the Amman - Zarqa basin. In general, the drainage network is developed radially from the centre of the working area. The watersheds of Tanoor and Rasoon springs partly lie on the water divide between Yarmouk and Northern Rift Side basins. Since the development of Rasoon and Tanoor springs for drinking water production, outflow towards the wadi has been greatly reduced and the wadis are dry for long periods along the year. Surface discharge is not being monitored in the working area.

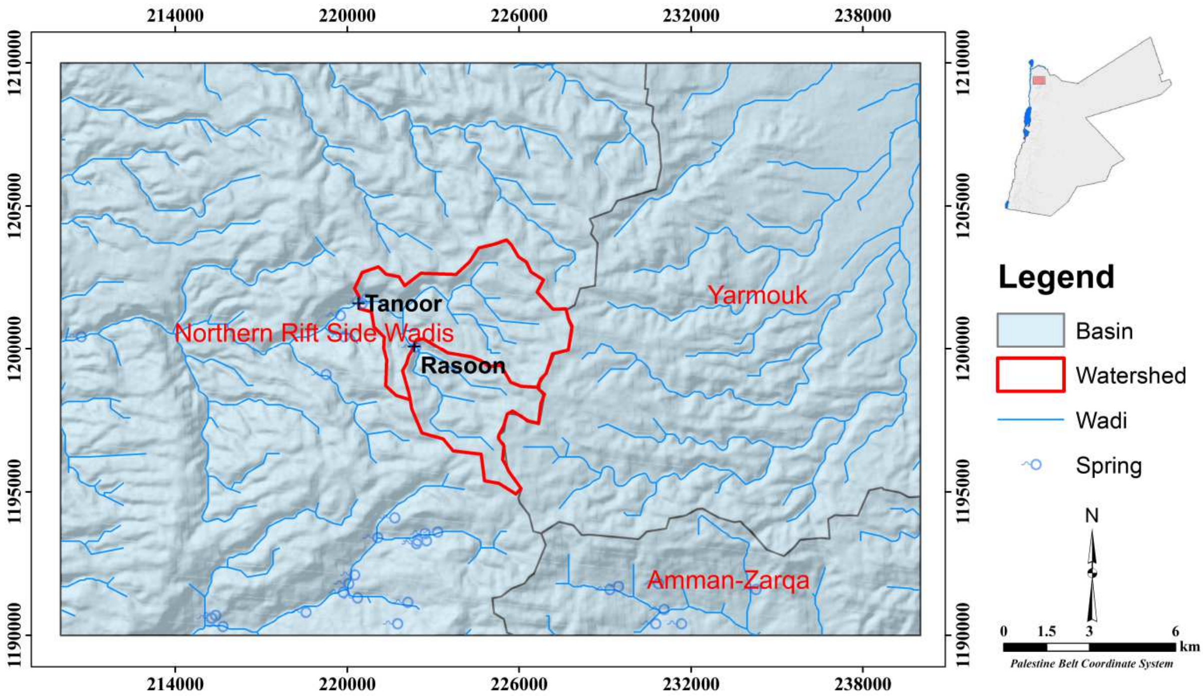


Figure 17 Hydrology of the working area

5 Description of the Water Supply Facilities

Tanoor and Rasoon springs mainly supply the adjacent villages. Excess water is distributed to Ajloun, Anjara, and Ain Janna via Ba'oon and Ishtafeina reservoirs (Figure 18).

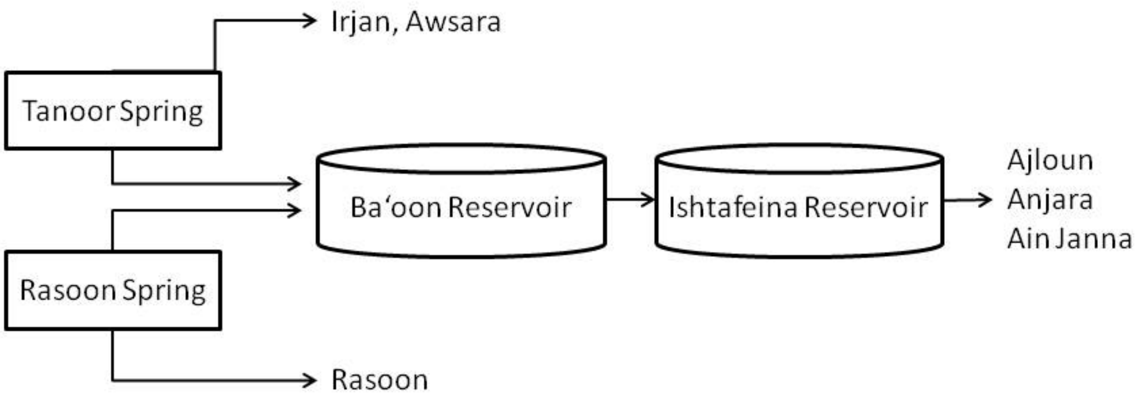


Figure 18 Overview of the water supply network

Sketch maps of Tanoor and Rasoon spring facilities are shown in Figure 19 and Figure 20.

Because of the construction of the springs total spring discharge is the sum of three components:

1) the pumped water (from spring chamber via delivery pipes to collection chamber)
2) overflow from the delivery pipes B1, B2 in Tanoor and from the concrete channel "F" in Rasoon
3) overflow from the collection chamber ("H", only Tanoor spring)

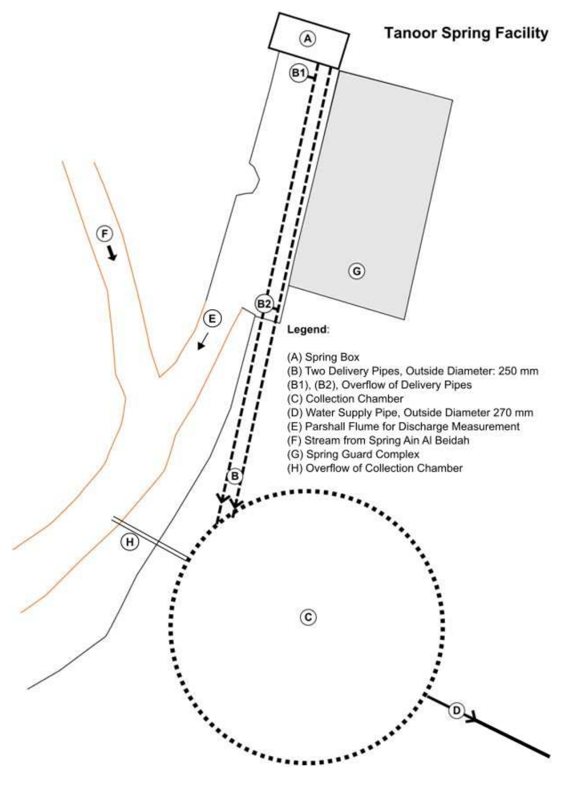


Figure 19 Sketch of Tanoor spring facilities

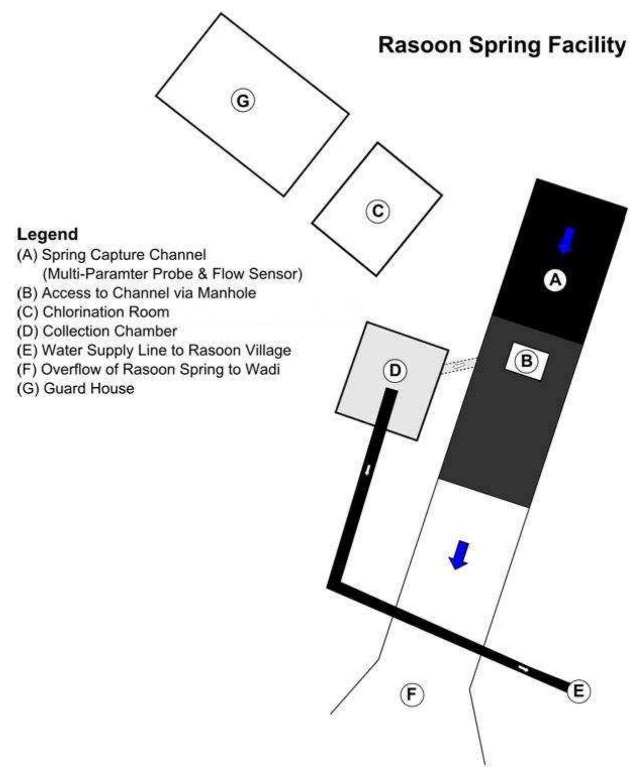


Figure 20 Sketch of Rasoon spring facilities

Pumping amounts are recorded hourly by the spring guards in Tanoor and Rasoon springs, however the data is not digitized and there is no routine to store records. The available data was digitized by the BGR project team (Table 15), but there is only complete data for one year. Missing values were estimated by averaging the meter readings. The average pumped water from 2010 to 2014 was 0.96 MCM/a. The daily production is shown in Figure 21.

Table 15 Pumping rates at Tanoor spring (in 1,000 m^3). Red: missing values, interpolated by averaging meter readings

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum
2010	87	93	130	63	129	102	96	83	73	73	66	64	**1058**
2011	77	77	77	77	77	77	77	77	77	77	77	77	**925**
2012	77	77	77	77	77	77	77	77	77	77	77	77	**925**
2013	77	77	79	135	139	135	117	100	70	85	80	75	**1169**
2014	90	79	81	81	76	55	66	63	57	29	29	29	**736**
2015	44	63	95	113	129	101							**544**

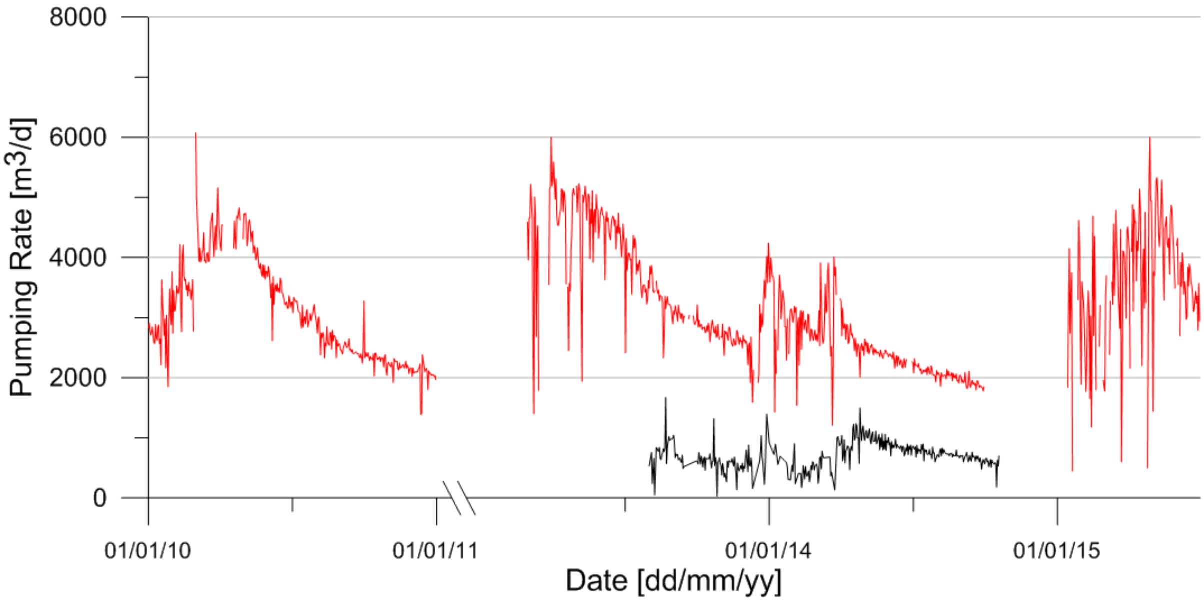


Figure 21 Daily pumping rates at Tanoor (red) and Rasoon spring (black). Note the break in the x-axis.

There are little available records for Rasoon spring (Figure 21). However, the available data depicts that pumping rates in Rasoon are approximately 1/3 of the pumping rates at Tanoor spring.

Overflow from the delivery pipes in Tanoor and from the concrete channel in Rasoon occurs either in the winter months or when pumps are stopped for maintenance. Overflow was not measured until the installation of a Parshall flume in Tanoor in 2014. The dimensions of the flume are standardised and calibrated, so that water level can be converted to discharge volume by an empirical formula (e.g Bos et al., 1989). Water levels in the flume are recorded since 01/04/2014. The calculated overflow is shown in Figure 22 compared with precipitation data and daily pumping rate for the period 01/04/2014-30/06/2015. Overflow in Rasoon could not be recorded, due to constructional works for a new collection chamber.

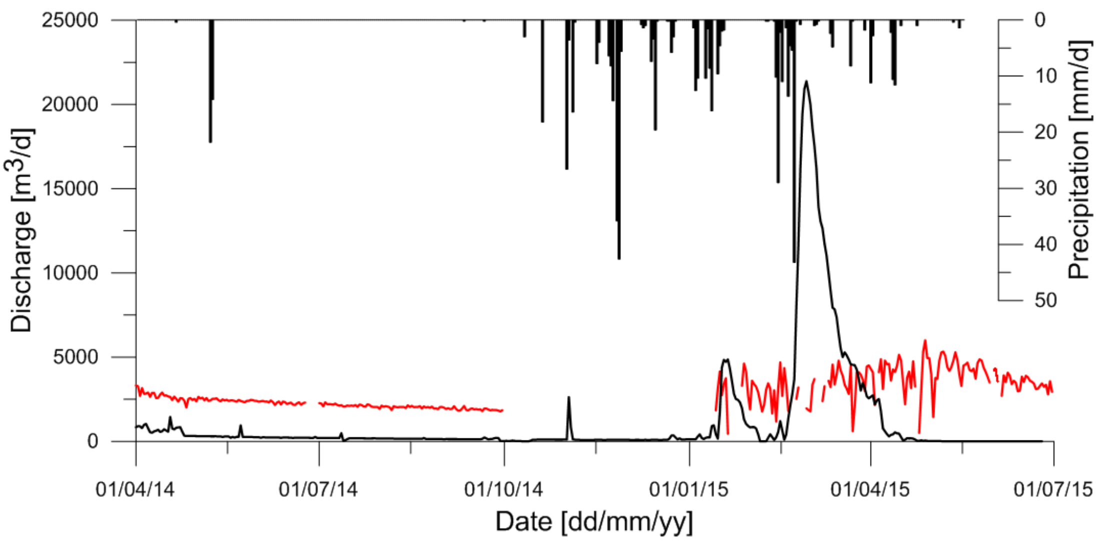


Figure 22 Overflow from the delivery pipes in Tanoor spring (black line) in comparison with daily pumping rates (red line). Precipitation from Ras Mouneif station.

Overflow from the collection chamber in Tanoor could not be measured. It is considered insignificant however, in comparison to the other two discharge components.

Based on the abstraction numbers and an average supply of 124 l/c/a (liter per capita per year) for Ajloun governorate (MWI, 2015), the two springs can provide water for around 29,000 people per year.

6 Hydrogeology

6.1 Description of the Aquifer System

The springs emerge from the Hummar (A4) formation. Outcrops of this formation are limited to incised wadis. In other areas it is covered by the A5/6 aquitard and the A7/B2 aquifer. After rainfall events, the spring discharge shows rapid increases and subsequently decreases back to the discharge rate before the event. This proves that the aquifer is interconnected hydraulically to a great degree with the overlying strata. Because of the karst features and fractures this is not surprising, but it is important to note that the A5/6 formation does not act as an aquitard in the watershed. The quick decrease to antecedent flow rates demonstrates furthermore the low storage potential of the aquifer.

There are no monitoring wells in the working area. Groundwater flow in the A4 aquifer is thought to generally follow the topographic gradient, ultimately discharging into the Jordan valley.
Because of the high precipitation, the existence of karstic features, high permeability of the wadi beds, and highly fractured outcrops of limestone aquifer rocks, this area is considered favourable for groundwater recharge. A chloride mass balance by Bajjali (2006) for the adjacent watershed east of Ras Mouneif station yielded recharge values of 10 to 48% of yearly precipitation, but few values of chloride contents in precipitation exist for the study area. Hobler et al. (1999) calculated regional recharge to be 25 – 30% of precipitation. Recharge is highly variable and difficult to estimate because of the importance of single rainfall events and antecedent moisture conditions. The role of snowmelt for groundwater recharge has not yet been investigated in detail.

6.2 Groundwater Chemisty

The chemical composition of spring waters reflect the lithology, the main water type is Ca-HCO_3. Several samples of the last 20 years are available for each of the springs Tanoor, Rasoon, and Beidah. The Schoeller plots (Figure 23) show the absolute concentrations of all samples for each of the springs. All the springs have the same trend, but in Tanoor and Beidah some samples have higher values of sodium and chloride and, to a lesser degree, also higher magnesium and sulphate.

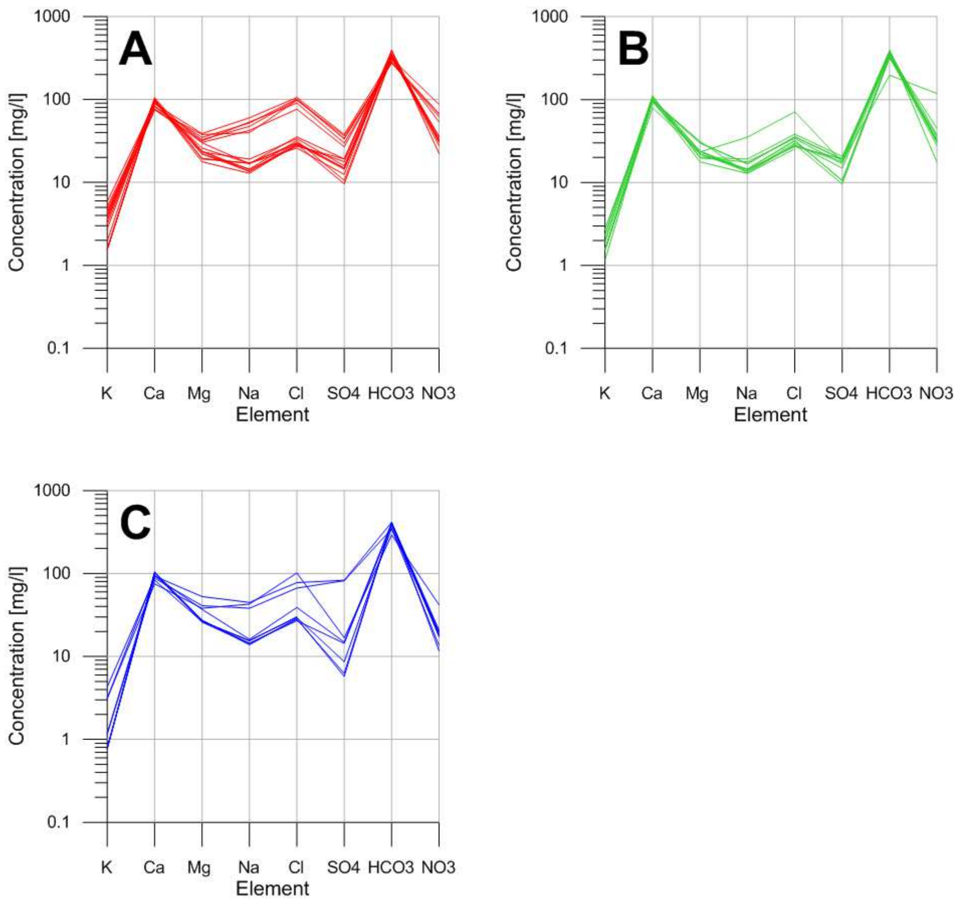


Figure 23 Schoeller plots of Tanoor (A), Rasoon (B) and Beidah (C) springs

Two samples in Beidah spring show unusual high concentrations of sulfate, more than 80 mg/l, compared to around 15 mg/l in the other samples. No additional information other that the concentrations are available. Furthermore, in one sample from the Rasoon spring an elevated concentration of chloride (~70 mg/l) was measured compared to the other samples (30 mg/l).

When plotting the relative concentrations in a Piper plot (Figure 24), samples with higher sodium and chloride lie further to the right in the anion ternary diagram and far on the top in the diamond diagram.

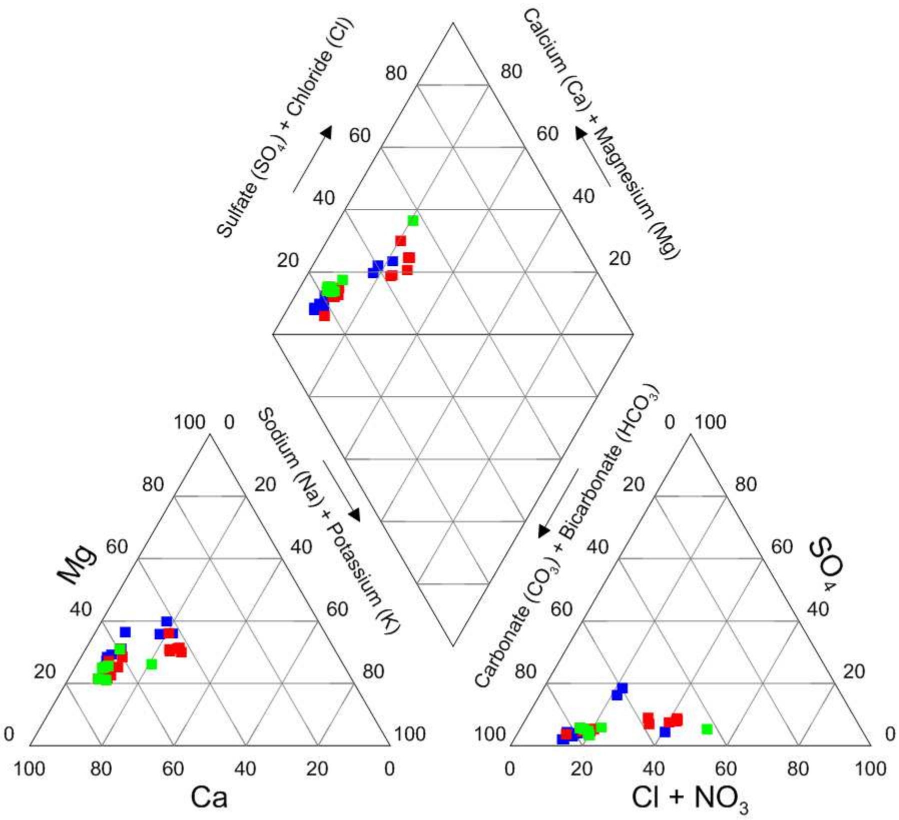


Figure 24 Piper plot for Tanoor (red), Rasoon (green) and Beidah (blue) springs

Sampling intervals are not small enough to show variations of spring water quality in a satisfactory temporal resolution because it changes rapidly after precipitation. This applies also to the measurement of the frequent contamination with olive oil wastewater. To monitor contamination and quality in Tanoor spring, a SEBA multiparameter probe, a HACH nitrate probe and a HACH UVA probe for the measurement of organic carbon were installed in the spring chamber. The multiparameter probe contains a pressure sensor (0-3 m), a TetraCon conductivity sensor with automatic measuring range selection (0-200 mS/cm), a temperature sensor, an optical oxygen saturation sensor (0-100%), a turbidity sensor (0-100 NTU), and a pH-electrode (pH 0-14). Due to lifetime and calibration efforts (every 14 days) of the pH electrode, this parameter was only measured during the rainy season. Recorded values are stored every hour in a UniLog data logger and transferred via GPRS to the SEBA and MWI server.

Another purpose of the continuous measurement in Tanoor spring was to determine a suitable parameter for the implementation of an early warning system.

Another multiparameter probe was installed in Rasoon but had to be uninstalled due to construction works.

The measured parameters in Tanoor spring are shown in Figure 25. In addition to the physicochemical parameters, precipitation and overflow from the spring are shown. The periods of contamination that are caused by Zeebar discharge between November and February are marked in grey. This is the first time that the effect of olive oil wastewater on spring water has been measured in Jordan. In the course of the contamination events, electrical conductivity and turbidity values rise rapidly in addition to a slight increase in temperature. Contrarily, dissolved oxygen is consumed entirely. The UVA-probe shows the high organic load of the pollution, reaching up to 400 mg/l TOC.

After each of the two contamination events, a rainfall event was recorded. These events are characterized by a slight increase in conductivity caused by the flushing of solutes in the soil and unsaturated zone. Temperature decreases, while there is a peak in turbidity and a quick recovery of dissolved oxygen.

A big precipitation event in the end of February has no effect on the spring chemograph, but lead to a high overflow at the spring.

After the start of the dry season approximately in May, all parameters remain fairly stable and are not shown in the graph. During base flow conditions, oxygen saturation is nearly 100% and electrical conductivity is around 700 µS/cm. pH values are stable at around 7.1 and only decrease to 6.9 during the contamination events.

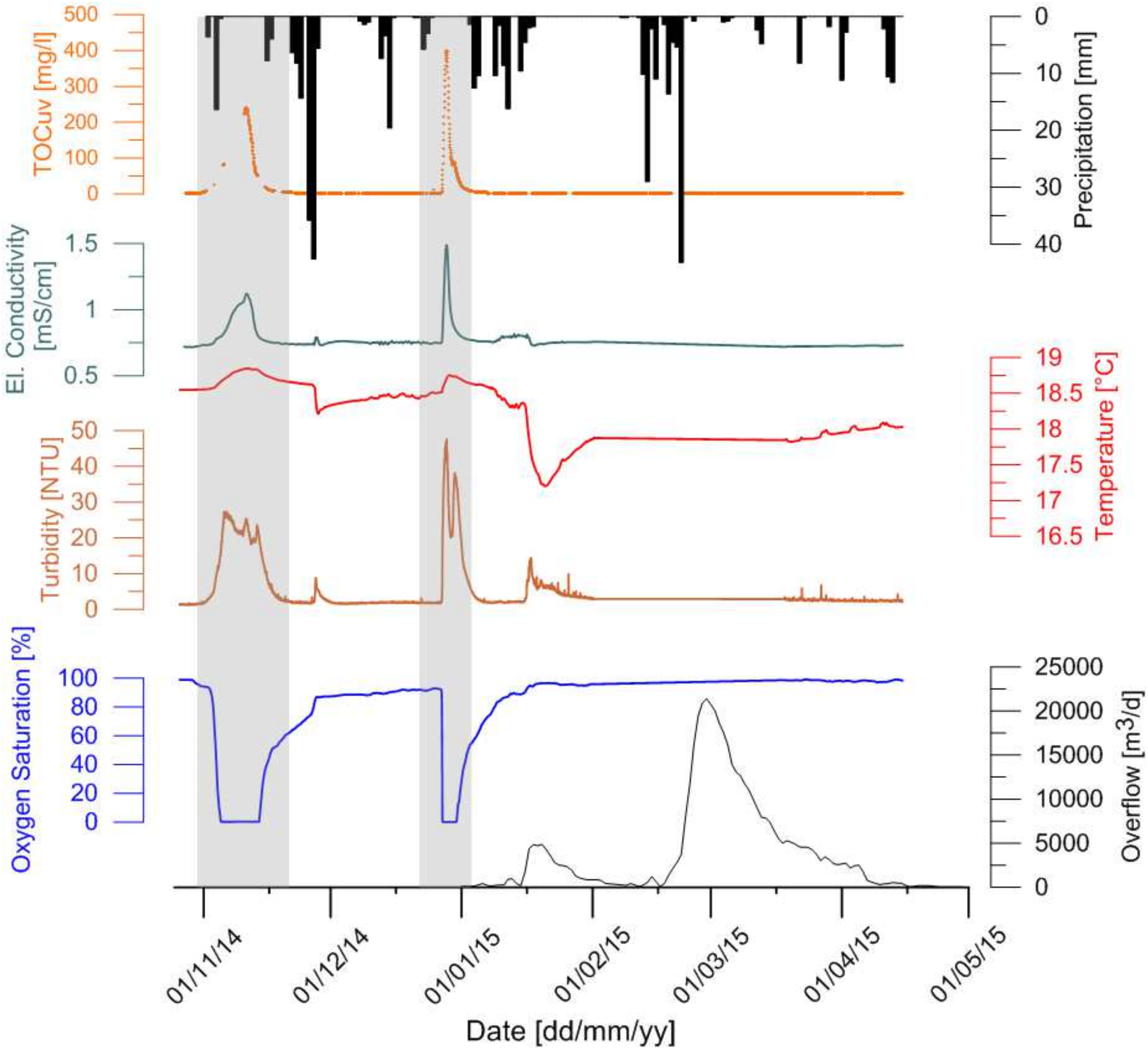


Figure 25 Chemograph for Tanoor spring. Rainfall data from Ras Mouneif station. Grey areas: Zeebar contamination events

It can be concluded that with the records of the multiparameter probe, the olive oil wastewater contamination can be identified unambiguously and the additional UVA probe is not necessarily needed. The oxygen saturation is considered as a good parameter for the implementation of an early warning system, since oxygen saturation does not change with precipitation, but only after Zeebar contamination. Additionally, an oxygen sensor is more economic than a UVA sensor. In order to minimize maintenance, it is recommended to use an optical sensor like the one used here, instead of an electrochemical one.

The fast reaction of the chemographs after rainfall shows the significant contribution of recharge water to the spring. This means that the spring is highly vulnerable due to the karst system.

The nitrate measurements are shown in Figure 26. The complete measurement interval is depicted in part A whereas part B shows the contamination events in more detail (grey areas).

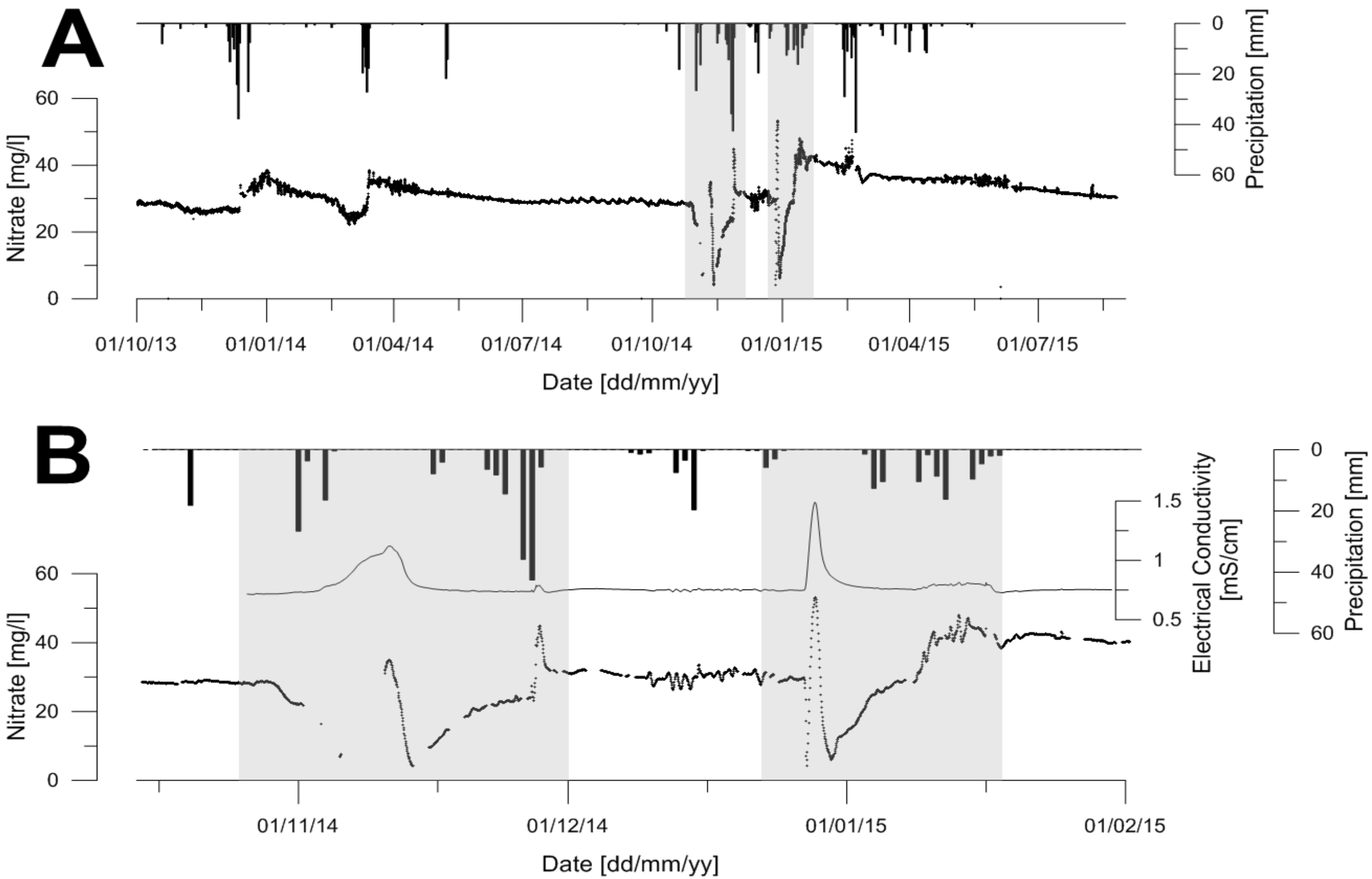


Figure 26 Temporal variations of nitrate in Tanoor spring. **A:** entire period of observation, **B:** detail during Zeebar contamination events (grey areas). Rainfall from Ras Mouneif station

Under normal conditions, nitrate concentrations of about 30 mg/l are recorded, which is relatively high for spring water. The cause of the elevated nitrate conditions is likely to be related to the numerous cesspits scattered in the area. After precipitation event without Zeebar contamination, concentrations rise up to 40 mg/l and decrease slowly back to the prior concentrations. This is due to the flushing of solutes in the soil and unsaturated zone by direct recharge from precipitation. In contrast, concentrations during the contamination events decrease to around 10 mg/l after reaching the peak (Figure 26 B). This is likely to be caused by denitrification that takes place after all the dissolved oxygen is consumed. It is recommended to investigate the source of nitrate to be able to implement measures that can prevent a further increase. A combination of nitrogen and oxygen isotopes in nitrate have successfully been used to differentiate between various sources of nitrate in groundwater such as manure, sewage, fertilizers and atmospheric deposition (e.g. Kendall & McDonnell, 1998).

In Rasoon, the multiparameter probe could only record for little more than three weeks before it had to be removed. Records were continued with a battery-powered multiparameter probe measuring temperature, electrical conductivity, and turbidity. After seven weeks of measurements, this probe also had to be removed because of the extension of construction work. A comparison of the chemographs of both springs is shown in Figure 27.

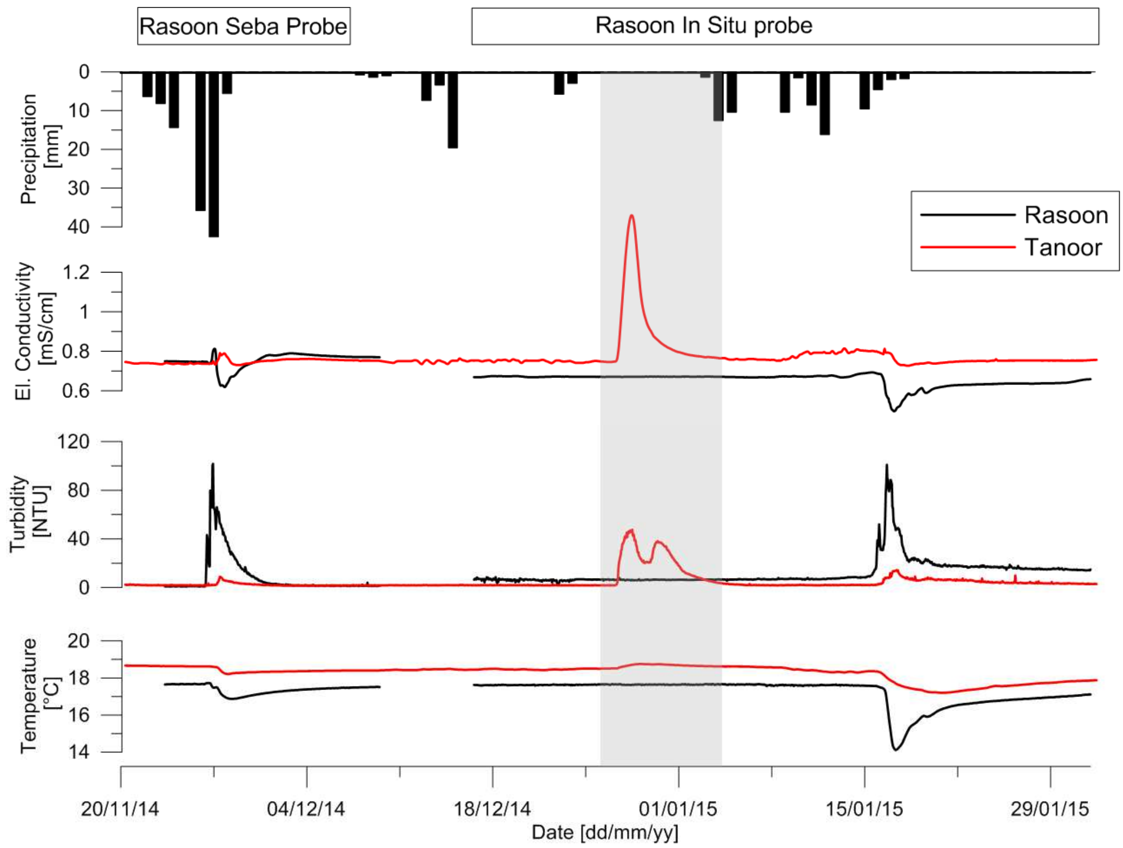


Figure 27 Comparison of the chemographs of Tanoor and Rasoon springs

Electrical conductivity is almost the same in both springs. The slightly lower conductivity measured in Rasoon spring after the installation of the “In Situ” probe is caused by the different manufacturer of the probe (some 100 µS/cm). As in Tanoor spring, direct recharge from precipitation events are indicated by small increases in conductivity due to the “first flush” phenomenon indicated above. However, the electrical conductivity decreases then below the precedent conditions to recover slowly thereafter. This indicates a relative shallow unsaturated zone that is washed out rapidly to allow then the flow of clean precipitation water. Similarly, turbidity increases much more in Rasoon spring than in Tanoor spring because of the low protection from the unsaturated zone.

Regarding bacteriological pollution, total coliforms and E.Coli are detected regularly in both Tanoor (Table 16) and Rasoon springs (Table 17). Positive tests are usually confirmed by a second sample.

Table 16 Occurrence of bacteriological contamination in Tanoor spring

Date	E. Coli [MPN/100mL]	Total Coliforms [MPN/100mL]
24/02/2008	30	1600
24/02/2008	50	900
07/04/2010	10	>2419.2
11/04/2010	<1	>2419.2
11/04/2010	<1	>2419.2
14/04/2010	<1	2419.17
18/04/2010	<1	1299.65
18/04/2010	<1	1732.87
21/04/2010	<1.8	110
22/01/2011	>2419.2	>2419.2
24/01/2011	1553.07	>2419.2
24/01/2011	1553.07	>2419.2
27/01/2011	230	
06/02/2011	98.7	>2419.2
06/02/2011	116	2419.17
22/02/2011	2	178.5
22/02/2011	<1	201.4
09/02/2012	8.5	178.9
09/02/2012	2	123.6
11/02/2012	2	95.9
28/10/2012	>2419.2	>2419.2
29/10/2012	<1	>2419.2
01/11/2012	<1	>2419.2

Table 17 Occurrence of bacteriological contamination in Rasoon spring

Date	E. Coli [MPN/100ML]	Total Coliforms [MPN/100ML]
16/12/2002	26	≥1600
06/01/2003	2	110
12/05/2003	2	8
18/06/2003	<2	13
09/02/2012	8.5	261.3
09/02/2012	14.6	224.7
11/02/2012	2	325.5
11/02/2012	5.2	178.5

6.3 Stable Isotopes ^{18}O and D

Samples for analysis of ^{18}O and Deuterium were taken during the rainy season between November 2014 and the end of May 2015. Eighteen samples were taken for each of the springs Tanoor, Rasoon, and Foqa and 17 in Beidah spring. Additionally, seven samples of precipitation at Ras Mouneif and five at Tanoor spring were collected with an isotope sampler. An overview map of the sampling points is shown in Figure 28.

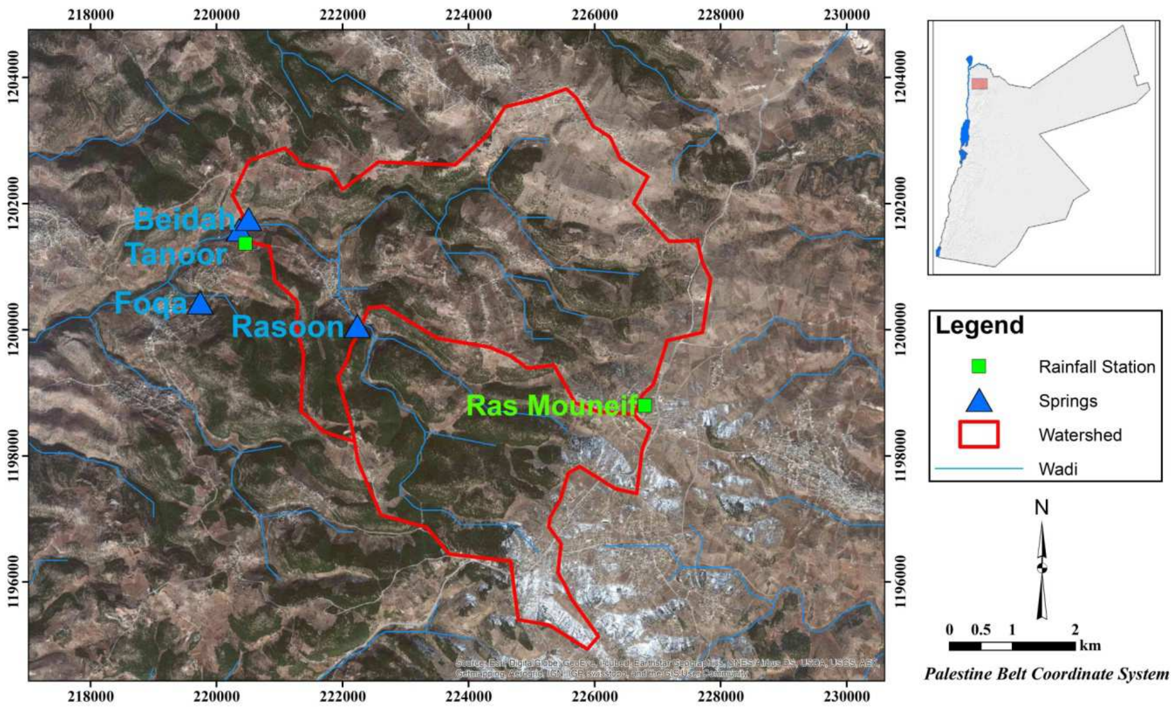


Figure 28 Sampling points for stable isotopes ^{18}O and Deuterium

The isotopic composition of all samples is shown in Figure 29. A local meteoric water line was established from the precipitation samples. Considering the limited data, a LMWL from Hamdan et al. (2015) for the same watershed but with more data is shown for comparison. The samples of the spring lie on a line that is slightly displaced from the LMWL indicating evaporation effects in the recharge water. The dominant composition of rainfall is shown as the volume weighted mean (VWM) composition.

The variation of the isotopic compositions in time is shown in Figure 30. Precipitation samples, especially from Tanoor, show a seasonal trend. Oxygen-18 is enriched in the beginning of the rainy season, decreases to a minimum of around -8 ‰ during the rainy season, and increases again towards the end of the rainy season. The isotopic compositions are correlated positively with the temperature (Figure 31).

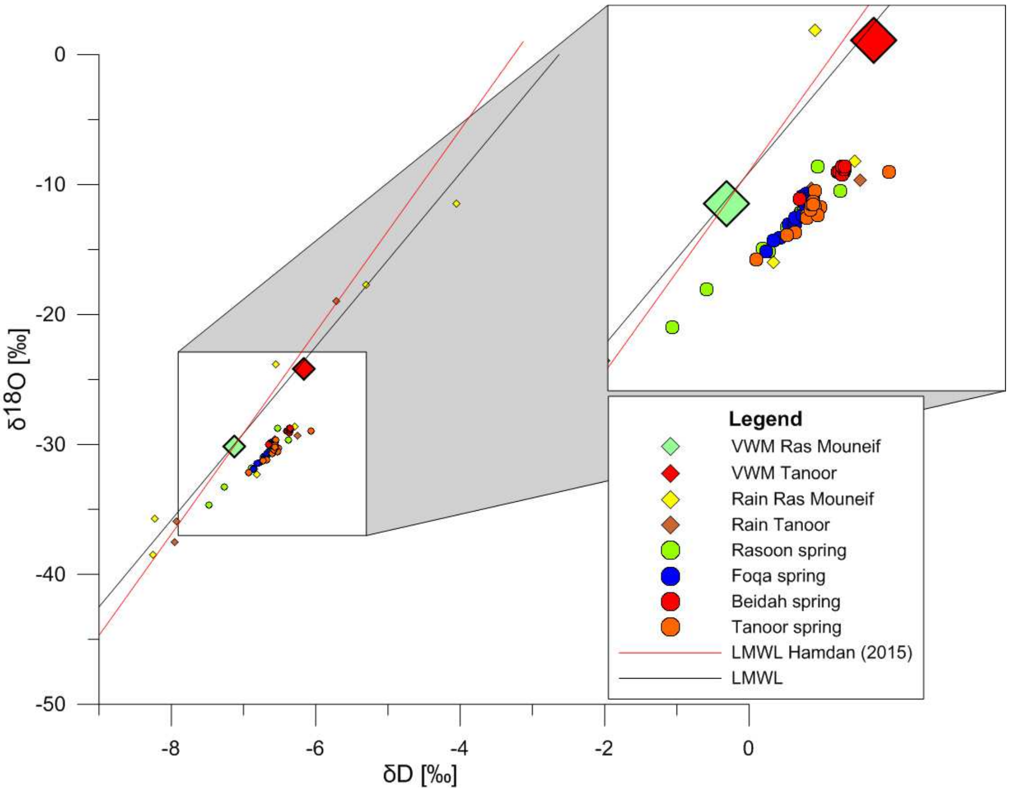


Figure 29 $\delta^{18}O$ versus δD for springs and rainwater samples

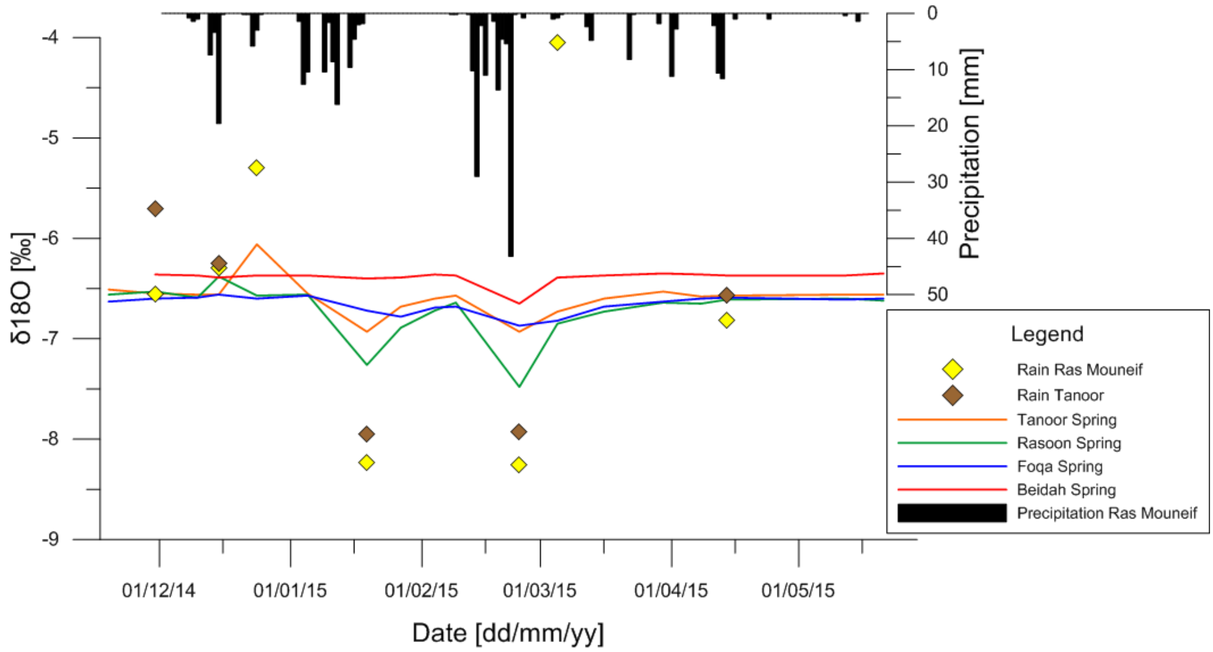


Figure 30 Temporal variation of $\delta^{18}O$ in spring and rainfall samples

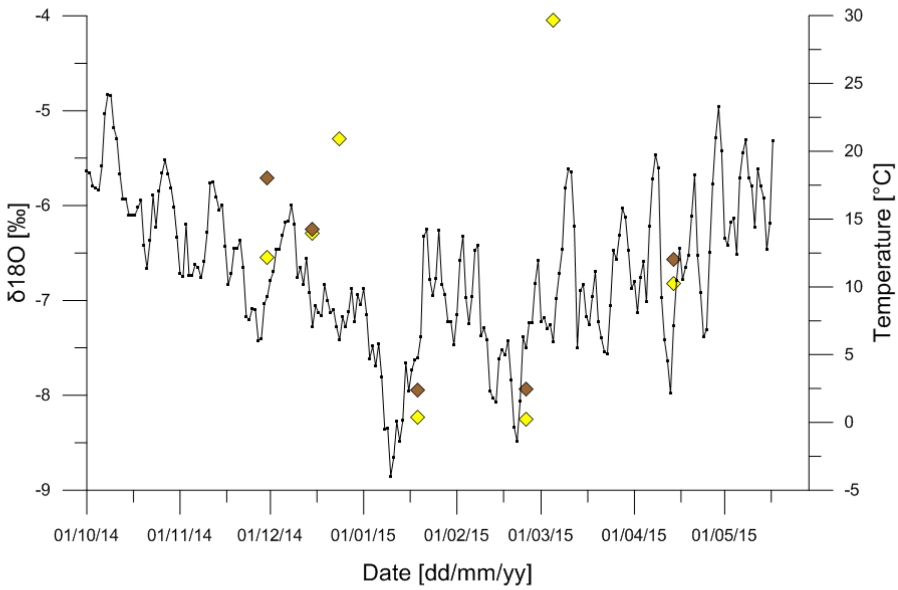


Figure 31 Mean daily air temperature (black) and $\delta^{18}O$ of Tanoor (brown) and Ras Mouneif (yellow) rainfall samples

Figure 30 shows similar compositions of spring waters before and after the rainy season. This is the composition of the baseflow, which can be used with the composition of event water (precipitation) to estimate the fraction of baseflow in spring discharge with a simple two component mixing model (e.g. Sklash & Farvolden (1979), Klaus & McDonnell (2013)):

1) $Q_t = Q_p + Q_e$
2) $C_t Q_t = C_p Q_p + C_e Q_e$
3) $F_p = (C_t - C_e)/(C_p - C_e)$

Where:

$\mathbf{Q_t}$ = maximum discharge; $\mathbf{Q_p}$ = discharge before event (baseflow); $\mathbf{Q_e}$ = discharge during event

C = isotopic composition ($\delta\ ^{18}O$ [‰], $\delta\ ^{2}H$ [‰]); $\mathbf{C_t}$ = spring water during event; $\mathbf{C_p}$ = before event (baseflow), $\mathbf{C_e}$ = event water (precipitation)

$\mathbf{F_p}$ = fraction of baseflow

For the isotopic composition of event water (C_e), the volume weighted mean of the precipitation at Tanoor and Ras Mouneif station was used. For the composition of the base flow, the average compositions before and after the precipitation events were used. Figure 32 shows the result of the calculations for Tanoor and Rasoon springs. Two events were considered because of their temporal resolution and clear difference in isotopic composition: 19/01/2015 and 24/02/2015.

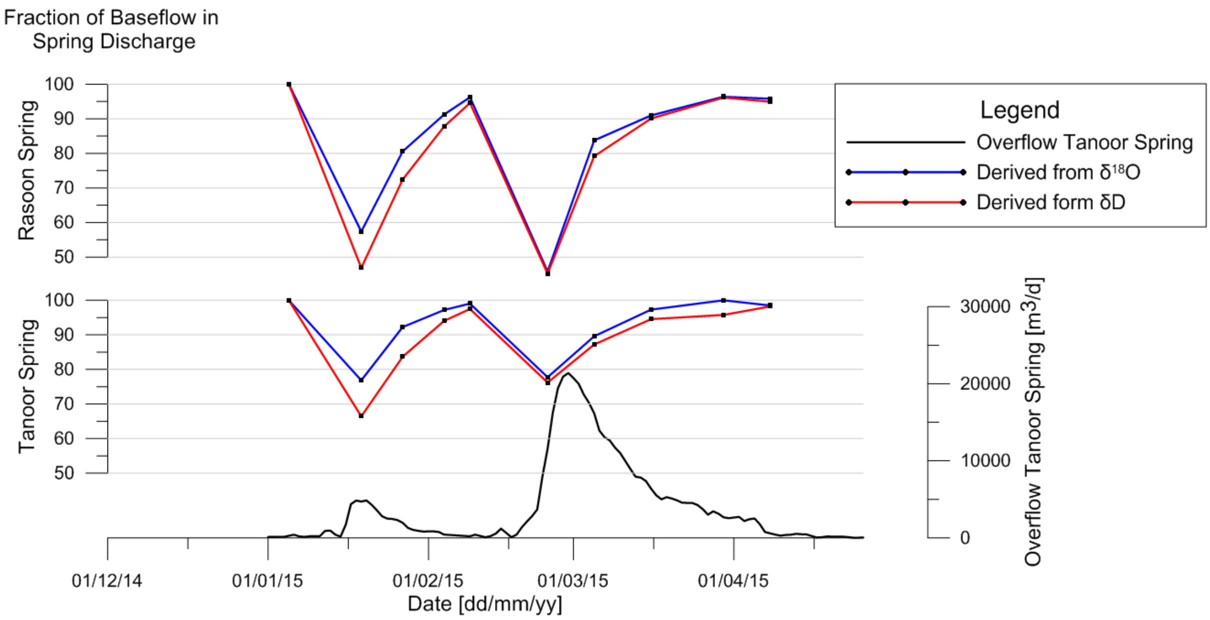


Figure 32 Fraction of baseflow in spring discharge

The figure shows the high fraction of precipitation in spring discharge. In the two events, precipitation provides between 40 to more than 50% of spring discharge in Rasoon spring and between 20 to more than 30% in Tanoor spring. The calculation with δD yields slightly higher proportions of precipitation. This is in agreement with the chemograph analysis and shows the high vulnerability of the springs, especially for Rasoon spring.

Figure 31 shows that precipitation at Ras Mouneif station (1150 m.a.s.l.) is generally more depleted of heavy isotopes than precipitation at Tanoor station (682 m.a.s.l.). This is caused by the height effect. In the first samples there is a higher variation between the stations that can be caused by different storm trajectories (Mediterranean, Balkans, North Africa, etc.). With the difference in altitude and isotopic compositions, the average elevation of the watershed can be estimated (Figure 33). Because isotopes in precipitation were only measured at two locations, data from Bajjali (2012) is shown for comparison. This author used data from three stations in the region (Table 18).

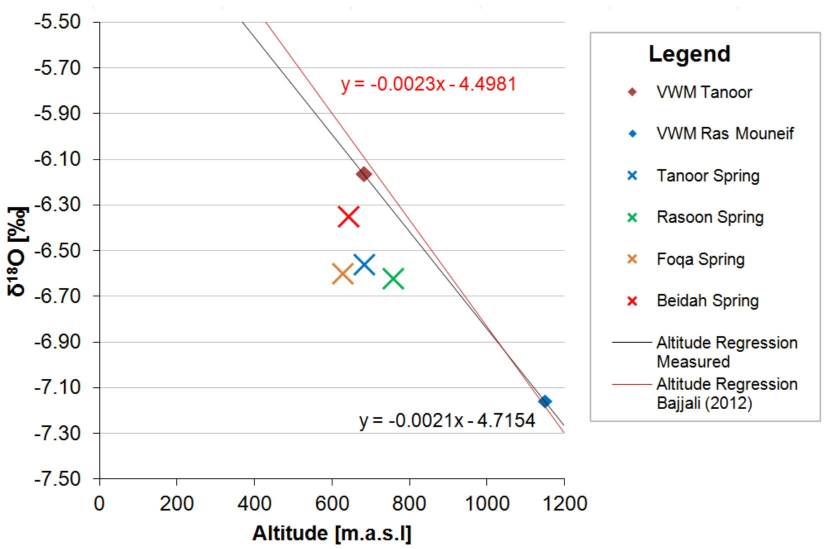


Figure 33 $\delta^{18}O$ versus altitude for determination of the height effect

Table 18 Volume weighted mean $\delta^{18}O$ for three precipitation stations in the region (Bajjali, 2012)

Station	$\delta^{18}O$ [‰]	Elevation [m.a.s.l.]	No. of samples
Ras Mouneif	-6.8	1150	66
Irbid	-6.36	555	68
Deir Alla	-3.73	-224	55

The height effect on precipitation is 0.21‰ $\delta^{18}O$/100 m and 1.32‰ δD/100 m. The average elevation of the watershed is approximately 900 m.a.s.l. for Tanoor, Rasoon and Foqa and around 800 m.a.s.l. for Ain Beidah.

7 Hazards to Groundwater and Assessment of Pollution Risk

Contamination appears regularly in Tanoor and Rasoon springs. The main sources of pollution are olive mill wastewater and bacteria.

Olive oil wastewater pollution appears almost every year during the olive milling season between November and February. Olive farming and its processing to oil is the major agro-economic activity in the local communities in Ajloun and the surrounding areas. For a detailed account of Zeebar in Jordan, including detailed socio-economic, environmental and institutional aspects, the reader is referred to the USAID (2013b) report on this topic.

Because of its phytotoxicity and toxicity to microorganisms, it is not only harmful to the environment but also impossible to dispose in a domestic wastewater system. During inspection of the olive mills it was noted that all facilities comply with environmental standards except for minor spillages. It is therefore assumed that the wastewater is disposed of illegally instead of costly transportation to the distant Al-Kaider landfill site north of Mafraq.

Domestic wastewater is usually collected in cesspits at the household level, since many of the small villages are not yet connected to a wastewater system. Contamination can occur either from leaking of poorly designed cesspits or from illegal disposal of the stored wastewater. Bacteriological contamination in the springs usually occurs after rainfalls together with an increase in turbidity. While Tanoor spring lies at a small distance downstream of Rasoon village, in the surface watershed of Rasoon spring there is almost no human development. Regardless of this, bacteriological contamination occurs in both of the springs.

Other potential hazards include gas stations and quarries. Especially spillage of hydrocarbons can pose a serious threat considering the karstic nature of the area. In the case of quarries, the risk is increased by the removal of the protective cover.

A map of potential hazard sites to groundwater is shown in Figure 34. Residential areas are shown because of the hazard of contamination by leaking cesspools.

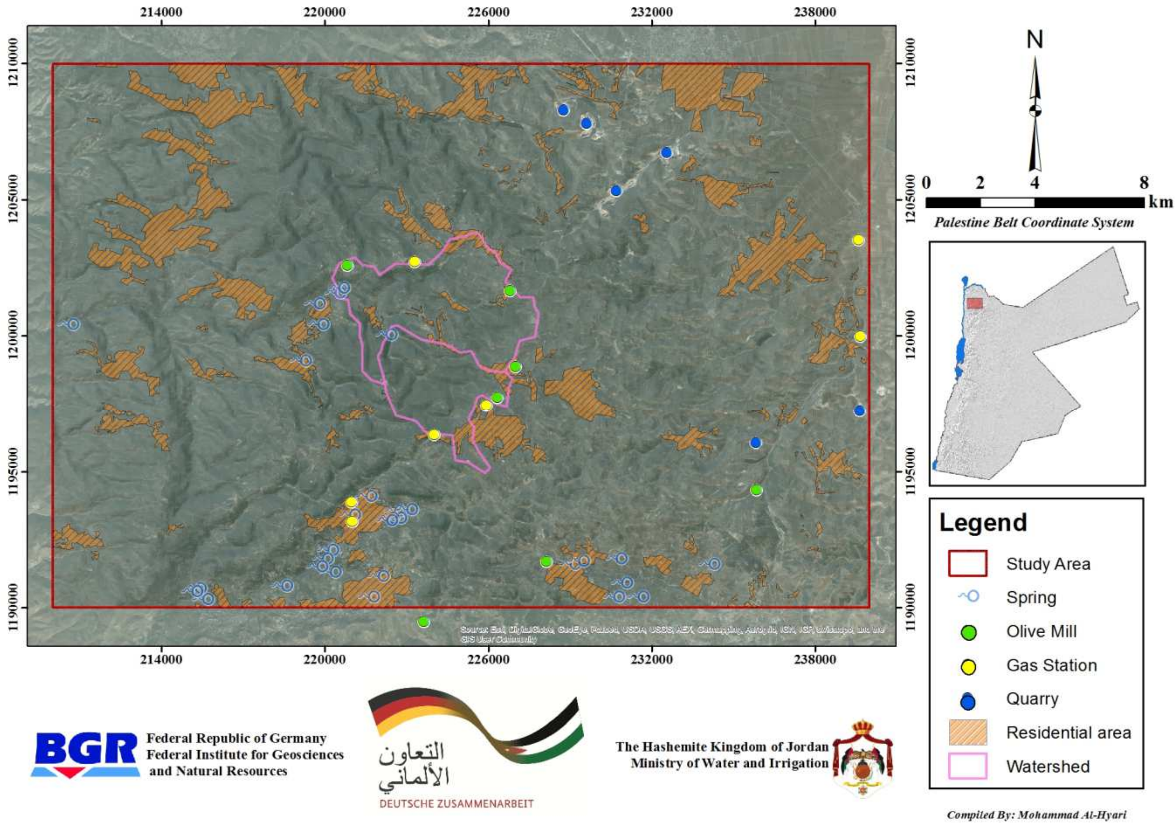


Figure 34 Inventory of possible hazards to groundwater in the working area

The recurring contamination by bacteria, olive oil wastewater as well as the interpretation of chemographs and stable isotopes show that the springs are highly susceptible for pollution. In order to protect the springs against contamination, protection zones are proposed.

8 Delineation of Protection Zones

8.1 General Remarks

Considering the high costs associated with treatment of polluted water for drinking water supply, the protection of groundwater resources against pollution is a common practice in many countries. In order to determine the area that has to be protected against pollution, different methods can be applied depending on available data and the required precision of the delineated protection zones. As shown in Figure 35, there is a range of methods from simple fixed radius methods that need almost no data input to complex hydrochemical models. In general, uncertainty decreases when considering additional data.

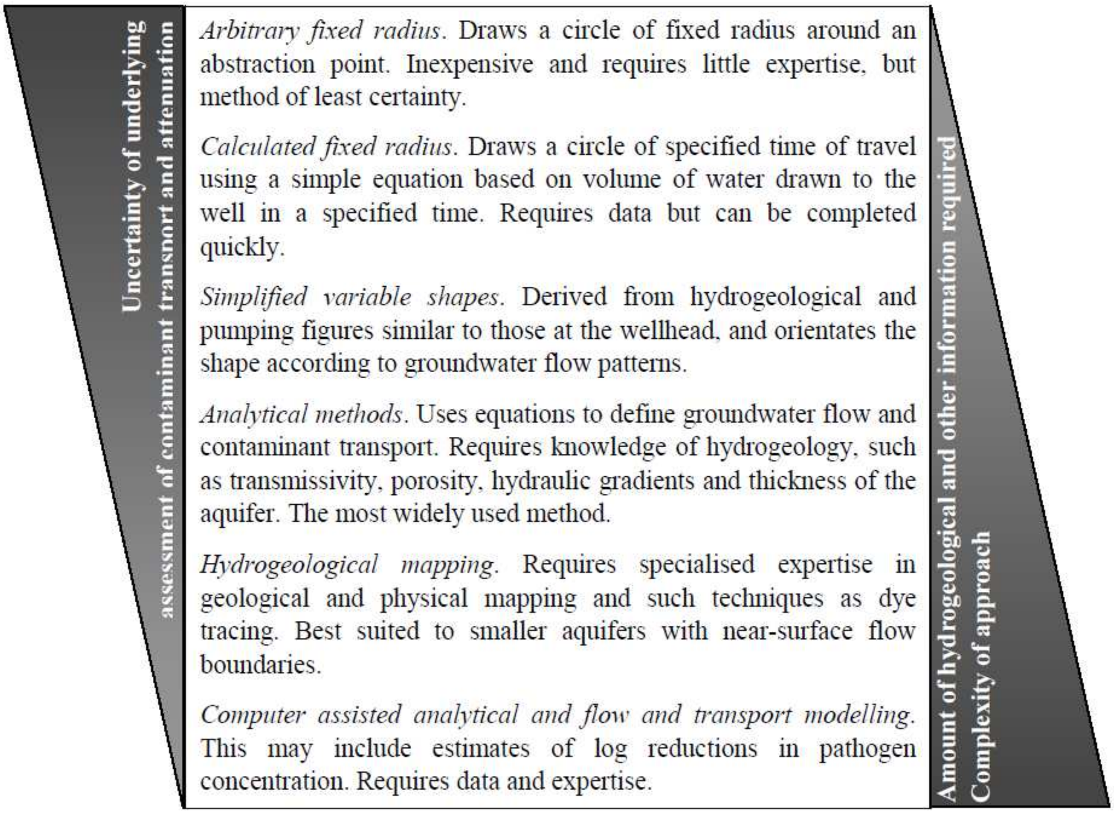


Figure 35 Methods for the delineation of Groundwater Protection Zones (WHO, 2006)

8.2 Protection Zone 1

According to the Water Resources Protection Guideline (Annex 5), protection zone 1 of a spring has to extend at least 50 m upstream of the well, 10 m downstream and 15 m to each side (Figure 36). The perimeter of protection zone 1 should be completely fenced and locked, allowing only authorized personnel to access to the facilities. Furthermore, protection zone 1 has to be marked accordingly with the corresponding signposts indicating restrictions and significance of zone 1 (Gassen, 2013).

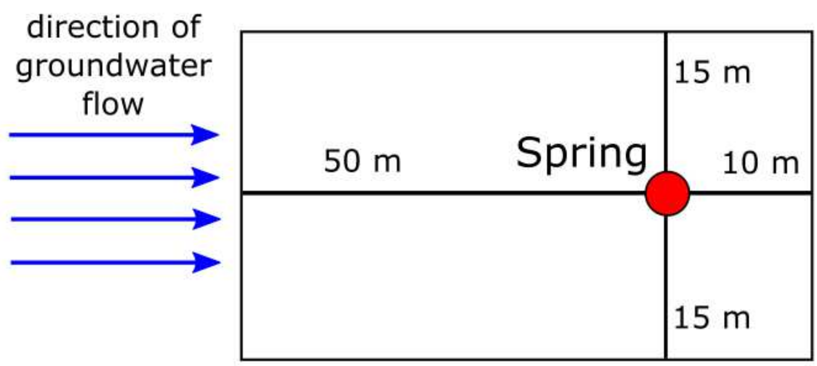


Figure 36 Dimensions of protection zone 1 for a spring

The dimensions of protection zone 1 for both springs do not comply with the guideline (Figure 37). The main road passes close by the springs in both cases, so it is not possible to extend the protection zones. In Tanoor, a garden with a café is located directly adjacent to the spring. Both springs have bathrooms with a cesspool, that is located downstream, but very close to the abstraction point. It should be made sure that no leakage can occur. The fences of both springs are in good condition and well guards are present at all times. Both protection zones should be equipped with the corresponding signposts (Figure 38).

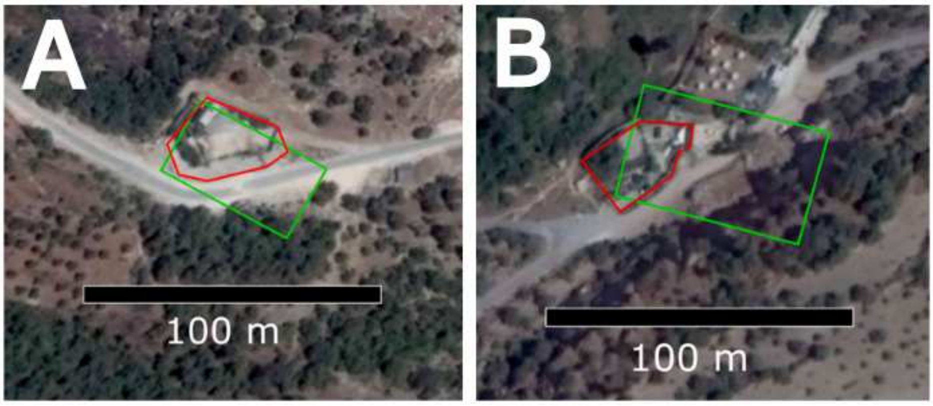


Figure 37 Protection zone 1 for Rasoon (A) and Tanoor spring (B). Red: actual protection zone, green: protection zone according to guideline

Figure 38: Signpost for protection zone 1

8.3 Protection Zone 2

Protection zone 2 starts at the outer border of zone 1 and ends at a virtual line from where the groundwater flow will take 50-days until it reaches the well. The 50 day line is based on the assumption that most pathogen bacteria die within a period of 40-60 days while travelling in groundwater. By preventing the entry of bacteriological contamination into the groundwater within this 50 day line, it can be assumed that the water arriving at the wells is free of pathogen bacteria (Gassen, 2013). Signposts should be installed to clearly visualize the most important restrictions (Figure 39)

The following activities are allowed:

Residential areas: Connection to a local sewerage system or installation of a properly managed cesspit. Priority is given to the establishment of an appropriate sewerage network or a safe sub-surface disposal system (cesspools) following the by-law of sewerage network No.66 of 1994

Agricultural activity: Organic agriculture. In case of producing wastewater which is having an impact on the environment and on the water resources, obligation to implement environmental sound practices

Existing industries: In case of producing wastewater which is having an impact on the environment and on the water resources, obligation to implement environmental sound practices

Other activities: New establishments, extensions or changes are not licensed unless the responsible organization gives permission referring to the Jordanian legislation and related studies.

Figure 39: Signpost for Protection Zone 2

In the absence of observation wells in the study area and taking into account the karstic nature of the aquifer, tracer tests are considered the most effective way to determine groundwater velocity. Tracer tests have not been used regularly in Jordan so far and their implementation with adequate tracer substances like sodium naphtionate and uranine is met with considerable difficulties in obtaining the necessary permissions. It was therefore not feasible to do this kind of test in the course of this study.

However, the spring hydrographs can be used for this purpose. Generally they respond to precipitation events after around six days. Furthermore, the isotope analysis and chemographs show that the fraction of precipitation waters is highest at this time. A rough calculation with an average flowpath length of only 600 m yields a velocity of 100 m/d. The actual flow velocity is probably even higher. This means that the protection zone 2 should extend at least 5 km upstream of the spring. However, the Jordanian water resources protection guideline (Annex 2) permits a maximum extend of 2 km.

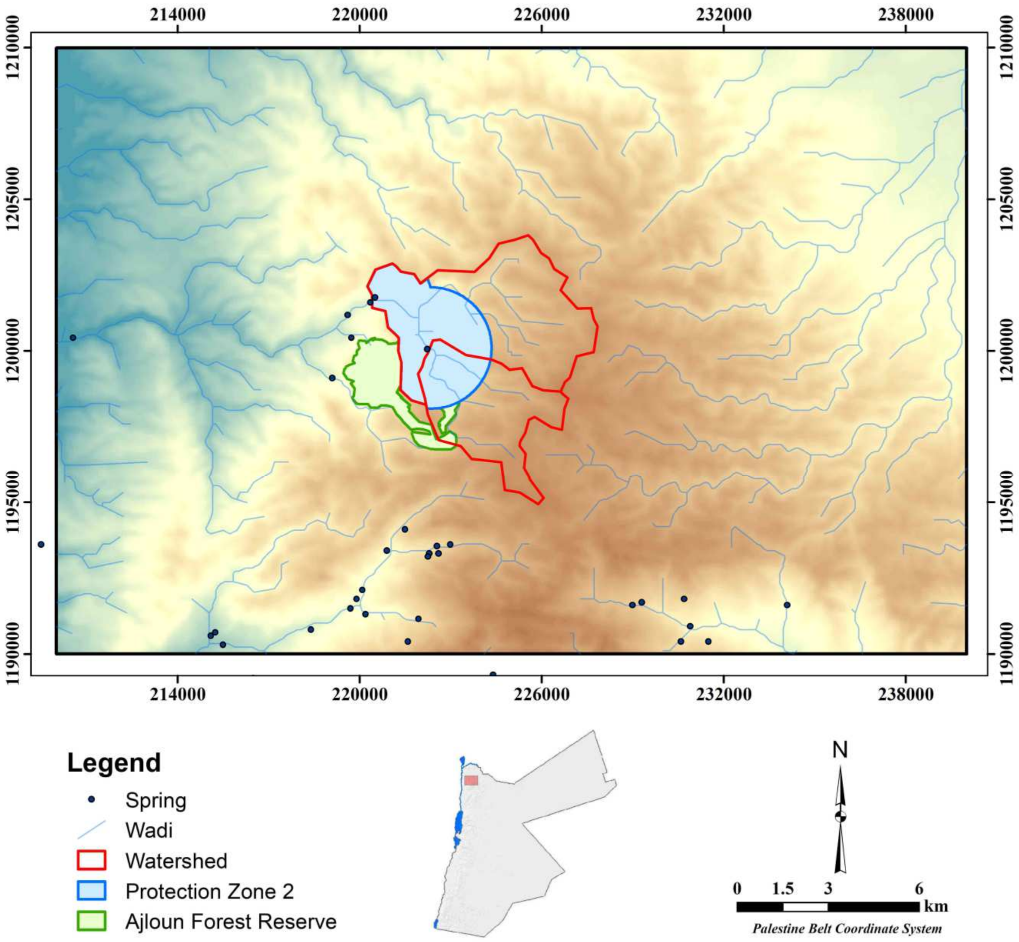


Figure 40 Proposed protection zones 2 for the Tanoor and Rasoon springs

Protection zone 2 in Rasoon watershed is mainly covered by forest and in part already protected by the Ajloun forest reserve. Rasoon village is located in the centre of protection zone 2 in Tanoor watershed and olive farms are the most common land use.

8.4 Protection Zone 3

Protection zone 3 includes the entire capture zone of the springs. No information is available about the location of the karst channels and underground water divides. As a first approximation, groundwater flow is estimated to follow the dip of the geological strata. Field investigations showed that solution develop along bedding planes in some parts of the study area (Figure 41).

Figure 41 Solution features parallel to bedding planes

Several dip measurements were taken along the surface watershed boundary (Figure 42). The measurements show that the dip of the strata is mostly directed away from the watershed in the north and south. In the eastern border of the watershed, no outcrops showing bedding planes are present. In the absence of additional data, the surface watershed is considered as a tentative protection zone 3. Further investigations about the location of karst channels as well as the hydrogeological function of faults and fractures are necessary to define a more exact extend.

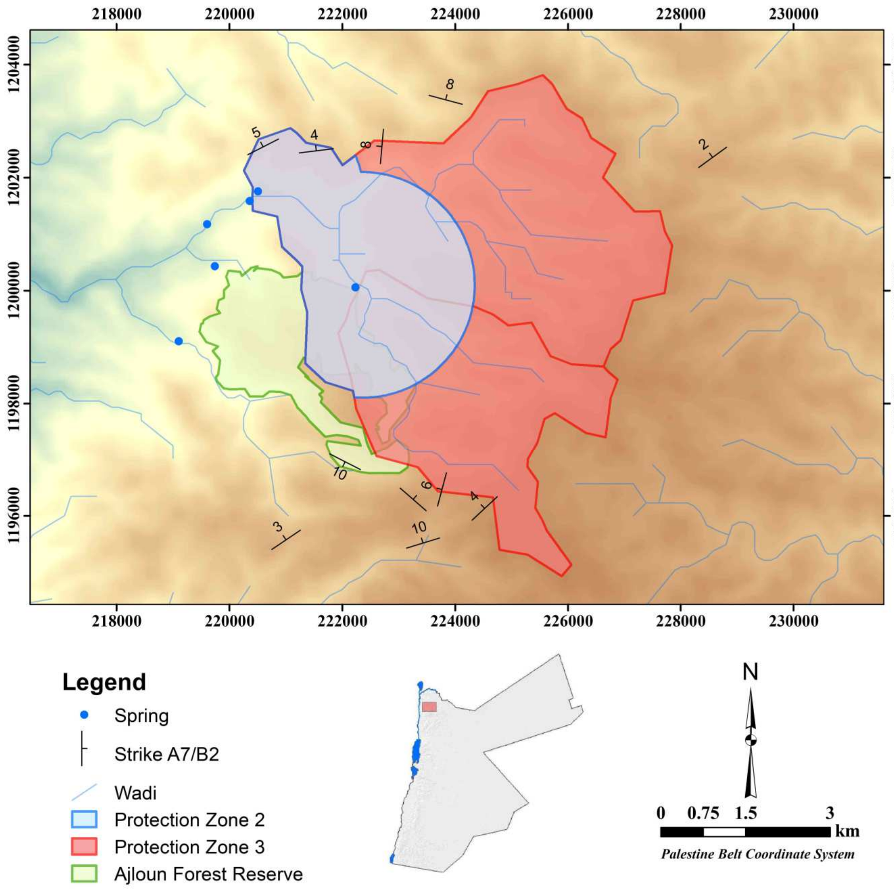


Figure 42 Tentative protection zone 3 and strike dip measurements

In protection zone 3, no specific regulations and restrictions are valid. The general environmental law, that is applied for whole Jordan is the basis of enforcement.

9 Recommendations

Only little data exists for the delineation of the protection zones. Nevertheless, it is obvious that the aquifer system is highly susceptible to contamination. Therefore, the use of the maximum extend of the protection zones foreseen in the water resources protection guideline (Annex 2) is recommended. Due to the absence of water level data in the area, the exact boundaries of the subsurface catchment could not be determined. Tracer tests are considered the most suitable method to investigate the size of the catchment, but their usage in Jordan has not been established so far and is met with considerable institutional and legal obstacles. In addition to the enforcement of the protection zones, several issues have to be addressed to ensure adequate quality of the spring water.

Long term monitoring data is important to evaluate the current status of the system and investigate possible challenges in the future, such as reduction of the discharge due to regional abstraction or changes in discharge due to climate change. Therefore, pumping rates and overflow should always be recorded in a database. The ongoing monthly flow measurement is not very useful regarding the importance of short term fluctuations. It is recommended that daily measurements are performed.

Regarding the contamination with bacteria, the sewage system is the most likely cause of pollution. Because of the remote location and relatively low population, the connection to a centralized sewage system does not have a high priority. USAID (2013a) recommends connection of Irjan village in the period 2020 – 2030 in their wastewater master plan. Therefore it should be made sure that the cesspools are properly sealed.

In order to stop the pollution of the springs with olive oil wastewater, environmental law has to be enforced. So far patrolling of the environmental rangers has not led to finding the responsible for the pollution. In the long term, a concept for the disposal of the wastewater in the region is necessary. This should include systematic control, but also allow the olive mill owners the disposal of wastewater at an acceptable price. Under the actual circumstances, it is often not feasible economically to bring all of the wastewater to Al-Kaider landfill. This kind of pollution cannot be treated with the actual treatment methods.

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Annex 2: Water Resources Protection Guideline

- Unofficial translation -

Introduction

Water availability for various purposes is considered as one of the most important factors of development in any country in the world, and is of particular importance as it is closely linked to the quality of life in the areas of water scarcity, such as Jordan.

Jordan, like other countries in the region, affected by climate change phenomena that led to a change in the prevailing pattern, rainfall fluctuating average and time, succession of droughts seasons which become more severe than we knew for decades.

This style affects the environment in the Kingdom in general, including signs of desertification. It also has direct impact on the groundwater and surface water sources in particular; the kingdom depends mainly on groundwater resources to meet water needs for all sectors, especially household usages.

Jordan has started suffering a large deficit in its water resources since the last two decades. This suffering has increased in the past decade as a result of successive drought seasons witnessed by Jordan as well as the forced migrations which led to increase in the demand for water for different purposes of drinking, agriculture and industry so as to keep pace with progress and technology. This led to the depletion of many of surface water groundwater resources, drought of many springs, and change in the dynamic pattern associated with it. Problem of water in Jordan was not limited to scarcity, but also transcended to the deterioration in its quality and salinity as a result of depletion of groundwater on one hand, and the various humanitarian practices resulted from urbanization on the other hand.

Based on this, protection and conservation of water resources become an urgent and national need for optimal management of the already scarce resources and maximize benefit through the application of a national policy regarding the protection of surface and groundwater resources.

In this regard, the first step started through identification of the groundwater resources protection zones and the application of rules and regulations in particular, as well as amendment of needed applicable laws so as to make it mandatory for the application.

These instructions submit limitation for areas and activities allowed or restricted or prohibited in each region and according to clear maps which will be adopted in the preparation of the kingdom master plans, based on the scientific considerations and the technical studies that are taken into account in the re-evaluation and modification of sites of protection zones according to the surrounding local circumstances and the prevailing natural and environmental phenomena.

These instructions are not related to any legal or compensatory data. Also, it do not address the powers of other parties in the Kingdom concerned with issuing licenses. Various parties should refer to these instructions to license any facility or activity or project which may threaten the quality of water resources.

Requirements for protection zone delineation

Overview

Delineation of surface and groundwater resources protection zones requires reviewing the available information and studies to demonstrate their adequacy to assess the watersheds located within it. Also, water resources should be reviewed in terms of the geological and hydrological aspects, including the vulnerability maps and maps of protection zones. Information is updated when necessary to conduct the field survey.

Also, delineation of these areas requires considering criteria of selecting sites of determined activities planned by the Ministry of Environment, and licenses issued in this respect by Ministry of Municipal Affairs, Ministry of Agriculture, and Greater Amman Municipality. The following protection zones were adopted according to methodologies adopted all over the world. These protection zones are the first, the second, and the third protection zones for the surface and groundwater resources.

Basic data for evaluation purposes:

In order to conduct sound evaluation process, the following data and information relevant to water resources must be provided:

- General information on public and private drinking water resources under protection (name, operator, location, resource height, and the technical description).
- Basic information relevant to water of public and private wells; licenses of digging, extracting, and permission.
- Results of chemical, physical, and biological analysis conducted on water resources (raw water) for several year, either these analysis done by controlling parties or operating parties. These results indicate situation of recharge areas, water resources productivity, water quality, and contamination possibility.
- Hydrological and hydrogeological data and environmental isotopes relevant to water resource.

Instructions on Water Resources Protection

In order to protect and monitor water quality in water resources and based on the provisions of Articles (4) {a} and (44) of the groundwater monitoring by-law number (85) for the year 2002 and its amendments, the following instructions were issued:

These instructions are called "instructions on the protection of water resources for the year 2011"

Definition

The following words and phrases, wherever mentioned, shall have the following meanings unless the context indicates otherwise:

Ministry	Ministry of Water and Irrigation
Minister	Minister of Water and Irrigation
Secretary General	Secretary General of Ministry of Water and Irrigation
	Secretary General of Water Authority of Jordan
	Secretary General of Jordan Valley Authority
Water Authority Law	Water Authority applicable law no. (18) for the year 1988

	and its amendments.
Jordan Valley Authority Law:	Jordan Valley Authority applicable law no. (18) for the year 1988 and its amendments.
Groundwater Control By-law and its amendments	By-law no.(85) for the year 2002
Groundwater	Water existing in subsoil and can be extracted through digging a well
Surface Water	All water bodies on surface; rivers or lakes or seas or permanent flow water or dams or ponds or springs water after flow
Spring	Water resource of ground origin. It flows to surface due to geological and hydrogeological factors; either continuous or intermittent
Aquifer	Layer of rock has the ability to store water ; this layer is solid cracked or fragmented and it have a permeable characteristic that allow movement and extracting of ground water
Groundwater recharge areas	Areas that fall under rain and snow accumulate on the surface or passing through the surface water resources and have permeable characteristics that allow water to seep into the ground to replenish groundwater
Main valley	Valley were flow of water lasts for six months or more
Well	Any hole or excavation occurred via machine or special tool used to access to groundwater aquifer to extract water by machine or automatically above surface.
Public well	Well owned by official parties or municipalities or companies

	manage water utility in governorates.
Private well	Well owned and exploited by non-formal parties and non-municipal ones.
Water contamination	Any change occur on the physical or chemical or microbiological or radium properties alone of in combination to limit the degree of suitability for the intended use.
Wastewater	Water resulted from household or industrial or agricultural utilizations.
Landfill	Site that includes the facilities and equipment for receiving waste with a view to disposal or treatment and storage.
Drinking water resources	Resources utilized or intended to be utilized for drinking purposes and household utilizations.
Watersheds	Is the area of land that falls under the rain or the water resources to supply the groundwater or surface water
Protection zones	Areas were various activities and practices are banned or restricted so as to protect the water resources from contamination and to limit negative impacts of these activities.
Karst layer	Is a limestone rock layer that contains the cavities and cracks, which are characterized by high permeability and water movement is not homogeneous.
The time of the arrival of microbial contaminants	The time of the arrival of microbial contaminant from contamination resource to the water resource
Cesspool	Hole is created from impermeable concrete or any other material impermeable and insulated to prevent the entry of wastewater to the water layer according to the Jordanian

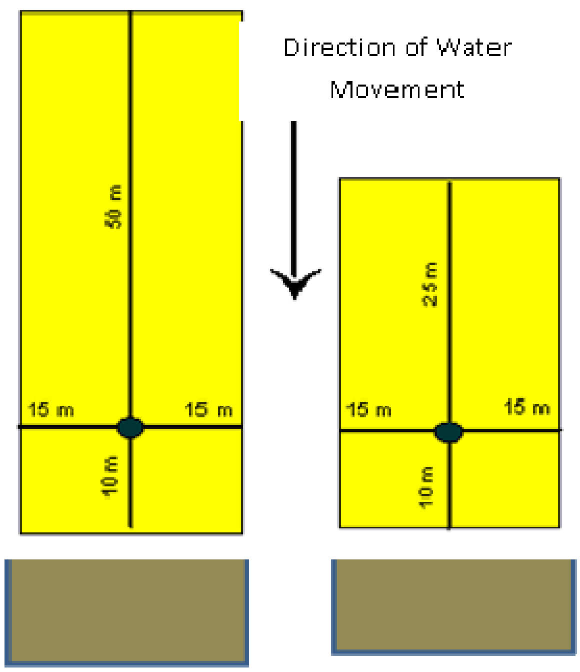
	specifications.
Public wastewater networks	All extensions, installations, facilities, and equipment for the transfer of wastewater from its production sites to the treatment plants
Cesspool	The hole specialized for the collection or disposal of wastewater and discharging it through the gaps and pores of the soil
Organic Agriculture	Agriculture that does not use any pesticides or chemical fertilizers
Population activities	Are the activities related to housing, tourism or trade and does not include development activity; artisanal or industrial or some activities such as fuel stations or washing cars or garages and olive presses

Groundwater Resources Protection Guidelines

Protection Zone:

- **Protection Zone I**
  - Zone I reaches at least 50 m and 25 m upstream of the spring or the well, respectively. The extension of the zone on both sides of the extraction point (spring/well) is around 15 m and 10 m in the downstream direction, as shown in Figures 1 and 2. Existing infrastructure and the current status of the area have to be taken into account.

Protection Zone[1]



Operation [2]

Area for

Water resource

Protection zone 1 for springs   Protection zone 1 for wells

- Each case is studied according to its nature so as to meet the sought purpose including lands allowed for acquisition and existing practices in the region (e.g: the surrounding area of some springs that exceeds (2) dunum and included within

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[1] Area of the water resource is the acquired area and/or fenced area surrounding the water resource

[2] Any activity is forbidden in this area except for activities relating only to water resource operation provided that activity should be performed in a secure area below the water resource, taking into account the following regulations:

documents of lands and survey department, in this case, all acquired area is considered as protection zone I of the spring).

- ✓ Private wells and springs not utilized for drinking must comply with the limits of the protection zone I , to fix resulted distance of protection zone, to comply with terms of protection imposed on public wells as a condition for granting new licenses[3] and any type of licenses issued by the wells relevant authorities. The existing status should be taken into account when licensing wells, and each case should be studied alone.
- ✓ If there is cesspool, it should be given priority either to connect to the sewerage network in accordance with the regulations and instructions of sanitation or the adoption of technical procedures necessary for this cesspools according to the Jordanian specifications. Supervision should be intensified over these areas to ensure sound health and environmental conditions in this regard by the concerned parties.

- **Protection Zone II**

- ✓ Zone II is delineated referring to existing hydraulic information, technical studies and reports. Based on this information, MWI specialists will calculate the velocity of groundwater flow and define the boundary of the protection zone. The protection zone II comprises the area between the outer limit of Zone I and a virtual line from where groundwater flow will take 50 days until it reaches the spring or well. This distance between the spring/well and this boundary should not exceed 2 km in the upstream direction of the extraction point and 50 to 150 m in the downstream direction. Every case will be studied individually. In karst areas, groundwater vulnerability maps are used if available and the technical consultancy is considered
- ✓ The boundary of protection zone II is to be recalculated if more detailed information about the geology and hydrogeology becomes available, (e.g. aquifer description, hydraulic parameters, groundwater flow and velocity and other

3 Granted licenses include: digging license, annual extracting license or annual license to sell valid or non-valid water

relevant information including hydro-isotope data, remote sensing data, tectonic data, geophysical data and mathematical groundwater models).

- ✓ Distance adopted as maximum for the second protection zone should be considered in case of availability of detailed studies with regard to the geological and hydrogeological situation, which represented in the properties of the layers, hydraulic elements, movement of groundwater and velocities, as well as applications of assistant science , including outlining the structural lines through remote sensing and applications of environmental isotopes, geophysical studies, and mathematical models of underground water reservoirs and others.

- **Protection Zone III**

The delineation of protection zone III comprises the entire groundwater recharge area for the well or spring. The procedure of defining the boundary of the groundwater catchment area (zone III) is based on hydrogeological considerations.

1.1 Activities allowed in Groundwater Water Protection Zones

- Activities allowed in Protection Zone I:
- Operation of the well or water resource, provided that it should be constructed downstream of the extraction point, including the cesspools, fuel containers or chemicals storage facility.

- ✓ First protection zone has to be implemented also for private wells. Private Wells are subject to the same protection conditions as governmental wells. This is an absolute condition for renewing the licenses of the wells (drilling license, annual abstraction license, or annual license for selling drinking water or other private licenses. The party responsible for the water resource should acquire the first protection zone where possible.
- ✓ There should be adherence to the instructions on the signs inside the well protection zone. Irregularities should be inspected by concerned parties such as

Ministry of Health, Ministry or Environment and other parties concerned with water resource protection in Ministry of Water and Irrigation, Water Authority of Jordan, and the Jordan Valley Authority.

- ✓ Any trespassing against the first protection zone should be stopped; complete fencing of the area. The activities in this zone are limited to those related to the operation and management of the water resource. Environmental and constructional sound practices have to be undertaken.
- ✓ Any installations necessary for operation and maintenance are to be designed in a way they cannot be hazardous to the groundwater.
- ✓ Priority is given to the implementation of sewerage networks in areas of water resources where possible, or to construct cesspools according to the Jordanian specification in this regard.

- **Activities allowed in Protection Zone II:**

- Activities in Zone II are limited to residential activities and organic agriculture. Priority is to be given to the establishment of an appropriate sewerage network or a safe sub-surface disposal system (cesspools) in accordance with the sewerage network by-law no. (66) of 1994 where possible, or to construct cesspools according to the Jordanian specification in this regard.

- Intensify control on these zones by ministry of Environment in coordination with other ministries and institutions according to its legal framework so as to ensure compliance with environmentally sound practices.
- No licensing of new establishments, extensions or changes in use has to be given unless the responsible organization gives permission after referring to related studies and recommendations. If there are no such studies, new studies have to be conducted. Every case has to be treated individually and requires correction measures to be undertaken to prevent any negative impact on the water resources in this zone.

- Agricultural development activities or existing industries which produce wastewater and may have an impact on the environment and on the water resources, are obliged to implement environmental sound practices according to the laws and by-laws applied in Jordan and comply with corrective measures decided by the responsible agencies[4].

- **Activities allowed in Protection Zone III:**

  All development, agricultural, industrial and social activities are allowed in this zone, under the condition that they comply with the laws and by-laws applied in the Hashemite Kingdom of Jordan and environmentally sound practices issued by Ministry of Environment.

4.1 Dams[5]

- **Protection Zone I:**

a- Protection zone I corresponds to the area surrounding the dam which is owned by Jordan Valley Authority for operational and implementation activities (registered on Jordan valley Authority maps).

b- **Future Dams and Projects:** Protection zone I corresponds to the area surrounding the dam which is acquired by Jordan Valley Authority for operational and implementation activities. The fenced distance has to be not less than 100 m (or as the geomorphologic condition of the area requires) around the embankment of the dam assuming the highest water level according to the original design or to plans of future expansion.

[4] Concerned parties include: ministry of interior, ministry of water and irrigation (WAJ, JVA), ministry of environment, ministry of municipalities, ministry of industry and trade, ministry of agriculture, Greater Amman Municipality.

[5] Existing dams, utilized or expected to be utilized for purposes of drinking or industrial recharge: Mujib dam,Waleh dam, Wadi Arab dam, Wehda dam, Tannour dam, and shurhabiel (zuglab) dam.

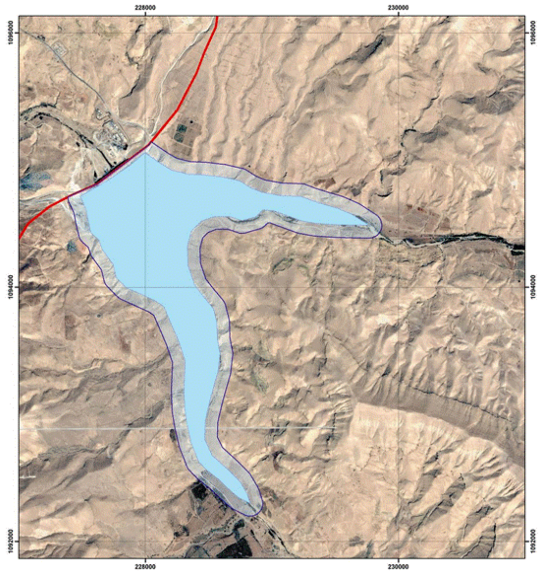

Figure 3: Protection Zone I (Example: Mujib Dam)

- **Protection Zone II**

Zone II begins at the boundary of zone I and is delineated case by case depending on the geologic and topographic situation (slope) of the area. The outer boundary of protection zone II should not be less than 2.5 km around the embankment of the dam or its edge.

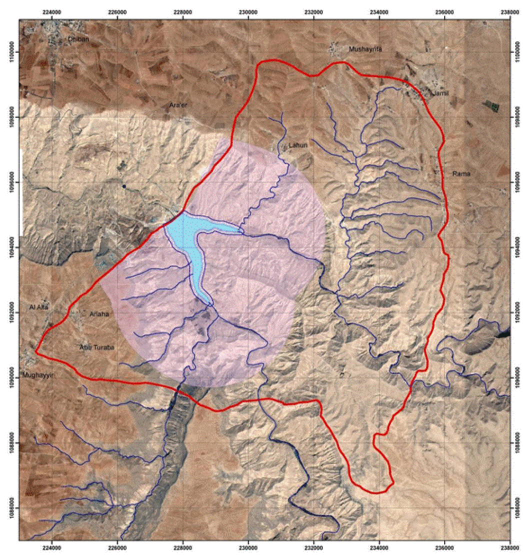

Figure 4: Protection Zone II (Example: Mujib Dam)

- **Protection Zone III:**

Zone III includes the entire catchment area which is estimated from the hydrogeological and hydrological condition of the area.

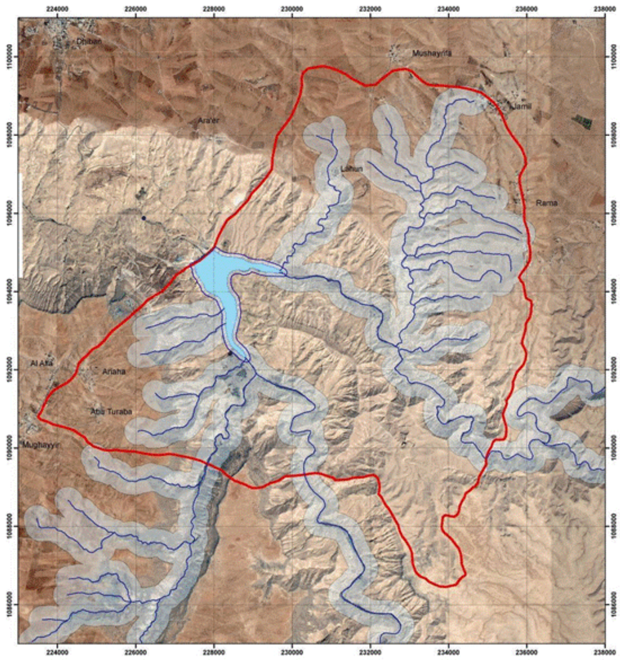

Figure 5: Protection Zone III (Example: Mujib Dam)

4.2. Wadis[6]

- **Protection Zone I:**

Zone I corresponds to the area of the wadi owned by the government and registered in the Land and Survey Department.

- **Protection Zone II**

Zone II starts at sides of wadis feeding the water body[7] around 350 m each side and for a distance of 5 km above the water body. These dimensions could be revised based on the geologic and topographic situation of the area and inclination factor of the region. Also, engineering or procedural control that will be taken by parties

[6] Valleys includes valleys feeding the dams and that released from dams and water bodies

[7] Water resource include dam, spring, well

concerned with region activities should be considered according to requirements of adopted licensing.

4.3. King Abdullah Canal (QAC):

Zone I corresponds to the area of KAC owned by the government. It comprises a total of 40 m on both sides of the canal according to the infrastructure in the area.

The canal has to be perfectly fenced and supervised along the canal extension.

• Activities allowed in Surface Water Protection Zones

Activities allowed in Protection Zone I

The activities in this zone are limited to those related to the operation and management of the water resource. Environmental and constructional sound practices have to be undertaken

Activities allowed in Protection Zone II

- The agricultural activities in this zone are limited to organic agriculture. This responsibility is undertaken by Ministry of Environment in accordance with applicable legal frames.
- When issuing licenses of any development activities, artisanal, investment or industrial; fuel stations, washing cars or garages or olive press, in addition to free zones and industrial zones, the issuing parties link issuing licenses to commitment not to produce and throw hazardous wastes.
- Priority is given to implement a sewerage networks in the inhabited protection zone II where water resources are available where possible, or priority is given to construct cesspools according to national codes in this regard.
- Intensify control on these zones by parties concerned with granting licenses, provided adherence to environmental sound practices issued by the Ministry of Environment.
- No licensing of new establishment, extensions or changes in use can be given unless the responsible organization gives permission after referring to related

studies and recommendations to prevent any negative impact on the water resources in this zone.

- The required correction measures are to be undertaken by the owner of the establishment according to the recommendations prepared by the licensing committee.
- Existing development, industrial and agricultural activities, which produce wastes that may have negative impacts on the environment and water resources, are obliged to implement environmental sound practices and to carry out corrective measures decided by the responsible agencies[8].

Activities allowed in the third protection zone:

All developmental activities are allowed in this zone, providing commitment to sound environment practices issued by Ministry of Environment.

1 Control and implementation

- ✓ Ministry of Water and Irrigation, Water Authority of Jordan, and Jordan Valley Authority implement requirements needed for the first protection zone including acquisition of lands surrounding the public water resource. Also, the aforementioned entities should address ministry of municipal affairs, Greater Amman Municipality, and Aqaba Special Economic Zone regarding the regulation of lands around the water resources so as to consider these instructions within organizational restructuring and detailed schemes relating to lands surrounding the water resources.
- ✓ Concerned parties in Ministry of Environment coordinate with the concerned official parties to control the second and third water resources protection zones, and should take necessary procedures according to the applicable laws.

[8] Concerned parties include: ministry of interior, ministry of water and irrigation (WAJ, JVA), ministry of environment, ministry of municipalities, ministry of industry and trade, ministry of agriculture, Greater Amman Municipality.

- ✓ Ministry of Agriculture coordinates with the concerned official parties to control the agricultural activities and the necessary protection requirements especially within the second and third protection zones.
- ✓ All private wells owners should adhere to instructions of the public wells first protection zone.

Secretaries General of Ministry of Water and Irrigation, Water Authority of Jordan, and Jordan Valley Authority should circulate these instructions, and all concerned and competent departments should adhere to its contents, and to apply it as of its publication in the national gazette.

Issued on: ……/……../…….

Minister of Water and Irrigation
Eng. Mohammad Najjar