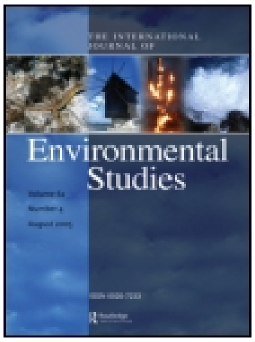

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Hydrogeological assessments of major springs in Wadi Al Bathan, West Bank, Palestine

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Wadi Al Bathan is one of the major tributaries of Wadi Al Faria River. Discharge measurements of six major Wadi springs taken over the past 24 years have been evaluated. The springs drained between 1.27 and 14.2 MCM/year during the hydrological years 1978/1979 (dry year) and 1991/1992 (wet year), respectively. The average calculated recharge area is about 16.8 km^2, which actually exceeds the orographic area (10.5 km^2), indicating one or more additional feeding water sources. It was found that there is a strong relationship between the discharge of this group and the intensity and distribution of rainfall. These results were confirmed using the hydrological data with the dissolved organic carbon (DOC) and total nitrogen (TN) in the hydrological year 2004/2005. The organic carbon and nitrogen show a flush-out response three and four months after a big rain event, which also reveals a long time until the conduits filled from the bottom to top of the layers.

Keywords: Al Bathan springs; Limestone aquifer; Discharge coefficient; Chloride balance

1. Introduction

Groundwater is almost the only source of water for the Palestinians in the West Bank and Gaza Strip. In the West bank it is used through the natural outlet springs and through abstractions from wells [1,2].

There are 297 springs (114 springs with more than 0.1 l/s) draining their water from limestone, dolomite and chalky limestone formations. Of these 297 springs, only six springs drain brackish water; these springs are located at the shore of the Dead Sea and in the Al Maleh area in the north-eastern part of the West Bank [3]. The annual discharge of these springs ranges from 90 to 100 MCM, and out of this volume, only 56 MCM are fresh water [2].

The surface geology of the West Bank comprises well-fractured and karstified carbonate rocks of limestone, dolomite and chalk from the Upper Cretaceous to the Tertiary Ages. Alluvial deposits in the Jordan Valley area from the Plio-Pleistocene Age form a chief aquifer in the Jericho area. Carbonate rocks from the Eocene Age comprise the Shallow Aquifer System in the Jenin and Nablus Districts while carbonate rocks of the Cenomanian-Turonian

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Ages cover the central and southern part of the country. These comprise the two main sub-aquifer systems: the upper aquifer system of the Turonian Upper-Cenomanian Ages and the deep aquifer system of the Lower Cenomanian Age (figure 1).

Rock formation outcrops are located at the surface where soil horizon is absent, while other sites are covered with a thin soil horizon that varies from one site to another. The thickest point reaches 10 m in the flat and depressed areas [4–6]. The outcrops at the top of hills where slopes are gentle and rocks are highly fractured and karstified receive varied

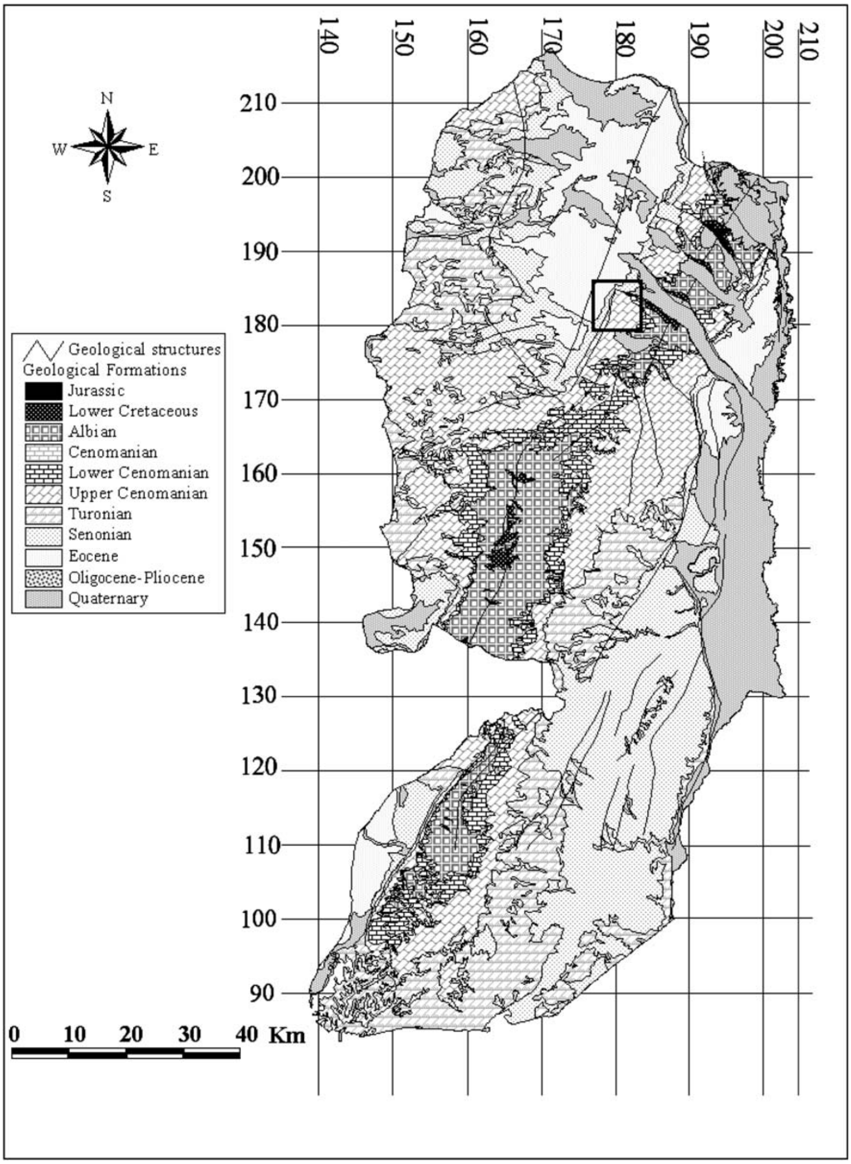


Figure 1. Geological map of the West Bank with the major structural features (modified after Rofe and Raffety [4]).

annual rainfall rates, ranging between 500 mm and 600 mm. This amount of rainfall varies from dry year to wet year. These areas are considered the major recharge zones for groundwater basins in the West Bank [5–9]. Groundwater flowing in carbonate rocks is generally controlled by various structural features such as faults, folds, joints, fractures and karstification [5]. Using the general groundwater flow system, three main groundwater basins were identified in the West Bank: the North-eastern, Western and Eastern Basins. These basins are composed of heterogeneous and anisotropic multi-layer carbonate aquifers with widely variable hydraulic characteristics. Some portions of the same water-bearing formation are unconfined and crop out at the surface while other portions are very deep and confined [4,5]. An example is Al-Bathan spring group, where a huge volume of water drains Al-Bathan during wet years, raising questions regarding the physical properties of the aquifer, the recharge rate, and the catchment area. This study focuses on the evaluation of the discharge coefficient of the six major springs in the Al-Bathan area as well as estimating the recharge rate and recharge areas of each spring.

2. Study area

Wadi Al Bathan area locates 5 km north-east of Nablus City as represented in figure 2. The study area is part of the North-eastern Basin with a total annual replenishment of 140 MCM [2]. Topographically, it consists of highlands with a steep gradient to the east. It lies within the semi-humid climate of the western part of the Wadi Al Faria catchment area which covers about 275 km^2. The amount in rainfall during the previous 30 years has varied from year-to-year (figure 3). The average annual rainfall for the time span between 1978 and 2006 was 608 mm, excluding the extremely wet year of 1991/1992. The minimum rainfall measured was 349 mm during the dry hydrological year 1978/1979 and the maximum was 1453 mm, recorded during the hydrological extremely wet year of 1991/1992 [10].

From top to bottom, the Eocene Aquifer System consists of reef limestone, nummulitcal limestone, limestone and chalky limestone. This local aquifer system in the Nablus and Jenin districts is very important for agricultural activities, as most of the Palestinian wells in these areas annually yield about 14 MCM of tap water by abstraction. Thin chalky layers inter-bed the lower part of the aquifer, from where many springs drain. The six major springs of this study (Ein Al Sedreh, Ein Al Qudeira, Ein Al Hamad, Ein Al Jeser, Ein Al Tabban and Ein Al Subyan) are located at elevations between 240 m and 130 m above sea level [4].

The total measured discharge of these six springs was 14.2 MCM during the extreme wet year (1991/1992) and sank to 1.27 MCM during the dry year (1978/1979) (Table 1).

The Al Bathan stream flows eastwards, and after a few hundred metres of steep flow, joins untreated wastewater originating from the sewer system of the Nablus municipality. Contributing to this stream is additional fresh water from the Al Faria group (Ein Al Faria and Ein Al Duleib), located 2 km to the west of the drainage system with a volume ranging from 19.1 MCM in 1991/1992 and 1.7 MCM in the dry year (1978/1979).

Located eastward and flowing into the stream is additional freshwater from Ein Shibly and Ein Miskah with an average annual discharge between 1.05 and 0.9 MCM. Most of this water is used for irrigation during normal hydrological years, and only after the high flooding period in winter months can water reach the area of Jordan River. In order to capture the flooding water, Israel constructed a 2 million cu m dam reservoir [11].

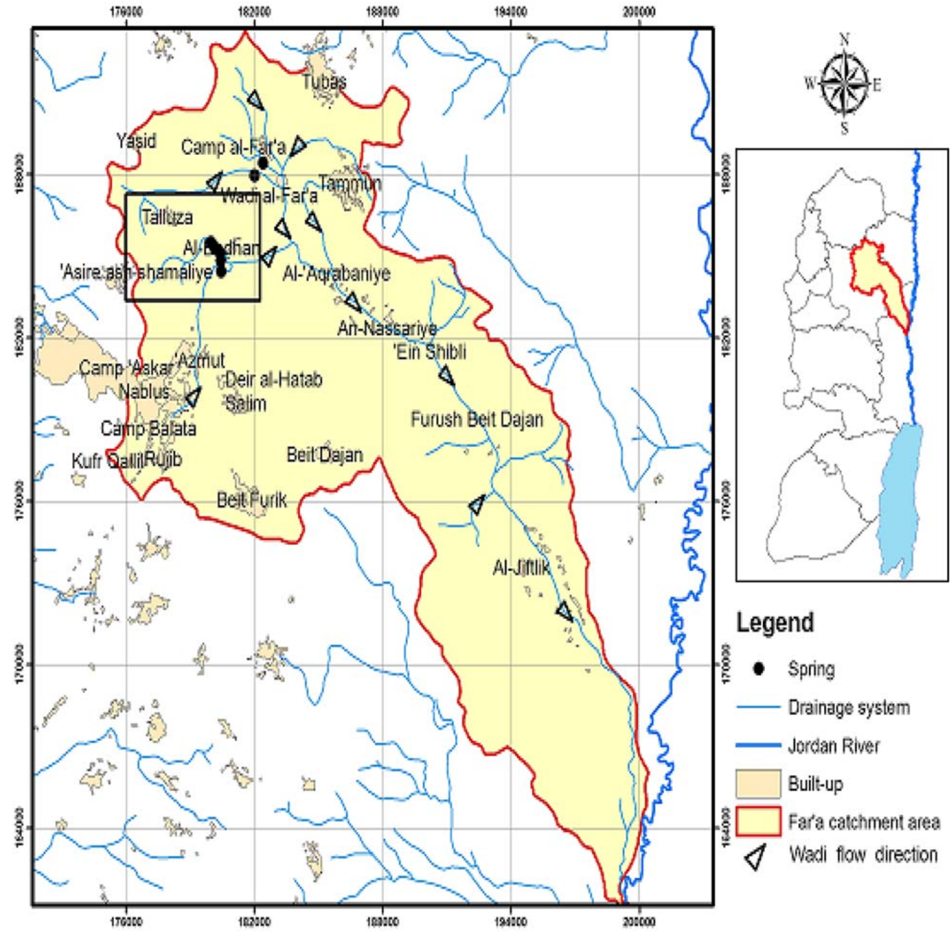


Figure 2. Location of Wadi Al Bathan study area.

2.1. Hydrogeology of Wadi Al Bathan

Hydrogeologically, the study area is part of the North-eastern Basin, one of the three groundwater basins in the West Bank. Water flows into the North-eastern Basin from the south-west to the north-east, but turns slightly to the south-east due to the NW–SE fault system of Al Faria graben and discharges in the form of springs in the Al Bathan and Al Faria areas (figure 4). The Eocene Aquifer System, from which many springs drain, composes the local aquifer system in the Nablus and Jenin areas. The carbonate rock of the Eocene Age overlies about 80 m of aquiclude chalky unit interbedded with cherty nodules of the Senonian Age. The chalky layers act as barriers thereby separating the Eocene Aquifer from the Upper Cretaceous Deep Aquifer System [12].

The Wadi Al Bathan springs line the bottom of the wadi, which is filled with alluvial deposit of a recent age. This spring zone, situated along the NW–SE minor fault system, is part of the southern axis of Al Faria Graben. This distinct structural feature strikes the Eocene rocks and elevates the impermeable Senonian chalk unit opposite to the Eocene

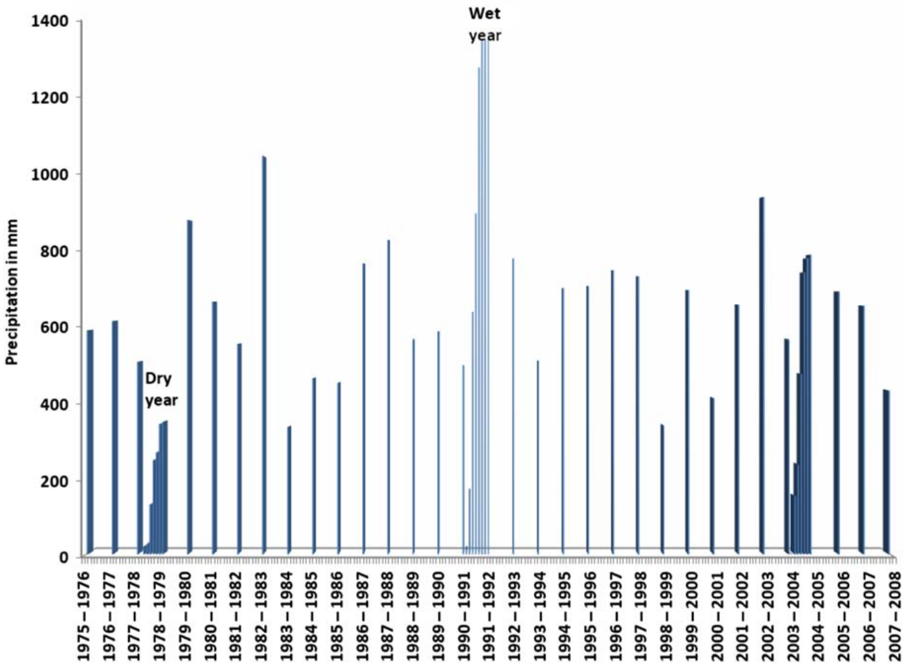


Figure 3. The amount in rainfall during the previous 30 years between the years 1978 and 2008.

Aquifer, thereby acting as a barrier for the groundwater flow. The Al Bathan spring group emerges along this fault axis (figure 4).

3. Methodologies

From 1970 until 2000, the West Bank Water Department and Palestinian Water Authority (PWA) carried out a monthly rainfall and springs discharge measurement campaign for all springs in the West Bank, including the study area [2,3]. Spring discharge measurements for the extremely dry hydrological year of 1978/1979 and for the extremely wet hydrological year of 1991/1992 were obtained for the six major springs. Group I, which includes Ein Al Sedreh, Ein Al Qudeira and Ein Al Hamad, is dominated by a conduit-fracture flow system that responds shortly after rainfall events, whereas group II, which includes Ein Al Jeser, Ein Al Tabban and Ein Al Subyan, responds with delay (figure 5). Dry weather lines (DWL) were extracted from spring recession curves. The segments of DWL were plotted on semi-logarithmic charts and the discharge coefficient of the aquifer λ was calculated using the Maillet equation [13,14]. The chloride mass balance method was used to estimate the recharge rate [15].

The TOC-Total Organic Carbon and TN-Total Nitrogen are used as a pollutants flush-out indicator in order to estimate the rate of recharge pressure effect. The TOC was measured as Non-purgable organic carbon by acidifying samples to a pH less than 2.0 and sparging with CO_2 free air using Analytical Jena instrument. The orographic catchment area of the Wadi Al Bathan spring group is calculated by using Arc View GIS 3.2 software.

Table 1. Discharge of Wadi Al-Bathan major springs in the northeast of the West Bank [3]

Spring name	Coordinates[a]		Elevation m.a.s.l	No. of measures	AD[1] (l/s)	SD	AD[2] (l/s)
	°E	°N					
Ein al Sedreh	180.0	185.5	240	24	42.3	70.0	33.0
Ein al Qudeira	180.1	185.3	215	21	42.3	20.0	40.7
Ein al Hamad	180.1	185.3	215	24	25.5	9.7	24.1
Ein al Jeser	180.4	185.1	170	19	4.3	1.7	4.1
Ein al Tabban	180.4	184.8	160	24	43.8	5.7	43.4
Ein al Subyan	180.4	184.4	130	24	6.1	0.7	6.0
Total discharge				164.3			150.9

[a]Coordinate: is according to Palestine Grid, 1923.
AD[1]: Average discharge recorded from 1970/71 to 1993/94.
AD[2]: Average discharge without the hydrological year 1991/1992.
SD: standard deviation.

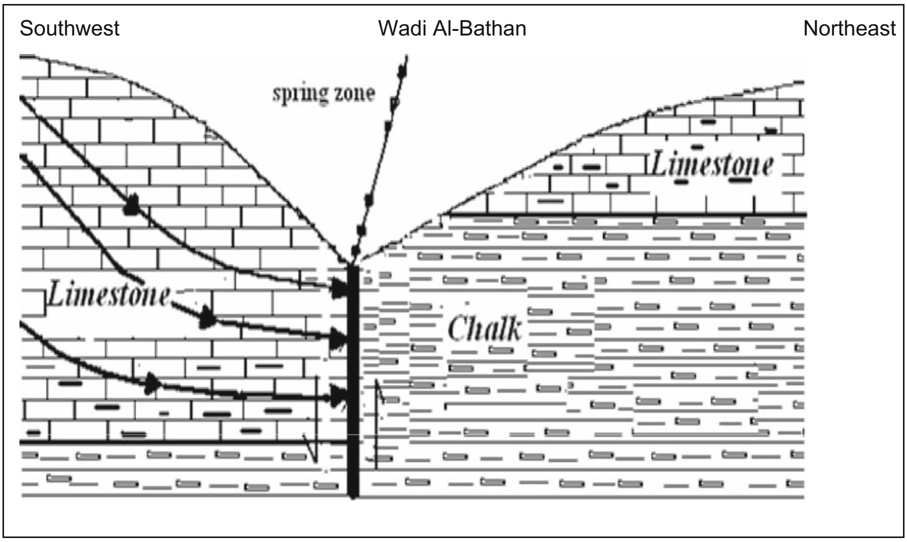


Figure 4. Schematic cross-section of the spring zone (showing groundwater flow and different lithological formation).

4. Results and discussion

4.1. Recharge area estimation

The orographic catchment area of the Wadi Al Bathan Springs is about 10.5 km^2. This area extends west and southwest. In this rural area, only 20 houses exist and no intensive land use practices can be found. In addition to range land, olive and almond orchards are the only major vegetation that covers the area.

The recharge area of the spring group is calculated by dividing the total measured discharge of the spring by the average annual recharge rate. Table 2 summarises the related recharge area depending on the average discharge of the six springs during the hydrological years 1991/1992 (maximum) and the average for 24 years. The total recharge area for Al Bathan group ranges between 39.74 km^2 and 16.8 km^2 as an average recharge.

In subtracting the 10.5 km^2, which is the orographic catchment area, from the total needed area (depending on the discharge volume and recharge rate), a deficit of 29.4 km^2 for the hydrological wet year 1991/1992 and 6.3 km^2 for 24 years average is found.

According to this calculation, three possibilities could be considered as additional sources of water that feed the spring group:

1) The underground recharge area is larger than the orographic area.
2) An additional source of water, possibly leaking from the lower aquifer, finds its way along the fault axis.
3) Part of the surface runoff infiltrates the aquifer system through the fractured and karstified limestone.

4.2. Discharge coefficient of Al Bathan springs

Measuring the spring discharge for long period, including the dry and wet hydrological years, is essential for evaluating the physical properties of the aquifer – especially the

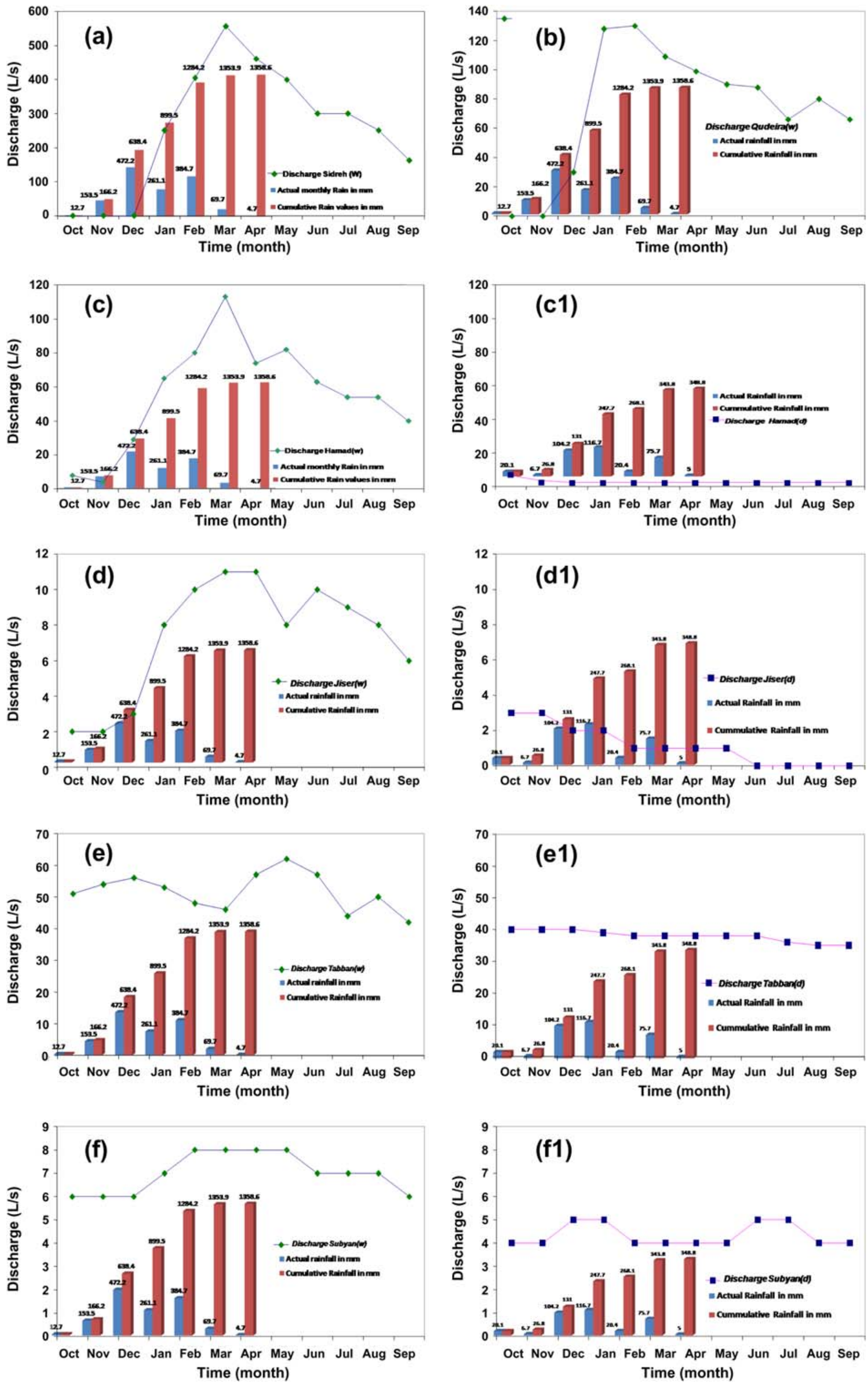


Figure 5. The springs discharge in wet and dry season.

Table 2. Catchment area of Al Bathan springs according to the recharge rate calculations

Status	AMD (MCM/y)	R.A (km^2)	VD (MCM/y)	R.A (km^2)
Wet year	14.2	39.74	5.99	16.8
Dry year	1.27	3.56		

AMD: Average Measured Discharge.
R.A: Recharge Area.
VD: Annual Average Discharge.

discharge coefficient of the aquifer system. The Maillet equation (1905) can be used for evaluating the recession curve of spring discharge. The discharge coefficient of an aquifer is governed by many factors such as the geometrical extension of the aquifer (x, y and z direction), porosity, permeability, density and viscosity of the liquid [14].

Maillet equation [13,14]:

$$Q_t = Q_0^* e - \lambda t \tag{2}$$

Where 'Q_t' is the flow at 't' time after the recession started (m^3/s); 'Q_0' is the flow at the start of the recession (m^3/s); 'λ' is a recession constant for the basin (day^{-1}); and 't' time since the start of the recession. The use of equation (2) presents the discharge coefficient of the aquifer, λ reflects the physical characteristics of the aquifer system.

The local aquifer system is composed of carbonate rocks of Eocene Age, which consist of chalky limestone, limestone and nummulitcal limestone from bottom to top of the aquifer. A thin chalk layer interbeds the aquifer and separates it into sub-systems that are hydraulically connected by fractures. Depending on the lithology of the aquifer, Wadi Al Bathan springs can subdivide into two groups, which are:

Group I. This group includes Ein Al Sedreh, Ein Al Qudeira, and Ein Al Hamad. The three springs drain from the limestone layer, Ein Al Sedreh from the upper part, and Ein Al-Quderia and Ein Al Hamad from the lower part. The altitude difference between these two springs is 25 m. This also illustrates the difference in flush-out response for both springs in term of TOC and TN, where the Sedreh in the upper part shows quicker response than Hamad which come two months later (figure 6a–c).

But, both the Ein Al Qudeira and Ein Al Hamad springs drain from the same spring niche with a distance of 5 m and show the same flush-out period.

This group (Sedreh, Qudeira and Hamad) is characterised by high discharge and high fluctuation. Rainfall volume and intensity govern the discharge starting time and the discharge fluctuation. There is a strong relationship between the discharge of this group and the intensity and distribution of rainfall (figure 5 a–c). During the hydrological dry year 1978/1979, all three springs drained completely, while during the hydrological year 1991/1992 and after a heavy rainfall in November 1991 (with more than 600 mm), the discharge of the springs drastically increased, reaching the highest value in March 1992 [2].

4.3. Recession curve analyses

Group I. These springs issue when rainfall reaches and exceeds the annual average. The discharge history of these springs demonstrates that it is strongly controlled by the intensity and distribution of the rainfall (see the hydrographs). This was evident in

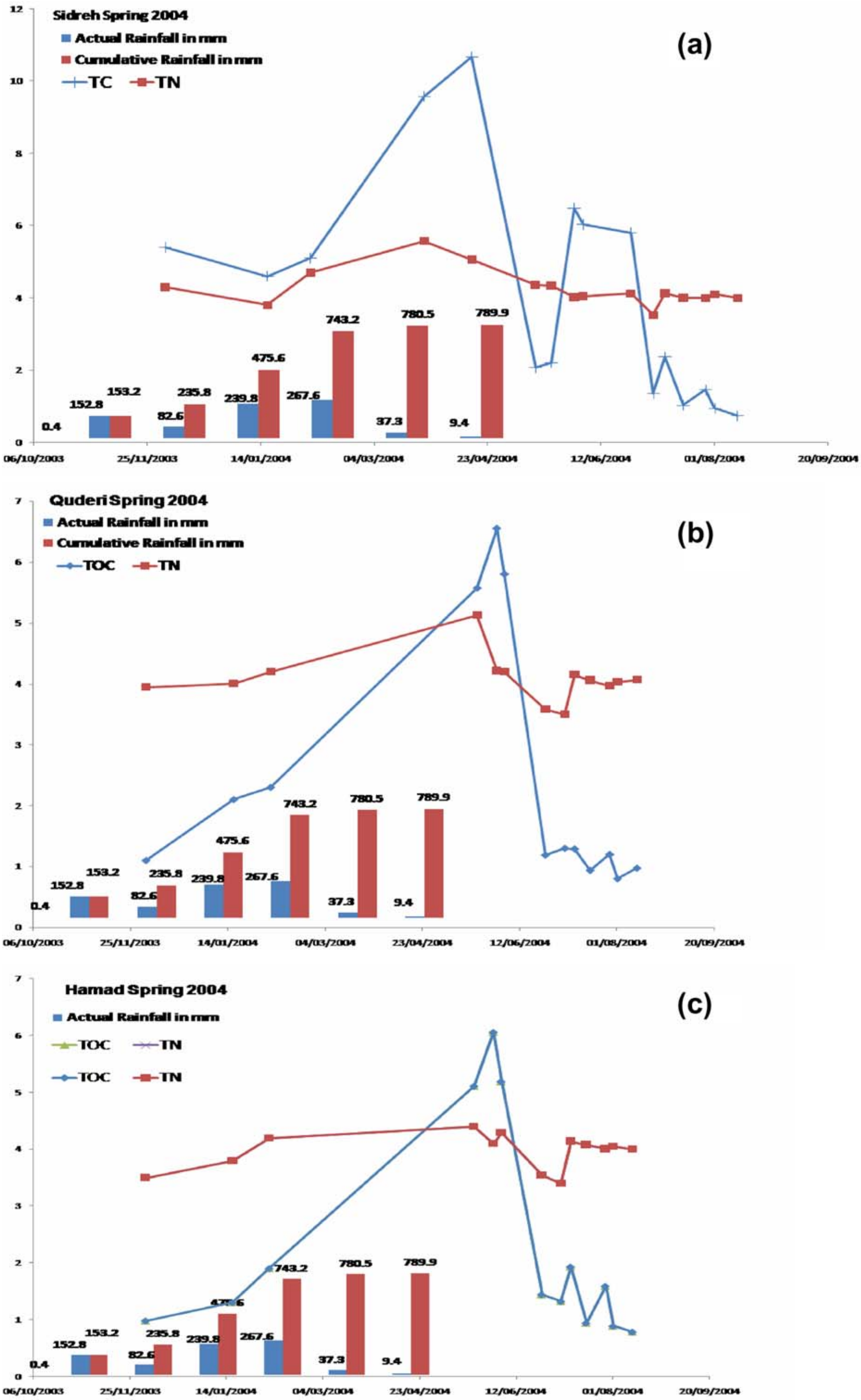


Figure 6. The Springs' pollutant response to rainfall intensity.

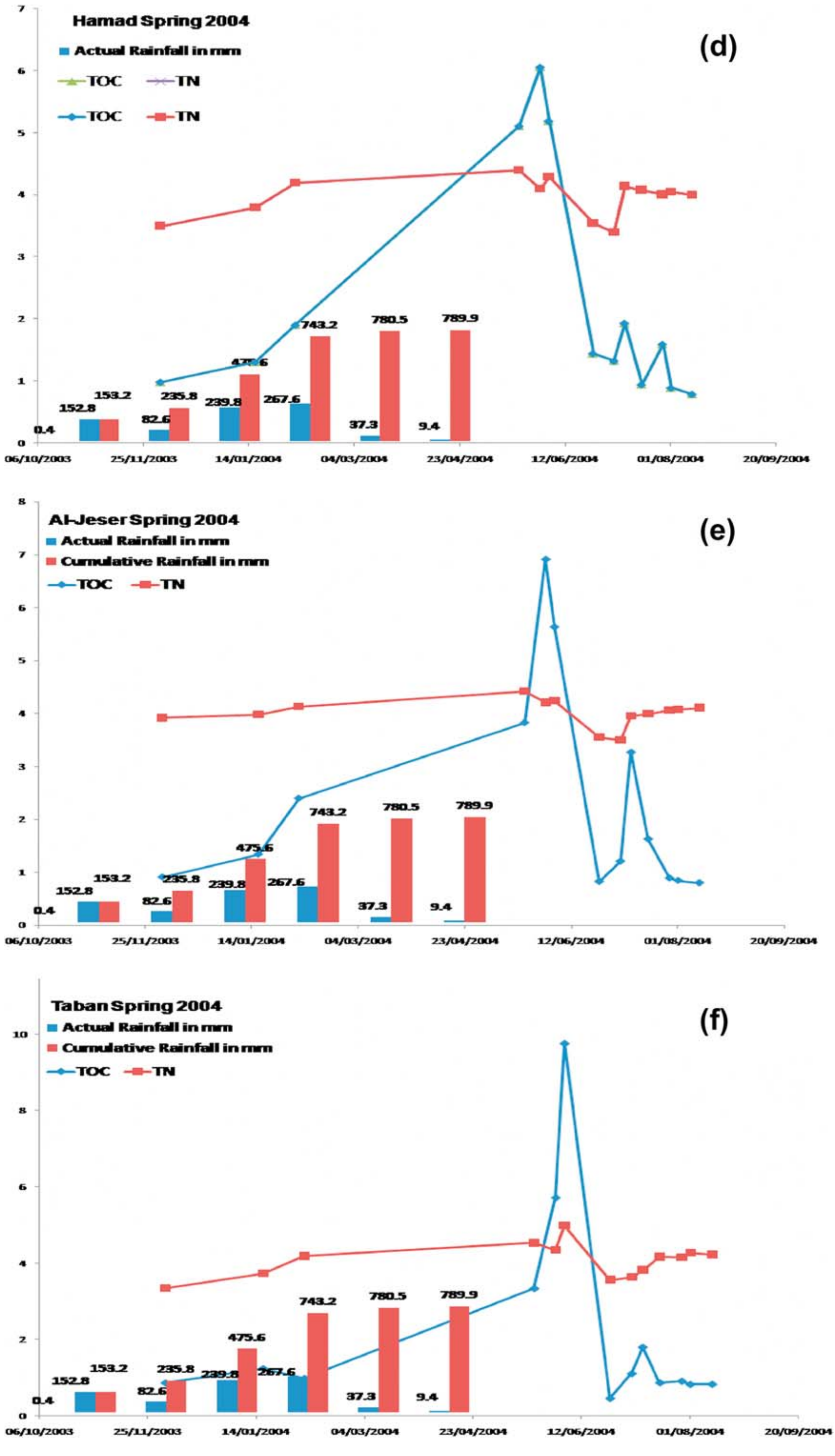


Figure 6. (*Continued*)

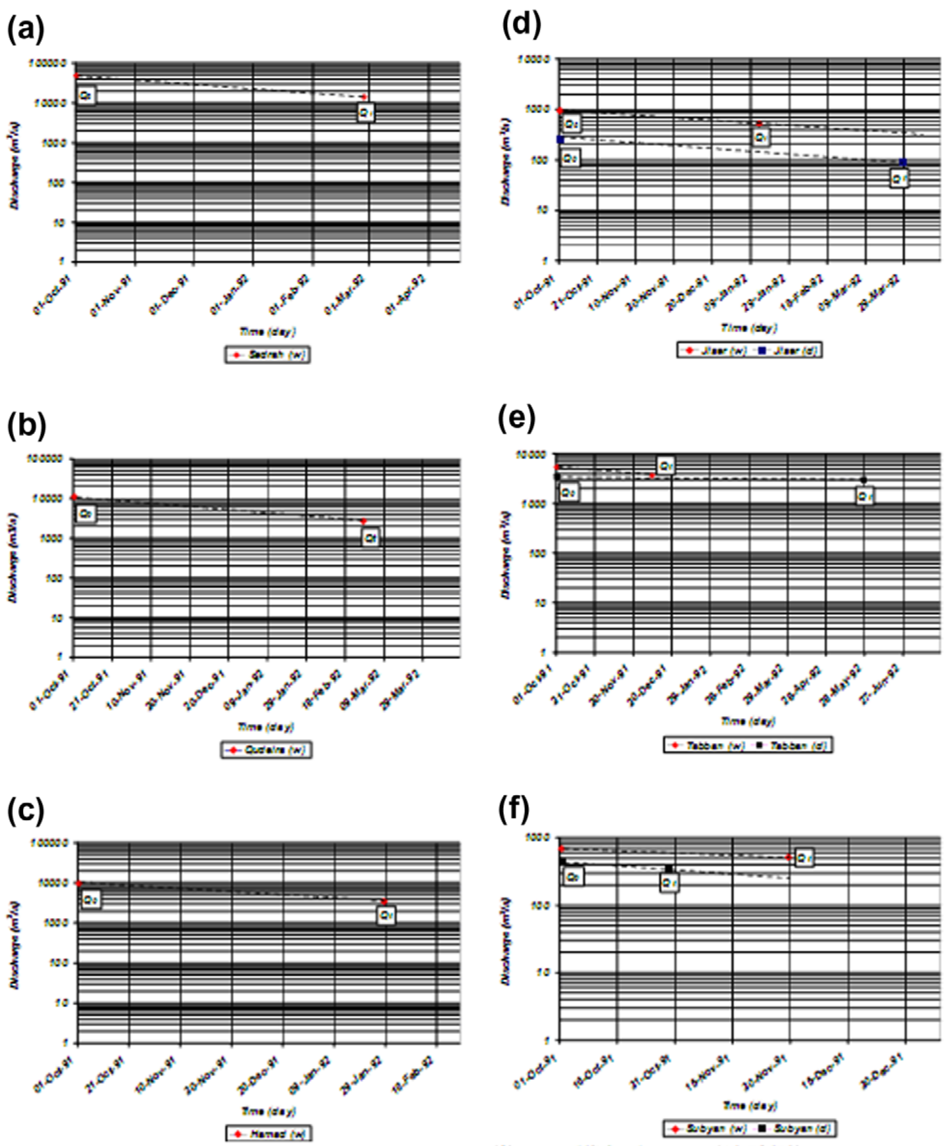
the hydrological years of 1982/1983, when 1123.5 mm of rain fell, thereby allowing this spring group to drain from March until September 1983. In January 1992, following a heavy rainfall (637 mm) in October and November 1991, Ein Al Qudeira began draining during December 1991 and Ein Al Sedreh began in January 1992. The total rainfall of 1991/1992 was 1453 mm at the Nablus weather station, and due to the heavy rainfall during this year, many secondary small springs discharged above the main spring niche along the Wadi floor [2]. The highest discharge peak was recorded during February and March 1992 with 130 l/s for Ein Al Qudeira 557 l/s for Ein Al Sedreh r. It is important to emphasise that the rainfall during the years 1988/1989, 1989/1990, and 1990/1991 was 566.6 mm, 588.7 mm and 504.9 mm respectively (figure 3) [2].

During these years, the rainfall was less than the annual average (608 mm/a). Therefore, no discharge was recorded for Ein Al Sedreh. It can thus be concluded that only when the amount of rainfall exceeds the limit of 600 mm, does this spring start to drain. During the following hydrological year 1992/1993 the amount of rainfall was 623 mm, less than that in the year 1990/1991, and the discharge of the spring continued to decline even allowing Ein Al Sedreh to drain out in January 1994 [2]. In summary, after the first few rainfall events during November and December 1991, rainwater infiltrated quickly through the high permeable reef and nummultic, highly fractured and karstified limestone layers, reaching the limestone layer from which these two springs issue. Dry weather lines (DWL) were constructed for Ein Al Sedreh, Ein Al Qudeira and Ein Al Hamad during the hydrological extreme wet year 1991/1992 (figure 7 a–c). The curves represent the depletion of the groundwater reservoir feeding these springs. The semi-logarithmic plot of the constructed dry weather lines shows that this group has one segment representing one flow system – the karstic-fractured flow system. The high discharge rate with the high slope of the recession curve presents a high hydraulic conductivity with a low storage coefficient, characterising the secondary porosity of the aquifer. The discharge coefficient λ of the flow system ranges between $8.2^{*}10^{-3}$ day-1 and $8.6^{*}10^{-3}$ day-1 (Ein Al Sedreh and Ein Al Hamad) and $4.5^{*}10^{-3}$ day-1 for Ein Al Qudeira (equation 2).

Group II. This group includes three springs: Ein Al Jeser, Ein Al Tabban and Ein Al Subyan, draining at elevations of +170 m, +160 m and +130 m respectively. The three springs drain water during the dry and wet years. Ein Al Jeser drains from the lower part of the limestone layer, whereas Ein Al Tabban drains from the upper part of the chalky limestone and Ein Al Subyan drains from the lower part of the chalky limestone, all springs in this group show late flush-out for TOC and TN nearly in the middle of June (figure 6 d–f).

Figure 5 d–f summarises the discharge hydrograph of the three springs during the hydrological year 1991/1992 and the dry year 1978/1979, which present the discharge fluctuation during these years. Ein Al Tabban and Ein Al Subyan have low fluctuation while Ein Al Jeser is affected by precipitation.

Ein Al Jeser: The relative low discharge of this spring (11 l/s) reflects the physical properties of this part of the aquifer system as well as indirect recharge, which leaks from overlying layers (leaky aquifer). Figure 7 d shows the Ein Al Jeser semi-log plot (time versus discharge rate) for the recession time, and the DWL is constructed from data related to the hydrological years 1991/1992 and 1978/1979. The discharge coefficient represents one flow system that ranges between $5.7^{*}10\text{-}3$ day-1 and $6.1^{*}10\text{-}3$ day-1. These values indicate that the fractured flow system dominates the feeding layer of the spring.



(*): zero l/S in dry year (1978/79)
(w): wet year (1991/92).
(d) : dry year (1978/79).

Figure 7. Dry weather line for Wadi AL Bathan springs: a) *Sedreh, b) *Qudeira, c) Hamad, d) Jiser, e) Tabban, f) Subyan (Environmental Lab 2005).

Ein Al Tabban: This spring drains from a thin bedded limestone layer interbedded within the chalky limestone formation. The discharge ranges between 42 to 62 l/s in wet year 1991/1992 and 35 to 40 l/s in dry year 1978/1979. There is limited influence of the rainfall on the spring. The relatively high discharge rate with low fluctuation during drought years presents a good source of water with a well connected flow system. During the hydrological wet year 1991/1992, the discharge peak was recorded during May 1992 with 62 l/s. Figure 7e shows Ein Al Tabban's DWL.

The discharge coefficient of this spring is represented in one segment. The discharge coefficient of this part of the aquifer is 5.1*10-3 day-1.

Ein Al Subyan: The average discharge is about 7 l/s and drains from the lower part of the chalky limestone formation that overlies the chalk unit of the Senonian Age. Recharge to this sub-aquifer system occurs only through seepage from the overlying beds. This can be seen through the continuous and relatively constant spring discharge during the hydrological years, ranging between 5 and 8 l/s (figure 5 f).

Ein Al Subyan's low discharge represents the chalky limestone layer. During wet year 1991/1992, the highest discharge was recorded in April 1992 with 8 l/s. During and after the wet hydrological year 1991/1992, no discharge trend was recorded. This indicates that the discharge of the spring is not controlled by the rainfall fluctuation, but that the effect of secondary permeability of the aquifer is limited, and consequently the infiltration rate through the porous matrix of the feeding formation is relatively constant.

Figure 7 f shows Ein Al Subyan dry weather line (DWL), demonstrating that one recession segment represents one regime of flow system. The coefficient discharge for this system is $4.8^{*}10^{-3}$ day-1 which is the lowest, but the highest in storage capacity.

5. Discussion and conclusions

This paper describes the effect of rainfall intensity variation on the hydrology and discharge of six major springs in Wadi Al Bathan. The results show that the springs are highly affected by the rainwater variation where the springs in the dry year 1978/1979 went to depleted. Besides the variation of the rainfall amount, the drought and re-enhancement of the springs in general are commonly related to the geological structure from which the springs break out.

The aquifer feeding the spring group (I) is dominated by the conduit-fracture system. This responds quickly to the rainfall events (maximum after two months). The hydrographs of these springs show one line segment on the recession curve. The second group (group II), which drains from the chalky limestone, is dominated by the fracture-matrix flow system. This responds to the precipitation with a delay of three months. The annual recharge rate was calculated using the chloride mass-balance method and is estimated to range between 64.8 mm and 269.8 mm. According to the discharge measurement of both spring groups and the calculated recharge rate, the related recharge area needed for the discharge of the springs is five times higher than the orographic recharge area, which is only 10.5 km^2. In general, the discharge response to the rainwater intensity can be described as a conservative response, where most of the springs show the discharge peak after a cumulative amount of 600 mm in wet season of 1991/1992. This amount normally accumulated by the end of the rainy season in the average rate. This also can explain the rescission of the discharge curve in the dry season of 1978/1979 in which the cumulative rain reaches less than 400 mm. But, the data from the year 2004/2005 indicate not much change with respect to recharge rate and mechanisms. It was found that there is a strong relationship between the discharge of this group and the intensity and distribution of rainfall.

These results were confirmed using the hydrological data with the TOC-dissolved organic carbon and TN-total nitrogen in the hydrological year 2004/2005, where the organic carbon and nitrogen show a flush-out response three to four months after a big rain event, which also reveals a long time until the conduits filled from the bottom to top of the layers. This produces a piston-like effect, exerting high pressure to flush out all the organics. This study give a clear understanding about the relation between the rainfall amount which is highly variable from one year to another in the study area and can be used as a helpful tool for any future action against the expected climatic change and its effect on the availability of the water resources in the area. Further investigations are required in order to identify additional sources of water.

Acknowledgements

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