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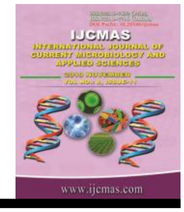

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Hydrological Study and Aquifer Characteristics Evaluation of Wadi El Arab Catchment Area/Jordan

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ABSTRACT

This study deals with Hydrological study and aquifer characteristics evaluation of Wadi Arab Catchment area/Jordan; Wadi El-Arab covers an area of about 267 km^2. The catchment lies between 210-230N and 208-230E according to Palestinian grids. There are several Wadis draining in the catchment area and no flow measurement data are available for these Wadis. The main objectives of this paper are to provide a hydrological and hydrogeological assessment for the water resources of Wadi El -Arab catchment area. Also to calculate the water budget and specify the different pollutants, their possible sources and their actual impacts on the groundwater resources. The determination of flows is carried out by applying the "Curve Number" approach of the "United States Soil Conservation Service (SCS)" to the available rainfall data. The average annual rainfall for the period 1980 -2018 is 426.42 mm, the rate of evaporation ranges between 83% in the wet year and 90% in the extremely dry water year. The infiltration rate ranges between 6.75 percent and10.61 percent. While the rate of Runoff ranges between 6.55 % in the wet year and 3.25 % in the extremely dry water year. The hydraulic system of Wadi El-Arab Basin is controlled by the geological and structural conditions, which also controls the recharge level, movement, and discharge of the groundwater. The aquifer systems of the entire study area are related to the Cretaceous Upper Ajlun Group (A_7) to the Cenozoic Lower Belqa Group (B_1 and B_2) is the main aquifer for water supply in the study area. On its top, the A_7/B_2 aquifer is hydraulically separated from the locally productive B_4 aquifer by the Muwaqqar aquitard (B_3). The transmissivity of the (B_2/A_7) aquifer ranges from 9 m^2/day to more than 900 m^2 /day. The storage coefficient of this aquifer in the confined condition vary from 10^{-3} to 10^{-5}, while the specific capacity vary from less than 0.01 L/s /m to more than 50 L/s/m and The permeability ranges from 0.01 to more than 100 m /day.

Keywords

Water resources, Curve number, Evaporation, Pollution, Catchment area

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Introduction

Water is an essential element of nature and is the elixir of life. The increasing water demand by population growing, industrialization, agriculture, and rising of living standards have led to increase the stresses on these resources. Water resources are decreasing due to unawareness of people as they think that water is renewable; this unawareness led to exploitation of all available water resources which and cause water quality deterioration.

Jordan has been classified recently as second poorest country of water resource. Due to unreliable and shortages in the supply of water sector, this makes it very difficult to face the required increasing demand.

Surface and groundwater sources are used to meet Jordan water demand. The groundwater extractions often exceed the natural recharge volumes, resulting in a decline of the groundwater table and in a deterioration of the soil and water quality.

The present paper focuses on the current situation of the water resources at Wadi El-Arab catchment area. Wadi El-Arab catchment area enjoys a Mediterranean to semi-arid climate, with hot and dry summer, cool and wet winter. The average annual rainfall is approximately ranges between 350 mm and 500mm (JMD, 2012).

The importance of this catchment area is that it contains perennial springs which exist only in the northwest part, and these springs are the main source of potable water for Irbid city, however, these springs dried out due to severe pumpage which started before 20 years ago. In the last decade, the groundwater level in Wadi El-Arab wells drop in a rate exceeded 25 m (Shatnawi and Diabat, 2016). Consequently, the aquifer balance is disturbed and a major decline in water level accompanied by deterioration in groundwater quality has taken place. The extension of urban area around the main springs, and the existence of Irbid and Wadi El Arab, which affect the water uses. These issues guided me to evaluate the water resources of the study area.

Physiography

Wadi Al Arab drainage catchment with an area of 267 km^2 is situated on the East Bank of Jordan Rift Valley about 10 km south of Lake Tiberius. The selected catchment area lies within 32°34'60" N and 35°34'60" E latitude or between 210-230N and 208-230E according to Palestinian grids (Figure 1).

The topography ranges from rolling hills in the East to steeper mountainous areas in the North and West. The general slope of the area is from East to West, that's from 800 m above the mean sea level (asl) at highlands south of the study area to less than 130 m below the mean sea level (bsl) at the site of dam (Figure 2).

Despite the small area of Wadi El-Arab catchment area, a very heterogeneous soil can be found. The major causes of this variety are the extreme climate conditions which form these soils in addition to variable geology (sedimentary rocks, alluvium, etc.) different topographic features and physical weathering from both water and wind modifies the soils, Figure 3 describes the different types of soil that are present in the catchment area, (MOA, 1994).

Wadi El-Arab drainage basin is a highly valuable agricultural land, fertile soil, the nature of slope and soil of this catchment making it suitable for cultivation. It is intensively cultivated with olives cereals and vegetables in the upper southern slopes of Wadi El-Arab an oak forest grows, while in northern slope it cultivated with pine, Figure 4 shows the different types of soil that present in the catchment area.

Materials and Methods

Geology and hydrogeology

The geological material existing in the catchment area is the important features affecting the hydrology regime. The flow rate of the surface water and subsurface water influenced by the nature of the bed material. The outcropping formations in Wadi El - Arab catchment range in age from Late Cretaceous to Quaternary sediments, basically the Ajlun (A) and Balqa(B) group. These deposits are divided into three groups, Kurnub (K), Ajlun (A) and Belqa (B) group in ascending order. the Belqa /Ajlun group (B/A) is underlain by the Kurnub (K) layer composed of sandstone layers of lower cretaceous period, which crops out at the lower limit of Wadi Shu'eib catchment area. The A/B (two groups of middle to upper cretaceous) is divided into several formations of A1 to A7, and B1 to B2. Some of the formation might strictly be considered as (sub-groups) and the groups as (super groups) but the division has been based on previously used mapping units and on a general classification of units into aquifers and Aquicludes. For those units which could be further divided, a double number has been assigned. For example, the A1/2 formation, the Na'ur limestone and marl formation can be split in some districts and this has been done wherever possible, (Shatnawi and Diabat, 2016).

The geological structure and tectonic features in the Wadi EL-Arab Catchment Area is highly related to the structure of Jordan Rift Valley, which was described in detailed by many authors. Uplifting and faulting has considerably affected the rock formations along the Jordan Valley Escarpment and further to the east (Figure 5).

The hydraulic system of Wadi El-Arab Basin is controlled by the geological and structural conditions, which also controls the recharge level, movement, and discharge of the groundwater. The aquifer systems of the entire study area are related to the Cretaceous Upper Ajlun Group (A_7) to the Cenozoic Lower Belqa Group ($B_1$and B_2) is the main aquifer for water supply in the study area. On its top, the A_7/B_2 aquifer is hydraulically separated from the locally productive B_4 aquifer by the Muwaqqar aquitard (B_3). The transmissivity of the (B_2/A_7) aquifer ranges from 9 m^2/day to more than 900 m^2 /day. The storage coefficient of this aquifer in the confined condition vary from 10^{-3} to 10^{-5}, while the specific capacity vary from less than 0.01 L/s /m to more than 50 L/s/m and The permeability ranges from 0.01 to more than 100 m /day, (BGR and MWI, 2001).

Data preparation under ArcGIS software environment

The geological formation of the study area has been identified by using the geological map from Natural Resources Authority (NRA). This stage included geo-referencing and scanning the available maps, after that digitizing the classified formation then symbolized the categories. The same process was applied to the different paper maps such as (soil map, geology map, aquifer media, and the land use map).

On the other hand, the topography of the study area has been achieved by using the DEM; which is displaying the geomorphology of the catchment area.

Determination of the areal rainfall

There are eight rainfall stations in the study area; all stations measure the daily rainfall, and five of them have also rainfall recorders, giving hourly rainfall events. The distribution of rainfall over the study area was represented in two methods; these are Thiessen polygon technique and Isohyethal method. Thiessen polygon was applied to estimate the areal rainfall for each considered storm. In this method it is assumed that the point rainfall at the station is representing the areal rainfall in its polygon, or its area of rainfall influence. Figure 6, shows the Thiessen polygons of Wadi El Arab catchment area.

Runoff

There are no gauging stations located in Wadi El Arab Catchment Area. Therefore, the US Soil conservation services method (SCS), was applied to calculate the runoff occurred from different storms of normal condition,(Aydin and Antal, 2019), This method takes in consideration the antecedent moisture conditions (AMC), the initial abstraction of rainfall, and the land use.

The first step for the use of the SCS model was to estimate the volume of direct of runoff, (Q), in inches.

$Q = (P - I_a)^{2}/(P - I_a + S)$ … (1), (Chow et. al, 1988)

Where

Q: is the accumulated depth of runoff in inches.

P: is the accumulated depth of storm rainfall in inches.

I_a: is the depth of the initial abstraction in inches.

I_a and S are related to soil cover conditions. Also the relation between initial abstraction (I_a) and potential abstraction (S) was derived from the studies of different watersheds in the United States of America as,

$I_a = 0.2\ S$ … (2)

The above equation for the accumulated runoff is formulated as:

$Q = (P - 0.2\ S)^{2} / (P + 0.8\ S)$ …(3)

The relation between the Curve Number (CN) And S was established by (Wanielista,1990) as,

$S = (1000 / CN) - 10$ … (4)

These universal equations are the basis of the runoff model used in this study where the flows were derived.

Evapotranspiration

The purpose of calculating the evapotranspiration in Wadi Shu'eib Catchment area is to estimate the direct recharge into the groundwater of the Upper aquifer system (B4). The potential evapotranspiration was calculated using Turc Equations. This equation is written as follows:

$E = P/(\sqrt{0.9 + (P^2 / f(t)^2})$ ….(5), (Turc, 1990)

Where

E: the annual actual evaporation (mm)

P: the average annual precipitation (mm)

T: the temperature function, which is equal to,

$f(t) = 300 + 25\ t + 0.05\ t^3$ … (6)

The essential climatological data which were needed for the computation of the potential evapotranspiration had been collected from Ministry of water and irrigation (MWI, 2017). In order to obtain the actual evaporation from rainfall, the potential evaporation was calculated during the occurrence of the rainfall storm.

Results and Discussion

Hydrogeological setting

The hydraulic system of Wadi El-Arab Basin is controlled by the geological and structural conditions, which also controls the recharge level, movement, and discharge of the groundwater. The aquifer systems of the entire study area are related to the Cretaceous Upper Ajlun Group (A_7) to the Cenozoic Lower Belqa Group (B_1 and B_2) is the main aquifer for water supply in the study area. The A_7/B_2 aquifer is hydraulically separated from the locally productive B_4 aquifer by the Muwaqqar aquitard (B_3).

Aquifer Systems

The main aquifer systems are as follows:

Muwaqqar formation (B3) has low permeability, and consists of marl and marly-limestone, so it considered as aquitard. The thickness of this formation is more than 300m, in the study area this formation has been slightly eroded, (MWI,2017).

Umm Ghudran - Amman formation ($B1_{/2}$) thickness ranges between 140 - 200 m, it considers as good aquifer, and consists of chert and phosphatic beds and chalky limestone.

Wadi Es-Sir formation (A_7) the thickness is varied from 190 m to less than 300m and is considered as good aquifer, it consists from white to light grey semi-crystalline limestone and dolomitic limestone, becomes more chalky towards the base of the unit. The A_7 formation and the overlying $B_{1/2}$ formations are one hydrogeological it is known as the B_2/A_7 aquifer. $A_{5/6}$ formation the base system in the Wadi El-Arab area is marly $A_{5/6}$ aquitard which overlying B_2/A_7 aquifer system, thickness of this layer is from 100 to 150 m, it characterizes by low permeability, and it is specified by yellowish marl with limestone, dolomite, and shale.

The flow net map gives the ordinary trend in groundwater flow direction and assist in the approximate delineation of groundwater of the Wadi El-Arab well field, Figure 7.

Groundwater recharge take places in the outcrop area of the B_2/A_7 aquifer in the central part of the catchment and the mountains south of Irbid, at which the B_2/A_7 unit is not saturated. The other parameters contribute in groundwater recharge, is the infiltrating rain water, which follows the dip in slope to north directions.

The direction of the groundwater flow is from eastern part of the catchment to the western part of the catchment that means from highlands to lowlands of the catchment. The transmissivity of the (B_2/A_7) aquifer ranges from 9 m^2/day to more than 900 m^2 /day. The storage coefficient of this aquifer in the confined condition vary from 10^{-3} to 10^{-5}, while the specific capacity vary from less than 0.01 L/s /m to more than 50 L/s/m and The permeability ranges from 0.01 to more than 100 m /day, (BGR and MWI 2001).

Water balance

Mean annual rainfall

For hydrologic analysis and process, it is important to know the areal distribution of rainfall. The most common methods used are the Isohyethal method and Thiessen method. To determine the areal rainfall, there are two basic methods and these are Thiessen method and Isohyethal method, Thiessen method of the catchment area subdivided the catchment area into polygons with the rain gauge in center. The weighted average for each polygon was utilized to evaluate the average rainfall in the study area.

Thiessen method is not preferable to use in mountainous region due to the influence of orographic. Table 1, shows the weighted area for each polygon and Figure 6 shows the Thiessen polygon of the study area.

The Isohyethal method is the most accurate approach to determine the average annual rainfall depth over an area for a proper use; it requires a skilled analyst and careful attention to topographic and other factors that effect on areal variability. Isohyethal map is used to show the mean annual rainfall over the catchment, Figure 8. The lowest annual rainfall of 250 mm falls over the western part of the studied area and the highest of 430 mm in Irbid station. Generally, the rainfall gradually decreases towards the Jordan Valleys.

Runoff

As discussed in the materials and methods section, there are no runoff gauging stations available at the Wadi El-Arab Catchment area. Accordingly, runoff is calculated using the SCS Curve Number Method, which relates storm runoff to rainfall by a relationship that depends primarily upon the potential abstraction of water by soil storage. High potential abstraction means less runoff for a given rainfall, represented by a lower curve number (Aydin and Antal, 2019).

The result of calculations, based on SCS method, it was found that, the average annual surface runoff for the normal year is 25.04 mm, for the wet year 37.38 mm and 12 mm in the dry water year condition, which represents 5.31%, 6.55%, 3.25% of the annual rainfall rate of the annual rainfall rate for normal, wet, dry years, respectively. Tables (2, 3 and 4) show the calculation of runoff for different water years using SCS - CN method.

Table.1 Rainfall station and area covered in study area

Station Name	Station_IDN*	Area (Km^2)	Cover percentage %
Husn	AD0010	6.5	2.44
Al-Taiyiba	AB0001	21.01	7.91
Irbid	AE0002	10.94	4.12
Kafr Yuba	AE0003	58.31	21.95
Kafr Asad	AE0004	87.89	33.08
Um Qeis	AD0005	21.78	8.2
Irbid School	AE0001	56.17	21.14
Baqura	AD0032	3.06	1.16
Total		**265.66**	**100**

***IDN:** Identification Number

Table.2 Estimation of the surface runoff using curve number method in the normal water year condition

Water year (2010 - 2011)	month	Al-Taiyiba	Um Qeis	Husn	Baqura	Kafr Asad	Kafr Yuba	Irbid School	Irbid Agr	S (mm)	Ia (mm)	Q (mm)	Annual Runoff
		7.91%	8.20%	2.44%	1.15%	33.08%	21.95%	21.14%	4.12%				
	Dec	1.96	0.96	0.31	0.165517	1.03	0.00	0.04	1.05	108.68	21.77	5.52	25.04
	Jan	0.09	0.06	0.02	0.00	2.02	0.23	0.16	0.060	108.68	21.77	2.64	
	Feb	0.82	0.26	0.41	0.07	4.90	1.30	0.11	1.54	108.68	21.77	9.41	
	Mar	1.05	0.49	0.01	0.082	1.09	2.02	0.07	0.03	108.68	21.77	4.83	
	Apr	0.49	0.28	0.00	0.00	0.67	0.63	0.57	0.00	108.68	21.77	2.65	

Table.3 Estimation of the surface runoff using curve number method in the dry water year condition

Water Year (2006-2007)	month	Al-Taiyiba	Um Qeis	Husn	Baqura	Kafr Asad	Kafr Yuba	Irbid School	Irbid Agr	S (mm)	Ia (mm)	Q (mm)	Annual Runoff
		7.91%	8.20%	2.44%	1.15%	33.08%	21.95%	21.14%	4.12%				
	Nov	0.92	2.10	0.00	0.30	1.26	0.68	0.09	0.29	244.04	48.81	5.63	12.00
	Jan	0.00	0.00	0.00	0.00	1.14	0.15	0.00	0.00	244.04	48.81	1.30	
	Feb	0.00	0.00	0.00	0.00	0.00	0.00	5.07	0.00	244.04	48.81	5.07	

Table.4 Estimation of the surface runoff using curve number method in the wet water year condition

Water Year (2014-2015)	month	Al-Taiyiba	Um Qeis	Husn	Baqura	Kafr Asad	Kafr Yuba	Irbid School	Irbid Agr	S (mm)	Ia (mm)	Q (mm)	Annual Runoff
		7.91%	8.20%	2.44%	1.15%	33.08%	21.95%	21.14%	4.12%				
	Oct	0.27	0.07	0.001	0.30	0.72	0.46	0.00	0.09	44.82	8.96	0.20	37.38
	Nov	3.91	7.16	0.66	0.25	32.55	10.19	19.12	2.74	44.82	8.96	9.54	
	Dec	0.46	0.66	0.13	0.19	1.41	1.64	10.21	0.34	44.82	8.96	1.86	
	Jan	4.19	3.42	1.95	0.15	46.60	6.3655	27.54	2.29	44.82	8.96	11.54	
	Feb	4.10	0.32	1.40	1.19	46.60	10.19	27.60	2.94	44.82	8.96	11.65	
	Apr	0.24	1.34	0.13	0.34	7.73	1.78	8.42	0.49	44.82	8.96	2.52	
	May	0.00	0.00	0.00	0.00	0.00	0.00	0.637	0.00	44.82	8.96	0.081	

Table.5 The annual evaporation for wet, normal and dry water years using Turc equation.

Condition	water year	Mean (T)	Annual Rainfall (mm)	f (t)	Evaporation (mm)
Normal	2010/2011	13.206	471.86	745.31	362.74
Wet	2014/2015	14.22	570.76	799.27	404.81
Dry	2006/2007	12.13	368.67	692.49	311.52

Table.6 The water balance for Wadi El Arab catchment area (Normal, wet and dry conditions).

Condition	water year	Annual Rainfall (mm)	Annual Runoff (mm)	Runoff Rate%	Evaporation (mm)	ET Rate %	Infiltration	Inf Rate %
Normal	2010/2011	471.863	25.04	5.31%	362.74	76.87%	84.083	17.82%
Wet	2014/2015	570.76	37.38	6.55%	404.81	70.92%	128.57	22.53%
Dry	2006/2007	368.67	12	3.25%	311.52	84.50%	45.15	12.25%

Fig.1 Location map of Wadi Al Arab drainage catchment area.

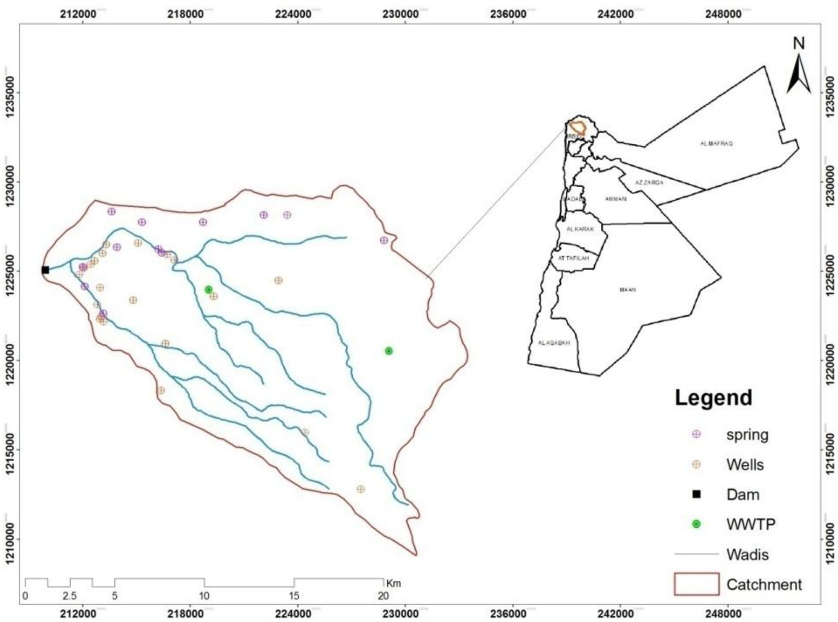


Fig.2 Wadi Al Arab drainage catchment area (Al-Adwan, 2018)

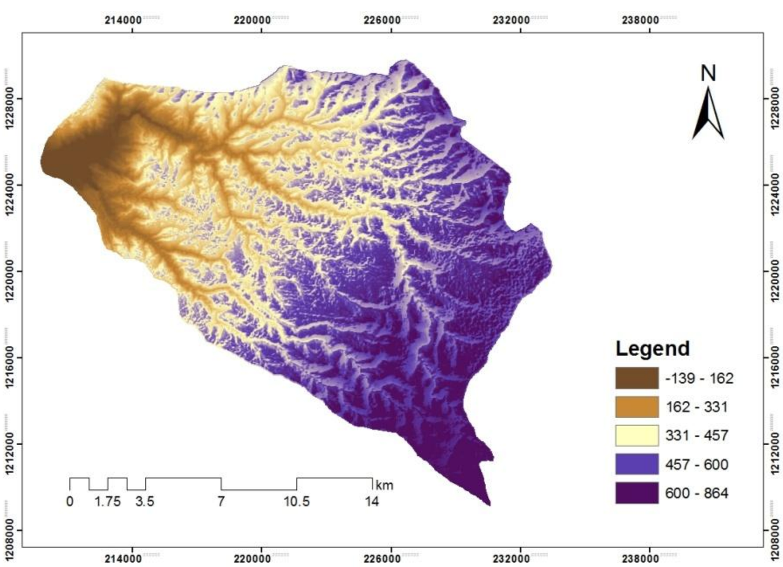


Fig.3 Soil map of Wadi El-Arab catchment area (MOA, 1994)

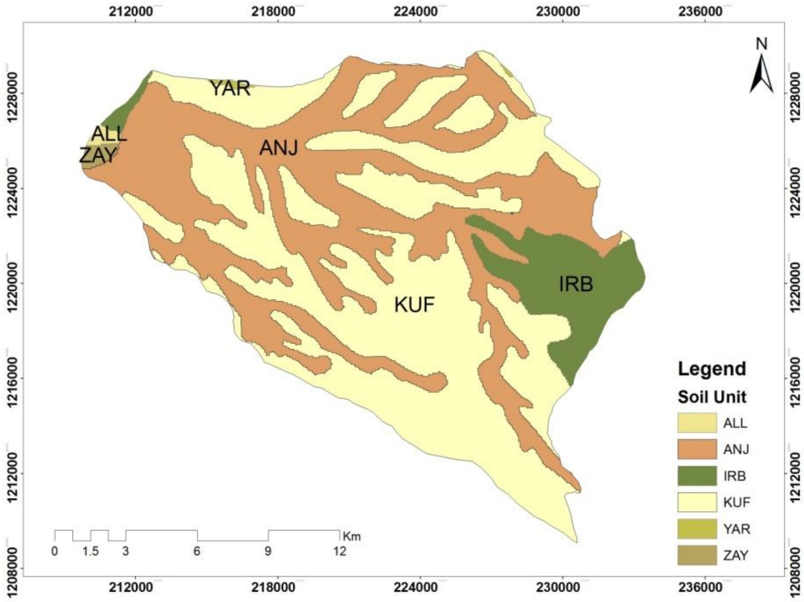


Fig.4 Landuse map of Wadi El-Arab catchment (MWI, 2016).

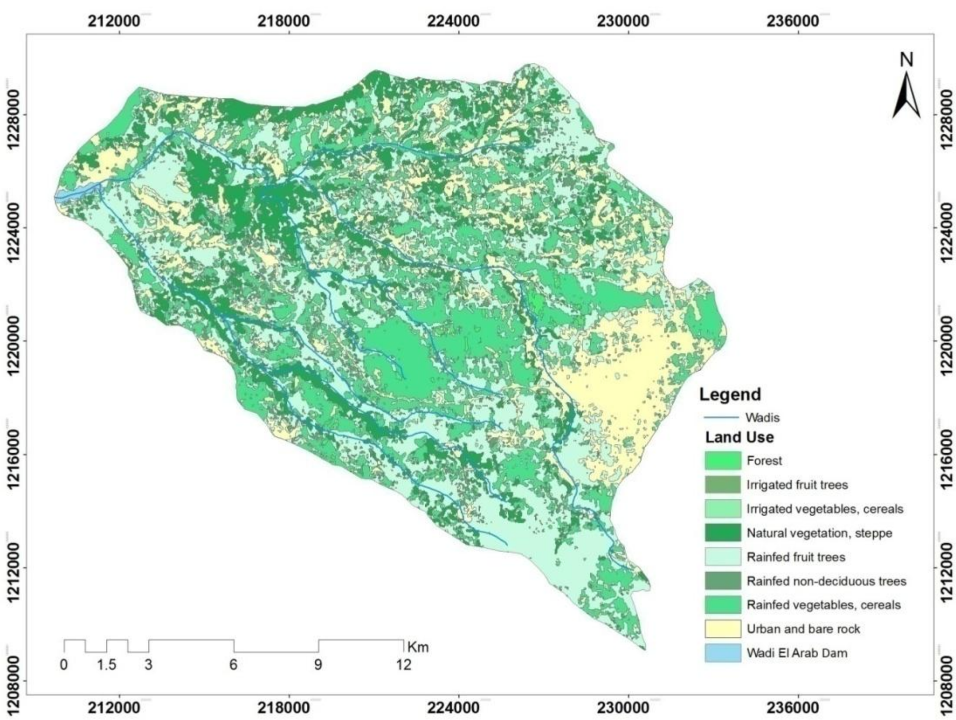


Fig.5 General geological and structural map of the Wadi El-Arab catchment (Margana, 2006).

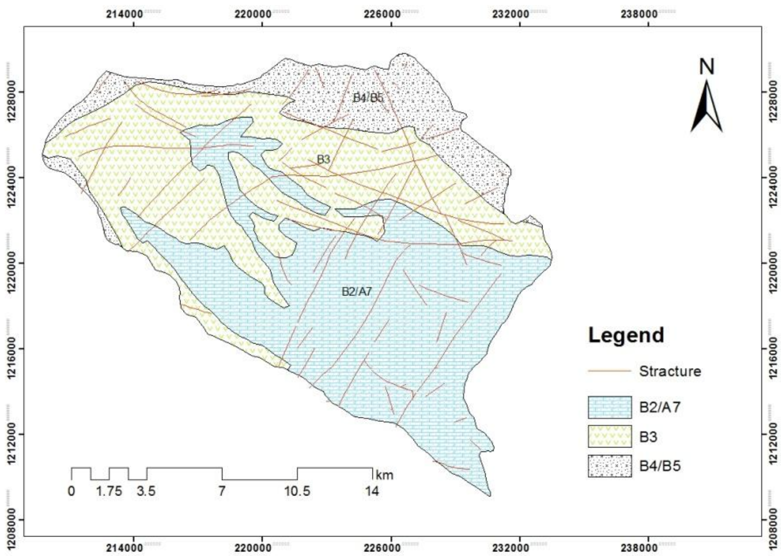


Fig.6 Thiessen polygons network of Wadi El- Arab catchment area.

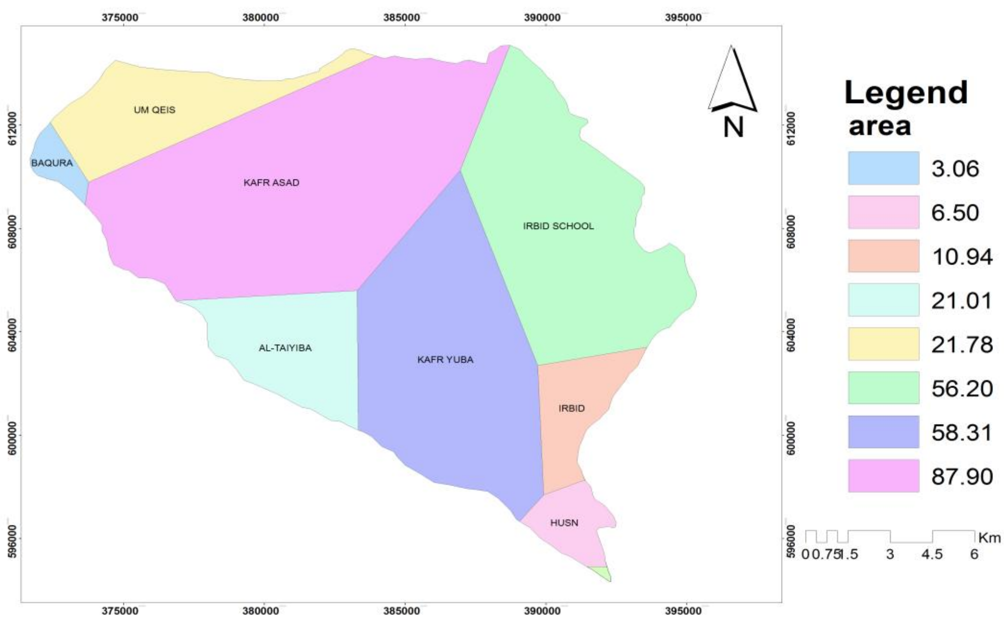


Fig.7 Groundwater Flow- net map of the Wadi El-Arab catchment.

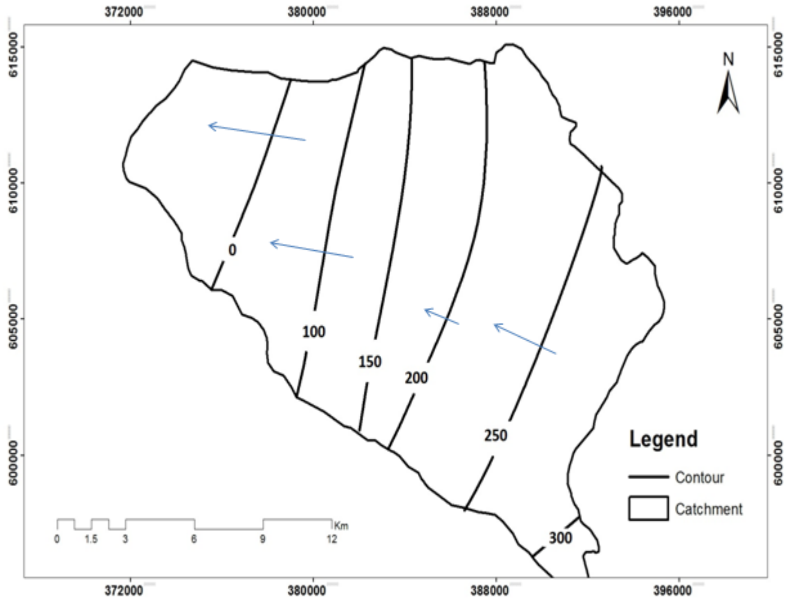
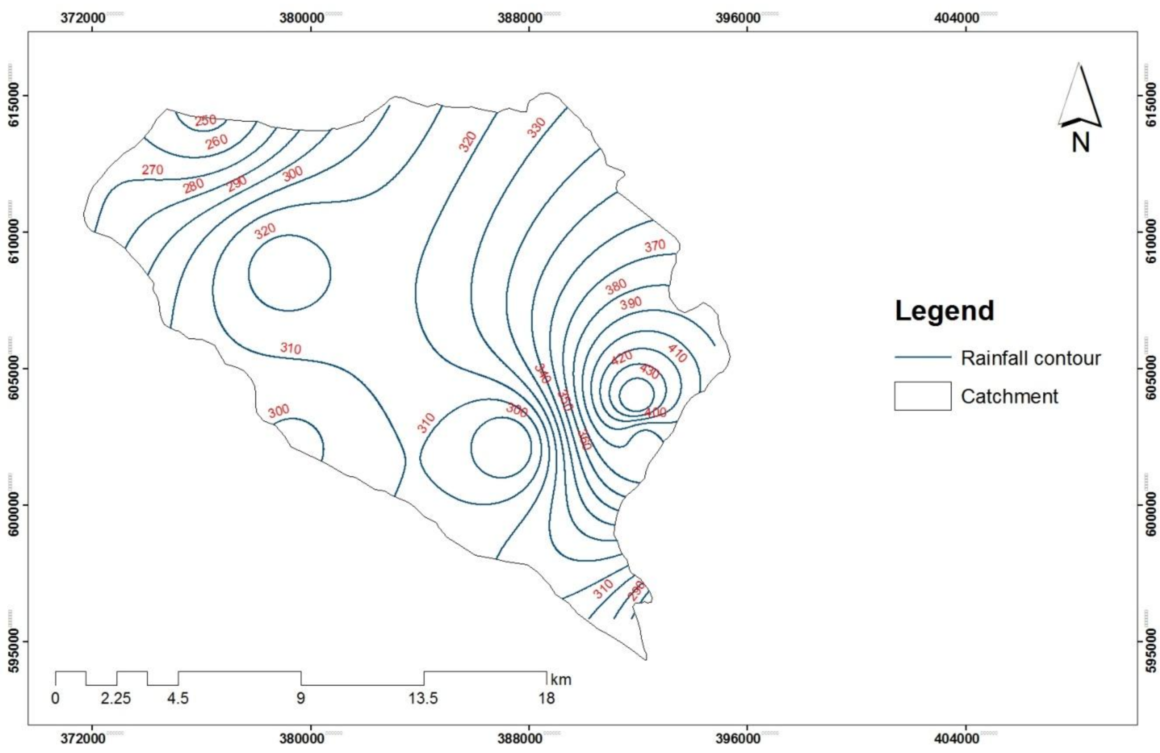


Fig.8 Isohyethal contour map of the annual rainfall averages of the Wadi El-Arab Catchment.



Under the assumption that, the evapotranspiration is calculated adequately, as well as, the runoff and the initial abstractions are properly determined, then the following water balance equation can be established as:

$\Delta S = P - (R + E) \pm I_a$ ... (6),(Chow et. al, 1988)

Where:

ΔS: the change of groundwater storage or recharge (mm).

P: the precipitation in (mm).

E: evapotranspiration in (mm).

R: runoff in (mm)

I_a: initial abstraction in (mm).

In Wadi El - Arab catchment area. The only measured parameter in this approach is the rainfall; evaporation and runoff were calculated using Turc and SCS-Curve Number method respectively. Then, the infiltration rate was found for wet, dry, and normal conditions. The results of recharge calculations are shown in Table 5 and 6.

The aquifer systems of the entire study area are related to the Cretaceous Upper Ajloun Group (A_7) to the Cenozoic Lower Belqa Group (B_1 and B_2) is the main aquifer for water supply in the study area. On its top, the A_7/B_2 aquifer is hydraulically separated from the locally productive B_4 aquifer by the Muwaqqar aquitard (B_3).

The saturated thickness of B_2A_7 appears in small part, as in Irbid area, which is located at the east boundary of catchment. The direction of the groundwater flow is from eastern part of the catchment to the western part of the catchment that means from highlands to lowlands of the catchment. The transmissivity of the (B_2/A_7) aquifer ranges from 9 m^2/day to more than 900 m^2/day. The storage coefficient of this aquifer in the confined condition vary from 10^{-3} to 10^{-5}, while the specific capacity vary from less than 0.01 L/s /m to more than 50 L/s/m and The permeability ranges from 0.01 to more than 100 m /day.

The average annual rainfall of normal years is 410 mm, the average annual rainfall of dry years is 205.39 mm and the average annual rainfall of wet years is 756.2 mm for (1995-2018). The runoff ranges between 1.44 MCM (1983-1984) to 72.89 MCM (1979-1980) for the period of study. The water budget of the study area was performed for (1991-2003) and the average values were (115.15 MCM) for rainfall, (20.68 MCM, 14.46% of rainfall) for runoff, (87.44MCM, 79.37% of rainfall) for evaporation, and (7.03 MCM, 6.17% of rainfall) for infiltration.

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