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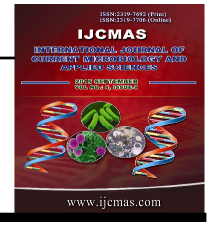

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Case Study

Watershed Characteristics: A Case Study of Wadi Es Sir Catchment Area / Jordan

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A B S T R A C T

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This study deals with the Hydrological Characteristics of Wadi Es Sir Catchment area. The investigated area is located within the western flank of Jordan along Wadi Kafrein within Palestinian Grids at 144-159.3 North, and 228.5-237.2 East. Precipitation is the primary source of groundwater because it seeps through the unsaturated zone to the water table. The amount and quality of recharge significantly affects the physical and chemical processes in the soil-rock-groundwater system. The greater the recharge the greater the contamination potential because, it may lead to leaching and transporting contaminants from the ground surface to the water table. This research aims at determining the geological and hydrogeological systems of Wadi Es Sir catchment area and calculating the volume of rainfall and runoff over the project area for dry, normal and wet years' conditions using the U.S SCS Curve Number Method of Bureau of Land Reclamation. The water balance equation was applied to calculate the net recharge in the study area. This equation was used to perform the water balance on daily basis for each storm event during the period under investigation. Rainfall is usually concentrated between December and March; in this period, rainfall duration is long and evaporation is low, so that it can be concluded that recharge occurs mostly during this period. The rainfall is the only parameter in the study area; therefore, the daily rainfall and initial abstraction were calculated from four rainfall stations, using the SCS-Curve Number method for each storm during a specific year. The potential evaporation was computed using Penman Equation, and then the water balance was solved for all storms that occurred during the period of the water years (1988-2014). The calculated average annual recharge to the upper aquifer was about 2.85 MCM in the wet water year and 0.62 MCM in the dry water year. The recharge rate ranges between 3.14 and 8.78 %. While, the mean annual runoff was11.23 MCM in the wet water year and 1.67 MCM in the dry water year. The runoff rate ranges between 34.58 % and 8.54 % in the wet and dry water year respectively.

Introduction

The total area of Jordan approximately 89,400 Km^2 with population of 5.98 million living in about 20 % of the total area, the population growth rate is about 2.2 % (DOS 2003). More than 90 % of the country lands classified as dry areas. The annual precipitation ranges from less than 50 mm in the south and desert to more than 500 mm in the north. The country climate ranges from hot and dry summer to variable cool winter. The rainy season is between October and May with 80 % of the annual rainfall occurring between December and March (JMD, 2010).

Jordan classified as the fourth scarce water country among the world. The available water resources per capita decreased from 3600 m3/cap/year in 1946 to 145 m3/cap/ year in 2008 and projected to decrease to about 90 m3/cap/ year in 2025 (MWI, 2011).

Due to water scarcity, it is believed that water resources can be developed through adaptation of non-conventional water such as wastewater treatment technologies to provide extra water recourses and it is considered as part of the country's water supply-demand budget. In Jordan, the volume of treated wastewater produced in 2005 reached 82 MCM per year of which about 95% is reused for irrigation, however, it was reported that around 2 MCM of treated wastewater produced from Kherbit Es Samra recharge the groundwater resources in Zarqa basin (Hadadin and Bdour, 2005).

Wadi Es Sir Wastewater treatment plant (WWTP) is located at the lower reach part of the catchment area. This plant treats wastewater produced from Al Bayader and Wadi Es-Es Sir discharge the treated water directly to Wadi Es Sir, Wadi Bukath, and finally downstream into the Wadi Kafrein Dam.

Municipal and industrial water requirements have increased sharply, as the population has increased and increasing urbanization and rising incomes have brought increased demands for water. Pollution is considered the most important problem facing the world in general and Jordan in particular long time ago. This issue is still increasing to be at the top of all problems, which needs a scientific solution as soon, as possible to protect of the water resources and the surrounded environment. In view of the increasing interest for water resources in Jordan in general and Wadi Es Sir Area, in particular to meet the rapidly growing demands, it is crucial to make water resources assessment and to protect the water from deterioration is becoming necessary.

Study area

The investigated site is located within the western flank of Jordan along Wadi Kafrein within Palestinian Grids at 144–159.3 North, and 228.5–237.2 East (Figure 1). Wadi Es Sir drains an area west of Amman and covers an area of about 73.77 km^2 lying at elevations ranging from 1093 m above the mean sea level (amsl) at Khilda town to about 785 m amsl at area adjacent to Na'ur town. Precipitation in the western parts of the catchment, averaging 550 mm/year, may fall in the form of snow, whereas in the eastern parts the average decreases to less than 300 mm/year and falls completely in the form of rain.

The potential evaporation ranges from 2700 mm/year in the eastern parts to 2400 mm/year in the western parts. The average discharge of Wadi Es Sir catchment area is about 2.6 MCM/year, (MoE, 2006). In addition, Wadi Es Sir and Hussein Medical Centre wastewater treatment plants end up in Wadi Kafrein or its tributary wadis. In the catchment area different towns and villages, like Wadi Es Sir and Na'ur. These two main cities and villages discharge their wastes along Wadi Kafrein or its tributaries.

The Kafrein Dam was built in 1968 on an area of about 800 ha with a capacity of 4.8 MCM and raised in 1994 to increase the capacity of the dam up to 8.4 MCM from wadi Kafrein and Wadi Es Sir Treatment Plant. This dam now serves as a storage facility for irrigating downstream lands. The reservoir provides water to the Hisban / Kafrein irrigation project.

Materials and Methods

Geology and hydrogeology

The geologic materials underlying a watershed are one of the most salient features influencing the hydrologic flow regime. The rate of flow of both surface and subsurface water are dependent upon the nature of the material in the path of flow. Certain basic geologic investigations are needed prior to intensive research. Geologic maps and cross sections are also needed to aid in accurate interpretations of groundwater movement and storage, stream transmission losses, infiltration rates, and groundwater quality.

The study area is covered by the Cretaceous rocks, which are subdivided into two main sequences. The Lower Cretaceous sandstone sequence (Kurnub) which is overlain by marine Upper Cretaceous limestone, dolomites, marls and cherts. The areal distribution of the outcropping formation of the watershed area is shown in figure 2. In this study area, the silicified limestone of A7 limestone formation has a good potential because of extensive development of solution channels, fractures and its large thickness. Infiltration is controlled by the steep slopes, but is quite good due to relatively high rainfall in the area. The limestone of the A1 Formation is good aquifer. Facious changes with the A4 limestone formation limit its potential. The marls and marl limestones of the remainder of the Ajlun Group (A5/6) must be considered as aquicludes.

The specific capacity of the aquifer system in the study area is determined to be in the range of 0.01–250 m^2/hr in few wells it goes up to 6200 m^2/hr. The transmissibility ranges between 0.1 to 100.000 m^2/day, and the hydraulic conductivity ranges between $2.9*10^{-8}$ to $3.25*10^{-2}$ m/s (Salem, 1984). Similar values are also found by Salameh (1980) and Rimawi (1985).

Determination of the areal rainfall

There are four rainfall stations in the study area; all stations measure the daily rainfall, and two of them have 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 Isohyetal 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 3 shows the Thiessen polygons for the catchment area. The rainfall distribution and water year conditions are listed in table 1.

Runoff

There are no gauging stations located in Wadi Es Sir Catchment Area. Therefore, to estimate the runoff which may occur in the winter season, the US Soil conservation services method (SCS), (Wanielista, 1990), was applied to calculate the runoff occurred from different storms of normal condition. 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)

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 Es Sir Catchment area is to estimate the direct recharge into the groundwater of the Upper aquifer system (A7). The potential evapotranspiration was calculated using Turc Equations. This equation is written as follows:

$$E = P / (\sqrt{0.9 + (P^2 / f(t)^2)}) \quad \text{(Turc, 1955)}$$

Where:

E: the annual actual evaporation (mm)
P: the average annual precipitation (mm)
T: the temperature function, which is equal to,

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

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

Results and Discussion

The occurrence of large springs generally, depends chiefly on the kind of rocks that yield water. Limestone and extrusive volcanic rocks are the main sources of the large springs in Jordan. The volcanic rock is chiefly basalt that was greatly jointed and broken at the time it solidified; large springs may also issue from sandstone rocks. The limestone is the main source of the major springs in the study area.

The rate and quantity of water that infiltrates into the ground is a function of soil type, soil moist is permeability, ground cover, drainage conditions and duration of rainfall. It is well known that when water reaches the surface of a soil, a part of it seeps into the soil; this movement of water through the soil surface is known as infiltration and plays a significant role in the runoff process. Hence, infiltration is the primary step in the natural ground recharge.

Runoff is a function of precipitation, soils, ground cover, elevation of catchments and slope; of these factors, precipitation is the most variable (Gupta, 1979). As mentioned previously, there are no gauging stations in the study area up to date. 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.

The curve number of the study area is estimated to be (60), derived from the soil classification, and the use of topographic maps.

$$CN = 60$$
$$S = 1000/CN - 10$$
$$S = 1000/60 - 10 = 6.667 \text{ inches}$$

The initial abstraction prior the runoff is,

$$Ia = 0.2\ S$$
$$Ia = 0.2^{*}\ (6.667) = (1.333) \text{ inches}$$
$$Ia = 1.333 * 25.4 = 33.86 \text{ mm}$$

The runoff formula becomes

$$Q = (P - 0.2(169.33))^2 / (P + 0.8(169.33))$$
$$Q = (P - 33.86)^2 / (P + (135.46))$$

This formula was used to estimate the runoff from each effective storm for wet, normal and dry condition using storm analysis. It is worth to see here that if the storm is less than the initial abstraction that means no runoff will be occurred.

Table 2 summarizes the annual runoff for Wadi Es Sir catchment area for wet, normal and dry conditions. It is seen that the annual runoff ranges between 22.7 mm or 1.68 MCM in the dry water year and between 152.21 mm or 11.23 MCM in wet water year. The long-term average runoff is 55.78 mm or 4.12 MCM, which forms 15.46 % of the annual rainfall.

According to this calculation, the heaviest floods occur between November and March and no significant floods occur in October and May. After that, the evaporation for wet, normal and dry condition was calculated using Turc formula and the results of these calculations are shown in table 2. The calculated long-term evaporation rates ranges between 56.64 % in the wet water year, and more than 88 % in the dry water year.

The "Water Budget Approach" was used to calculate the annual recharge in the study 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 solved for wet, dry and normal conditions.

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:

$$\Delta S = P - (R + E) \pm I_a$$

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).

The calculated amount of recharge for the completely studied area was about 24.98 mm, which forms about 6.94 % of the total rainfall. The recharge rates ranged between 3.14 % I the dry water year and 8.78 % in the wet water year condition. The results of recharge calculations for the main stations in the study area are shown in table 2.

Table.1 Monthly and annual rainfall in (mm) for the whole catchment area

Water Year	Months									Water Year Condition
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Annual	
1988/1989	9.3	19.2	142.2	60.3	50.6	87.9	0.0	0.0	369.6	**Normal**
1989/1990	2.4	26.6	50.4	129.3	59.4	60.0	48.4	0.0	376.5	**Normal**
1990/1991	6.1	18.4	1.7	135.3	66.8	117.9	15.1	1.7	363.1	**Normal**
1991/1992	5.8	82.5	300.2	136.3	288.8	36.9	0.0	4.4	854.9	**Wet**
1992/1993	0.0	70.4	149.6	104.9	88.5	20.5	0.0	6.7	440.6	**Wet**
1993/1994	4.5	13.2	19.1	118.2	58.4	44.9	4.2	0.3	263.0	**Dry**
1994/1995	32.0	149.1	109.0	12.0	57.2	17.9	11.3	0.0	388.4	**Normal**
1995/1996	0.0	16.4	21.6	121.1	14.1	98.4	14.9	0.0	286.5	**Dry**
1996/1997	10.5	7.5	49.9	129.6	130.9	72.5	3.2	8.4	412.5	**Wet**
1997/1998	18.7	26.8	92.6	95.1	37.1	87.0	0.5	0.5	358.4	**Normal**
1998/1999	0.5	0.6	1.2	57.7	69.6	16.0	8.9	0.0	154.4	**Dry**
1999/2000	0.4	1.2	9.4	144.4	45.4	58.3	0.1	0.0	259.1	**Dry**
2000/2001	16.5	2.9	108.6	62.2	44.1	5.6	5.4	12.1	257.3	**Dry**
2001/2002	6.1	45.7	99.6	156.9	67.8	73.7	34.1	1.9	485.9	**Wet**
2002/2003	6.6	21.8	141.8	43.7	188.6	118.4	17.4	0.0	538.4	**Wet**
2003/2004	0.6	8.8	65.0	89.5	39.8	24.4	1.1	0.8	230.0	**Dry**
2004/2005	0.4	103.9	32.8	122.6	75.9	35.8	5.9	2.0	379.4	**Normal**
2005/2006	0.7	20.2	53.8	48.1	57.5	5.1	95.6	0.0	280.9	**Dry**
2006/2007	**9.5**	**10.4**	**62.7**	**99.0**	**78.8**	**85.9**	**10.8**	**3.4**	**360.6**	**Normal**
2007/2008	0.7	43.3	24.5	66.7	73.5	1.7	0.0	0.1	210.4	**Dry**
2008/2009	28.4	0.5	28.6	13.9	143.7	127.2	3.3	0.0	345.6	**Normal**
2009/2010	16.5	73.6	97.1	76.6	201.4	9.8	0.0	0.6	475.5	**Wet**
2010/2011	7.3	0.0	56.8	101.2	61.8	40.9	24.7	11.9	304.6	**Normal**
2011/2012	**0.0**	**57.8**	**58.2**	**124.9**	**107.5**	**91.7**	**0.0**	**0.0**	**440.1**	**Wet**
2012/2013	0.1	31.9	73.7	191.4	40.6	0.3	12.1	3.6	353.6	**Normal**
2013/2014	**0.2**	**18.4**	**136.4**	**0.9**	**4.3**	**77.3**	**0.0**	**28.4**	**265.8**	**Dry**
Average	**7.1**	**33.5**	**76.4**	**93.9**	**82.8**	**55.1**	**12.4**	**3.3**	**363.7**	**Normal**

Table.2 Direct recharge for the whole W. Es Sir Catchment area

Whole Catchment	Annual Rainfall (mm)	Annual Runoff (mm)	Annual Evaporation (mm)	Annual Recharge (mm)	Runoff Rate (%)	Evaporation Rate (%)	Recharge Rate (%)
Wet Year Condition	440.1	152.21	249.28	38.61	34.58	56.64	8.78
Normal Year Condition	360.6	55.78	239.84	24.98	15.46	77.6	6.94
Dry Year Condition	265.8	22.7	214.76	8.34	8.54	88.32	3.14

Figure.1 Location Map of Wadi Es Sir Catchment Area

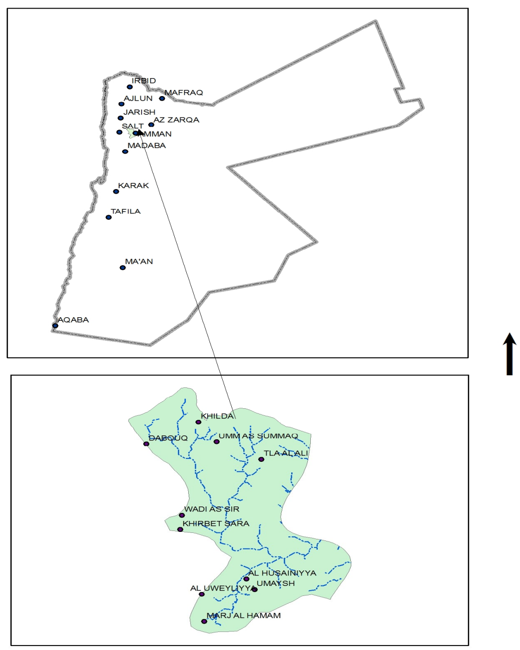


Figure.2 Geological Map of Wadi Es Sir Catchment Area

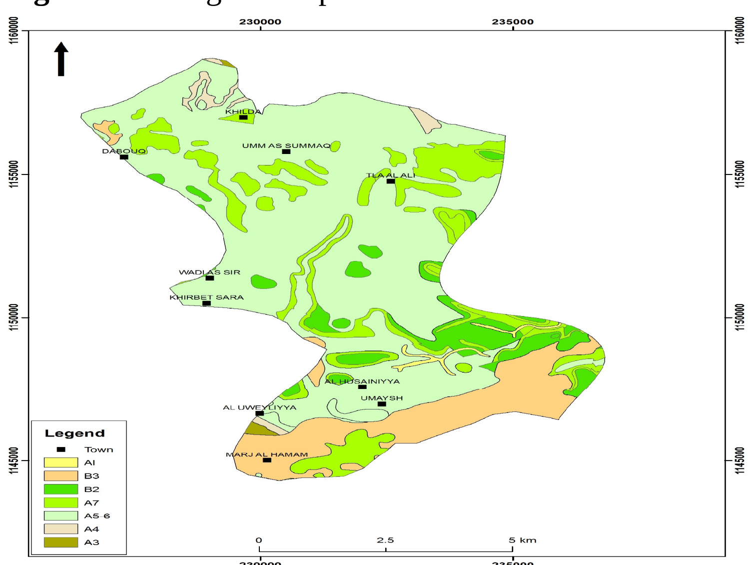
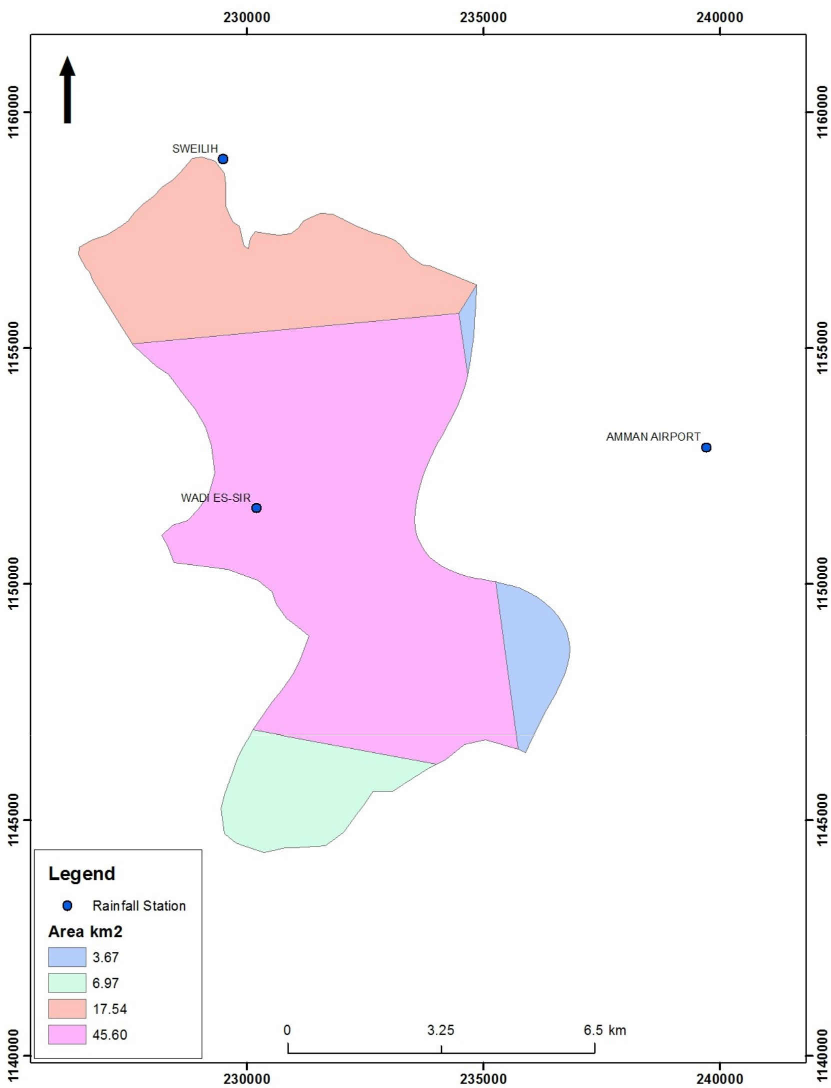


Figure.3 Thiessen Polygon network of Wadi Es Sir catchment area



In conclusion, there are no gauging stations in the study area up to date. 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.

The distribution of rainfall over the study area was represented in two methods; these are Thiessen polygon technique and Isohyethal Method. The average annual rainfall was calculated to be about 363.3 mm using Thiessen polygons technique and the maximum annual rainfall for the whole catchment area was recorded in 1991/1992 water year and was 854.96 mm. The annual runoff ranges between 22.7 mm or 1.68 MCM in the dry water year and between 152.21 mm or 11.23 MCM in wet water year. The long-term average runoff is 55.78 mm or 4.12 MCM, which forms 15.46 % of the annual rainfall.

The calculated annual direct recharge into the upper aquifer system by applying the water budget approach was about 38.61 mm in the wet water years, 24.98 mm in the normal year and 8.34 mm in the dry water years. The recharge rates ranged between 3.14 % in the dry water year and 8.78 % in the wet water year condition.

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