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EVALUATION OF STORM RUNOFF IN WADI HAURAN, WESTERN IRAQ

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Arid and semi arid regions are characterized by low frequency monthly rainfall events and high evaporation during the remaining dry days. Utilizing monthly rainfall means for water balance calculation risks a high error margin. Even when daily rainfall analysis methods are used to evaluate the resulting runoff in a valley course, errors may still be committed when wrong values are assigned to important field elements such as soil cover type, vegetation and land use. Accordingly and when the Soil Conservation Service method (SCS) is applied, single storm rainfall and validation of the estimated Curve Number (CN) value using valley flow measurements is necessary. The evaluation of annual runoff volume in a major valley in the Western Iraqi desert using the SCS method applied to single rainfall storm events and validated by actual historical runoff measurements has revealed that Wadi Hauran would exhibit no runoff flow in one year out of three and that runoff may exceed 69 mm depth in a single water year but the average depth for those years with runoff events is only 11.1 mm which amounts to about 64 Mm3 at a location in the center of its catchment area.

INTRODUCTION

In arid and semi arid regions runoff occurs as separate events following pronounced occasional rain storms. Due to the low frequency of monthly rainfall events and the high evaporation during the remaining dry days, methods that utilize monthly rainfall means for water balance calculation are hardly applicable. Even when daily rainfall analysis methods are used, errors may be committed when wrong values are assigned to important field factors. However a small error it may be, it is exaggerated by the fact that the runoff realized from these events usually represents the only surface water resource that exists in the desert area and a source to groundwater recharge as well. It is therefore essential for highly water scarce region such as the remote regions of the western Iraqi desert to determine with certain reliability the magnitude of potential runoff events in major valleys in order to plan for sustainable development.

Wadi Hauran is a major valley located in the Iraqi western desert with a catchment area that could reach 16550 km^2 falling almost totally inside Iraq with only a negligible part in Saudi Arabia (Sissakian et al., 2017). It flows in the north east direction from the Iraqi-Saudi border, passing through Ar Rutba town and terminating in the Euphrates River near the town of Al Baghdadi south of Haditha (Figure 1). The valley drainage system is of the deep cutting type (Jassim, 2006) demonstrated well after the joining of its two major contributors: Ghadafat Al Awaj and Wadi Al Nuhaidan. Although the average annual rainfall for Ar Rutba is only 120 mm (Aljawad, 2012) however occasional floods have encouraged the construction of at least two dams on the valley reach near Ar Rutba for water harvesting: Small Ar Rutba dam in 1971 and Large Ar Rutba dam in 1981.

Studies on Wadi Hauran runoff have been conducted since the seventies of the last century with some flood flow measurements (Consortium, 1978 & 1981).The studies were part of wider groundwater exploration of the desert area which considered valleys floods as an important source to groundwater recharge. A study more dedicated to Wadi Hauran was conducted by (Dawah, 2001) who attempted to determine runoff of Wadi Hauran using SCS method. He used monthly rainfall values for the years 1971 – 1994 to calculate monthly runoff for each year. His conclusion was that in an average year, annual volume of flood water in Wadi Hauran is in the order of $175 \times 10^6 m^3$

In this study, daily rainfall data for the period 1971-2012 are utilized to determine the depth of runoff events resulting from single storms. Historical flood volume records of Wadi Hauran are used to validate the storm rainfall- runoff relationship established.

MATERIALS AND METHODS

For runoff to occur in soil covered land, storm rainfall depth should exceed the depth of initial soil retention or its abstraction capacity. Land use and soil type factors play in this case a decisive role in the process. The Soil Conservation Service method, referred to in the literature as SCS, has been widely used to evaluate runoff in urban, rural and range lands. The method was developed by the USDA Natural Resources Conservation Service and is based on an empirical analysis of runoff from small catchments and hill slope plots. The established relation between storm rainfall and the runoff depths depends largely on an empirical value called a runoff Curve Number (CN) which is a function of hydrological conditions and soil type. Values of CN are given to vary between 30 & 100 with a range value for each soil class of the four identified classes in a defined hydrological condition. The relation between the curve number (CN) and the maximum soil potential retention capacity after runoff begins (S) is expressed by the following equation with S dimension is in inches *(*United States Department of Agriculture, 1986*,* Hawkins et al.,2002)

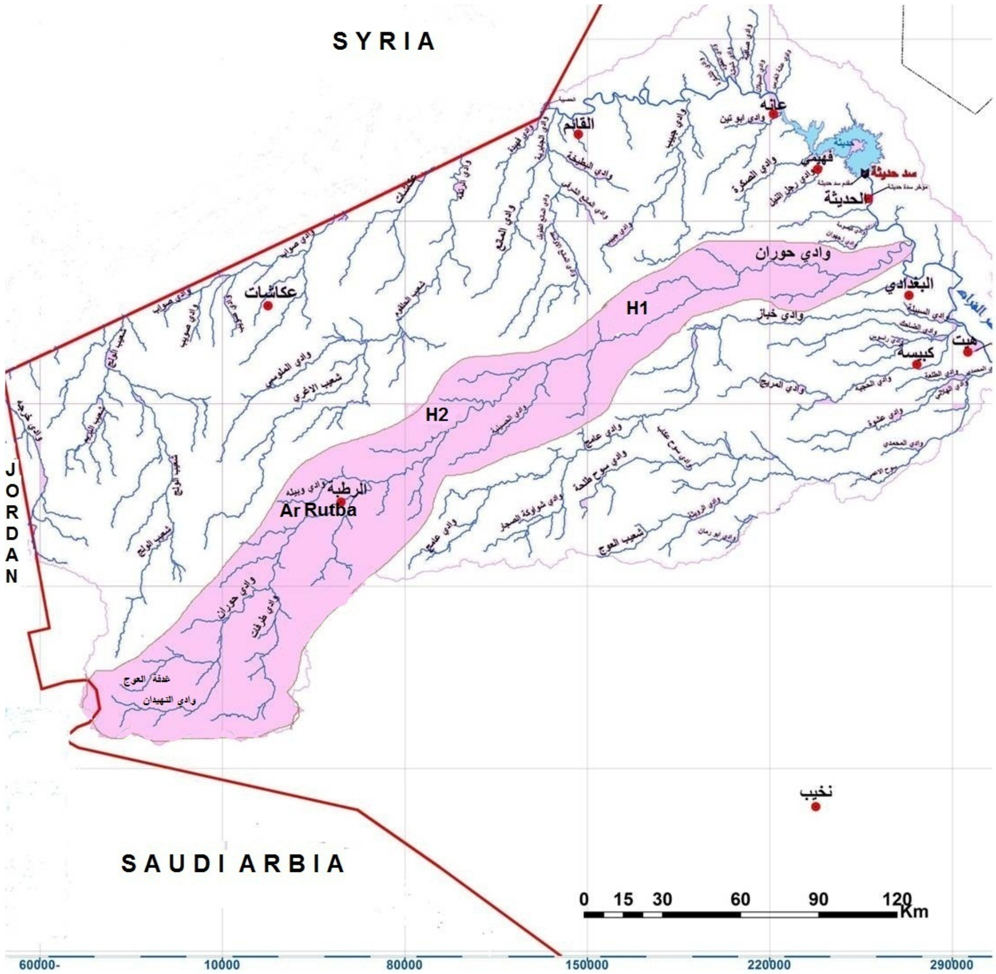

Figure 1. Location of Wadi Hauran in Western Iraq.

$$S = \frac{1000}{CN} - 10 \tag{1}$$

The initial soil obstruction (Ia) is evaluated to be 20% of S or:

$$Ia = 0.2S \tag{2}$$

Using the above two values, the runoff depth (Q) could be expressed in terms of rainfall (P) as in the following equation, with both Q and P in inches

$$Q = \frac{(P - Ia)^2}{(P - Ia) + S} \tag{3}$$

It is obvious that this method is very sensitive to the value of CN which is usually estimated in referencing to given tables. However, if field measurements of Q are available, the value of CN could be adjusted and the relation P vs Q could be validated.

RESULTS AND DISCUSSION

Single storms for each hydrological year were identified based on historical daily rainfall of AR Rutba meteorological station which is located at the center of Wadi Hauran catchment area. A single storm is the cumulative rainfall depth that falls in one day or successive rainy days, while a hydrological year is a 12 month year that usually starts at the 1st of October of the previous calendar year (Aljawad, 2012) In order to determine which of these storms creates runoff events, a specific empirical equation for Wadi Hauran that rules the relation between the two variables rainfall and runoff has to be established. The value of the constant CN is first estimated according to the soil group type and hydrological condition of Wadi Hauran and the criteria introduced by the SCS method.

According to the earliest available soil map of Iraq produced by (Buringh, 1957) the upper part of Wadi Hauran catchment is a limestone desert land, the middle is stony desert and the lower is gravely and stony waist in a deeply eroded phase. Soil type and soil structure are described later by (Thalen, 1979) as calciorthids in the plateau, being an extension of Al Hijara stony plain, *lithic calciorthids* in the rolling and hilly areas, whereas *lithic paleargids* and *lithic calciorthids* type in the lower valley. It is sub angular blocky at the presence of vegetation while it is structure less at bare areas normally poor in organic content but has good moisture holding capacity.

Attempts by (Consortium, 1978) to produce infiltration modules in the western desert for groundwater recharge had proposed two bare soil profiles: a heavier sandy loam 40 cm thick with 18% field holding capacity (FC) and lighter silty sand 15 cm thick with 8% (FC). With only general soil map available for the Hauran catchment area (Dawah, 2001) has assumed that the catchment is covered by three soil groups (A, B, C) of equal area. By averaging, he concluded that CN constant has a value of (80.66) which he used later to determine the values of the other parameters (Ia and S) by applying equations 1 and 2. His calculated value of initial soil retention (Ia) was (11.9 mm) and that for the potential retention (S) was (59.5mm).

The availability of historical separate storms records and their corresponding flood events at different times and at various locations of Wadi Hauran (Table 1) may verify the validity of these findings.

Table 1. Recorded measurements of runoff on Wadi Hauran (Consortium, 1978 & 1981)

Measurement Location	Catchment Area Km^2	Date & Duration	Cumulative runoff Mm^3
Bridge	5700	Dec. 1975 – May 1976	14.30
H2	5816	15/1 - 1/3 /1980	19.37
H1	7678	10/2 – 1/3 /1980	20.93

Using the values of soil initial and potential retention found by (Dawah, 2001) the calculated cumulative runoff for the durations and locations given in table 1 was found to exceed the recorded runoff. This implies that the estimated value of CN was exaggerated by assuming a lower permeability soil group. A lower CN value had to be introduced to satisfy the realized actual valley runoff and soil condition. A value of (71) which is the Curve Number of a desert area with fair to good hydrological condition and moderate B type soil was found applicable. Measured and calculated produced runoff for the given periods and locations are shown in table 2 below:

Table 2. Measured and calculated runoff in Wadi Hauran

Location	Number of effective storms	Depth in mm	Measured Cumulative depth of runoff in mm	Calculated Cumulative runoff Mm^3
Bridge	2	23.6 , 38.1	14.30	14.57
H2	1	41.1	19.37	19.42
H1	1	41.1	20.93	25.64

At location H1 measurement of runoff started the 10th of February 1980 while the effective rainfall storm started earlier during 8-10 February. It is therefore expected that the corresponding runoff volume was only partially intercepted which may explain the larger calculated runoff value than the measured in table 2.

Accordingly, the empirical storm rainfall-runoff equation for Wadi Hauran was established as follows:

$$S=\frac{1000}{71}-10 = 103.74 \text{ mm}$$

$$Ia=0.2S = 20.75 \text{ mm}$$

$$Q=\frac{(P-20.75)^2}{(P+83)} \quad (4)$$

Where Q and P are in mm

The theoretical rainfall-runoff curve for Wadi Hauran is shown in Figure 2.

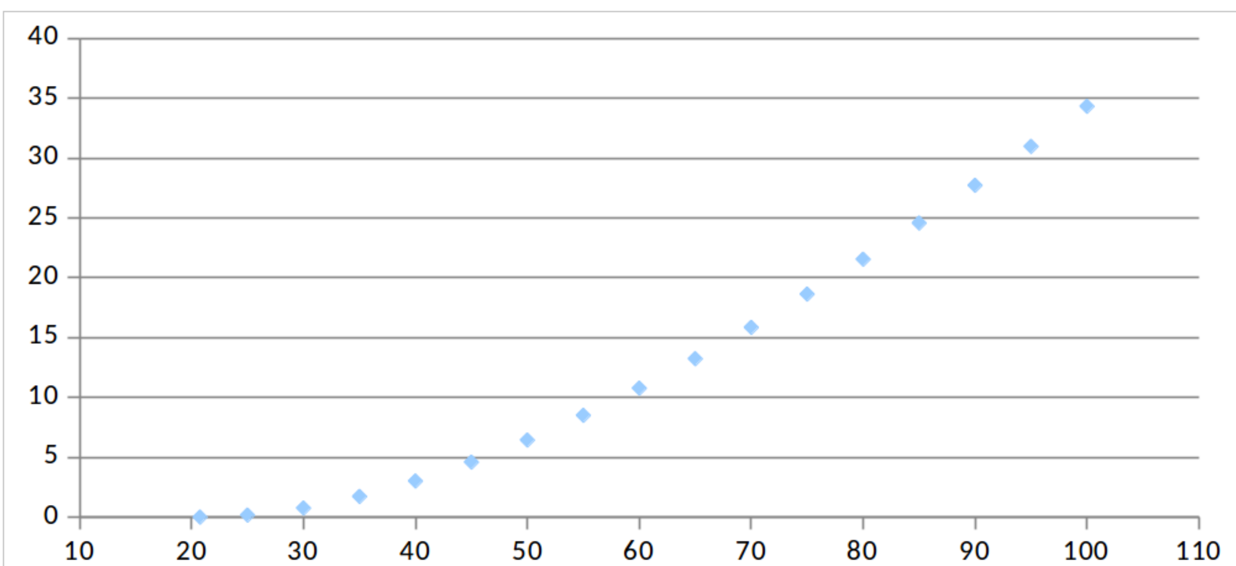

Figure 2. Storm rainfall-cumulative runoff curve for Wadi Hauran.

When this equation is applied to historical daily rainfall record, previous and future runoff events could be simulated. Table 3 is an account of all the storms that created runoff events in Wadi Hauran for the period 1971-2012

Table 3. Calculated Expected Runoff Volume in Wadi Hauran for the Period 1971-2012.

Year	Rainfall During a Water Year (mm)	Effective Storms			Total Depth of Effective Storms (mm)	Total Depth of Runoff (mm)	Runoff Volume at H2 Mm3
		No. Of Storms	Duration (days)	Depths in (mm)			
1971	167.7*	1	6	115.2	115.2	45	261.72
1972	219.9	3	5, 2, 2	66.6, 32.7, 26.2	125.5	15.64	90.95
1973	66.3	1	1	29.3	29.3	0.65	3.78
1974	159.2	2	2, 7	24.2, 26.8	51	0.44	2.56
1975	140.6	1	3	25.9	25.9	0.24	1.4
1976	140.9	2	2, 5	23.6, 38.1	61.7	2.55	14.86
1977	107.0	2	5, 3	21.1, 21.7	42.8	0.009	.052
1978	84.7	0					0
1979	56.3	0					0
1980	248.3	2	4, 3	101.4, 41.1	145.5	38.61	224.55
1981	92.1	0					0
1982	253.2	4	2, 2, 2, 1	23.5, 83.5, 55.8, 27	189.6	32.92	191.44
1983	131.9	1	3	34.2	34.2	1.54	8.96
1984	57.5	0					0
1985	129.3	0					0
1986	106.9	2	4, 7	31, 28	59	1.39	8.08
1987	67.7	0					0
1988	59.5*	1	4	52.8	52.8	7.56	43.97
1989*	**						
1990	85.7	1	9	59	59	10.30	59.90
1991	63.4	0					0
1992	124.4	1	2	25	25	0.17	0.97
1993	77.5	1	3	24.3	24.3	0.18	0.68
1994	64.1	0					0
1995	348.1	4	4, 4, 5, 2	89.2, 85.4, 50.1, 60.4	285.1	69.46	403.98
1996	95.2	0					0
1997	98.9	2	6, 5	32.2, 21	53.2	1.14	6.62
1998	234.5	3	3, 3, 4	56.6, 42.9, 39	138.5	15.83	92.07
1999	32.3	0					0
2000	55.6	1	5	24.5	24.5	0.13	0.76
2001	60.6	1	2	30	30	0.76	4.4
2002*							
2003*							
2004*							
2005*							
2006*							
2007	92.4	1	5	31.7	31.7	1.05	6.08
2008	30.2	0					0
2009	55.0	0					0
2010	101.6	2	3, 5	22.3, 44.2	66.5	4.34	25.25
2011	102.3	1	6	47.2	47.2	5.37	31.23
2012	32.2	0					0

*Unavailable data

The results of table 3 show the following:

Among the 36 years with available daily rainfall record, 13 had no chance of runoff occurrence which represents about 36% of the years.

Runoff events in one water year did not exceed four in number.

The total amount of runoff realized during a water year is more related to the depths of individual storms rather than to the total annual rainfall or total storms depth of that year.

During the study period, the maximum water volume magnitude due to a single storm that may have passed through site H2 in Wadi Hauran could have reached around $400 x10^6 m^3$.

Table 3 further indicates that the historical flood pattern of Wadi Hauran is not simple, thus a yearly average flood volume value for potential water harvesting at H2 cannot be easily deducted. Between the maximum flood value of year 1995 and the nil runoff chance in at least 13 years during 42 years span, the median runoff value for Wadi Hauran could be found to equal only $2 x10^6 m^3$ which is the average condition for the two water years 1974-1975. Furthermore, if the no runoff years are excluded, the average depth runoff for the remaining years will be 11.1 mm which is about 64 Mm3 per year. It is therefore well noticed that the yearly average runoff value of $175 x10^6 m^3$ found by (Dawah, 2001) can hardly be realized. This is due to the fact that in that study the runoff value was calculated by assuming a higher CN value and using a total monthly rainfall instead of single storm depth.

CONCLUSION

Single storm depth rather than monthly or even daily average rainfall depths is to be considered for the evaluation of frequency and volume of valley runoff events in arid and semi arid regions. Moreover, in case the SCS method is applied, validation of the estimated curve number value using field flow measurements is necessary. According to a nearly forty years period of analysis, an evaluation abiding by these considerations has revealed that Wadi Hauran would exhibit no runoff in one year out of three and that runoff may exceed 69 mm depth in a single water year but the average for those years with runoff events is only 11.1 mm which amounts to about 64 Mm3 at H2 location.

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