Journal of Applied Sciences

ISSN 1812-5654

science alert

ANSInet
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http://ansinet.com

Journal of Applied Sciences 10 (4): 298-304, 2010
ISSN 1812-5654
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Hydrology and Water Harvesting Techniques of Wadi Muheiwir Catchment Area-The Case Study of Jordan

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Abstract: The study area is located in the Eastern parts of Jordan in semi arid area. The determination of flows has been done by applying the United States Soil Conservation Services (SCS). Curve number approach to the available rainfall data since 1976 till 2006 taking in consideration the Antecedent Moisture Conditions (AMC), the initial abstraction of rainfall and land use. The Curve Number (CN), was calculated from the topographic maps, geologic map and land use map. Therefore, the curve number 80 was found for Wadi Muheiwir catchment area. The calculations of the flood volumes for Wadi Muheiwir catchment area were determined and statistically analyzed by applying Gumble theory (distribution). The calculations and the results for 10, 25, 50,100 and 200 years return period were estimated. The long-term average runoff is 0.063 MCM. It ranges between zero and 0.544 MCM. Macro and micro water harvesting techniques suitability for Wadi Muheiwir were reviewed depending on the criteria used in the classification and its suitability for agricultural activity.

Key words: Water harvesting, CN curve number, runoff predication, Wadi Muheiwir, Jordan

INTRODUCTION

Jordan is located in semi arid area. Rainfall is low and unpredictable in the country. Jordan has a per capita water supply far below the water poverty line of 1000 m^3 $annum^{-1}$. It is widely agreed that Jordan is facing increasingly water difficulties during the coming years. Wadi Muheiwir drainage area at its lower reach is located between 293 to 301 E and between 58 to 81 N according to Palestine Grids. The total area is about 100 km^2. Elevations range from 950 m in the extreme South to about 800 m at the confluence of Wadi Muheiwir with Wadi Ghadaf. Jordan is facing a water crisis. Population growth is expected to continue at over 2.3% per annum (AlZubi *et al*., 2008) while agricultural intensification is adding to the national water burden. Renewable resources do not meet present water demands (MWI, 2009; Haddadin, 2006) and alternative supplies are being sought e.g., desalination and recycling. Overabstraction of ground water has resulted in significant falls in the groundwater table in the Azraq basin and domestic supply is only provided two to three days a week in Amman. The situation is exacerbated by possible changes in the seasonal pattern of rainfall. Jordan requires more efficient use of its existing water supplies and this is particularly the case in the drier Eastern region known as the Badia. One strategy that has been widely practiced in the past in the Middle East is water harvesting. This technique aims to make more effective use of precipitation through capturing and directing surface flows or harvesting rainfall directly.

Wadi Muheiwir drainage area at its lower reach is located between 293 to 301 E and between 58 to 81 N according to Palestine Grids. It is closed to the Azraq basin which is located in the Eastern part of Jordan (Fig. 1). The total area of Wadi Muheiwir is about 100 km^2. Elevations range from 950 m in the extreme South to about 800 m at the confluence of Wadi Muheiwir with Wadi Ghadaf (Fig. 1).

The general shape of the Catchment is fern leaf, with the longer axis oriented S-N direction. Also, the general slope of the area is from South to North and the average slope of the stream channels varies between one to 3%.

The soil are originated mainly from laucstrine and alluvium deposits. They are saline and relatively low in organic matter. The vegetation of Wadi Muheiwir is mainly perennial shrubs and the Wadi is a grazing area. Rangeland is grazed by sheep and goats and no agriculture activities are available in the area (Al Zubi *et al*., 2002).

Jordan has a semi arid climate, with a long, dry, hot Summer, a rainy Winter and a drier-than-Spring Autumn.

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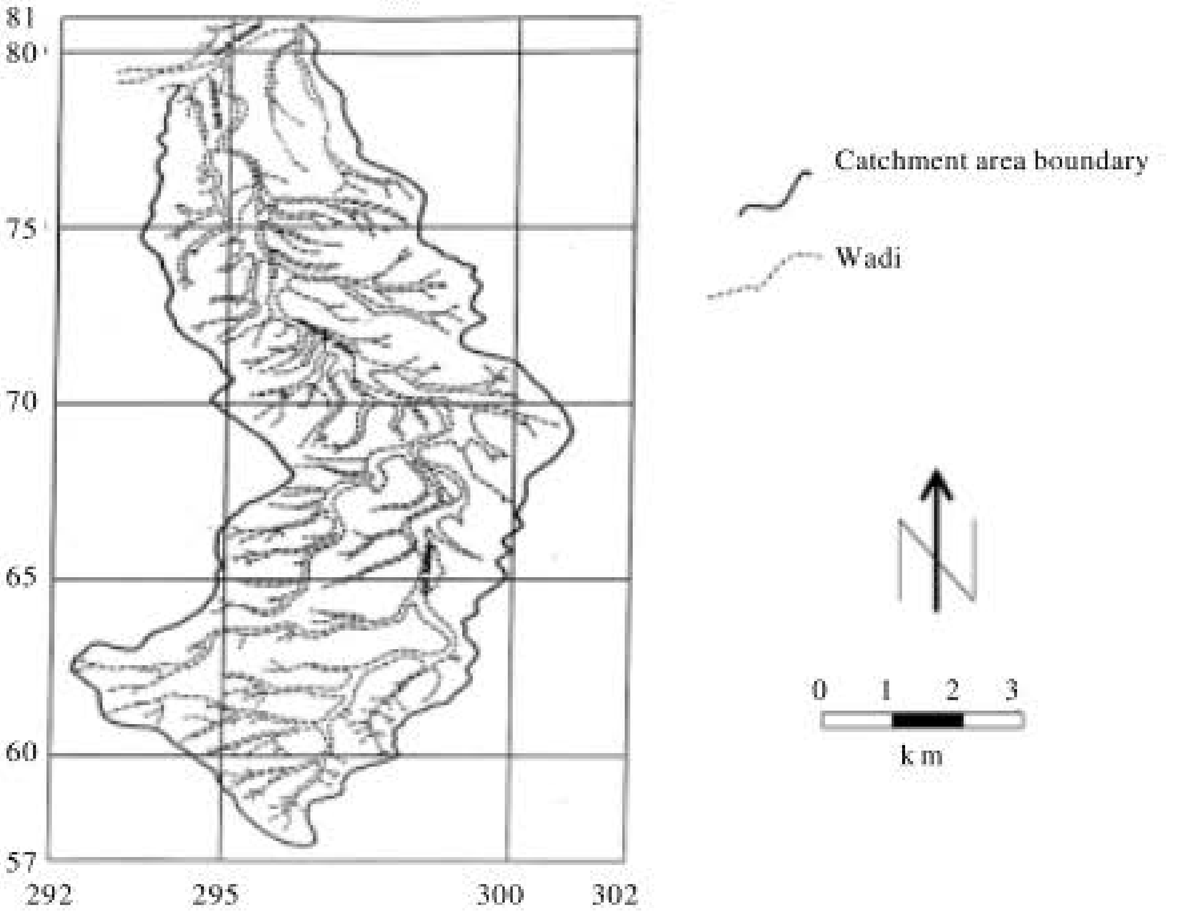

Fig. 1: Map of study area (Wadi Muheiwir catchment area)

The temperature increases towards the South, with the exception of some Southern highlands. Rainfall varies considerably with location, due mainly to the country's topography. Annual rainfall ranges between 50 mm in the Eastern and Southern desert regions to 650 mm in the Northern highlands. Over 90% of the country receives less than 200 mm of rainfall per year. Average annual rainfall gives a total volume of 8.43 km^3 (Al-Zubi, 2009). The low quality and seasonality of the rainfall restrict surface water supplies, making water a key issue for the country.

The thunderstorm rainfalls form great part of the total rainfall in the Catchment area, which is characterized by irregular intensity and duration. The largest amount of rainfall occurs during the months December and February. The average rainy days are 20 and the average annual rainfall precipitated over the Catchment area is 50 mm (Taany, 1996). The prevailing wind directions are Northwesterly winds in the Summer, shifting to the Southwest in the Winter. Easterly and South Westerly winds also occur, they are cold and dry in the Winter, but hot, scorching, dusty and consequently harmful to the vegetation, in the Summer. The annual average wind speed is 12 km h^{-1} (Taany and Al-Zubi, 2007; Haddadin, 2006).

The objectives of study were:

- To evaluate the available surface water potential for Wadi Muheiwir, using the hydrologic characteristics of the catchment and relevant storms
- To calculate the frequency analysis and the storm runoff to predict the 2, 3, 5, 10, 25 , 50, 100 and 200 years return period
- To propose scheme and location for water harvesting in the study area, depending on the topographic features of the catchment area, type of soil, land use and the site of stream's confluence

MATERIALS AND METHODS

This study has been conducted in the Eastern parts of Jordan. Wadi Muheiwir is located within the Azraq basin. The determination of flows is done by applying the United States Soil Conservation Services (SCS) Curve Number approach to the available rainfall data as it is described in the hydrology section. This method takes in consideration the Antecedent Moisture Conditions (AMC), the initial abstraction of rainfall and land use. The general equation relating the accumulated runoff to accumulated rainfall is: (Chow *et al*., 1988).

$$Q = (P - Ia) 2 /(P - Ia + S) \qquad (1)$$

Where:

Q = The accumulated depth of runoff in inches
P = The accumulated depth of storm rainfall in inches
Ia = The depth of the initial abstraction in inches
S = The depth of the potential abstraction in inches
Ia = A are related to soil cover conditions. Also, the relation between initial abstraction (Ia) and potential abstraction

S was derived from the studies of different watersheds in the USA as:

$$Ia = 0.2 S \qquad (2)$$

Thus, the above equation for the accumulated runoff is formulated as:

$$Q = (P - 0.2 S) 2 / (P+0.8 S) \qquad (3)$$

The relation between the Curve Number (CN) and S was found:

$$S = 1000/CN-10 \qquad (4)$$

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

Geology: Wadi Muheiwir catchment area, as well as the whole Azraq basin, is accounted as a part of the limestone eplateau in East Jordan. The youngest sediments which occur in the catchment area consist of gravel and sands of fluviatile origin (Bender, 1974).

The area as the whole of Jordan was affected by the transgressions and regressions that occurred during the time from Cenomanian until upper Eocene. These transgressions and regressions are represented by the changes of facies in the Ajlun group (limestone, dolomite, marl shale and dolomites limestone) and Belqa Group (marl, limestone, chert, silicified limestone, dolomite and chalk), that cropout in the whole catchment area.

During the period from Upper Oligocene and into the lower Miocene, the area has gone under erosion and tectonic activity. The Quaternary Deposits are mostly exposed at the mouth of the wadies in the catchment area. These sediments consist of strewn plain, comprising angular, poorly stored largely black chert clasts, in a silty to sandy matrix. At the periphery of Qa Azraq, these sediments 1.5 to 6 m thick consist of silt particles cemented by evaporates. Alluvial fans are developed at the mouth of some wadies. Figure 2, shows the geological map of Wadi Muheiwir area.

Hydrology: Wadi Muheiwir catchment area is drained by engaged tributaries. These tributaries are characterized by wide shallow flow beds with relatively low slopes. Therefore, the direct runoff in the study area is estimated using SCS method. The storm runoff mostly occurs during the months December and March. Flashy floods which occurred in the Winter season are directly discharge into Wadi Ghadaf at the lower reach of Wadi Muheiwir. The flood waters are not utilized in the catchment area.

Rainfall is the primary source of water in the study area. Generally, the rainy season starts in the beginning of October and lasts by the end of April . The thunderstorm rainfalls form great part of the rainfall precipitated over the catchment area, which is characterized by irregular intensity and duration.

There is only one non-recording rainfall station located in the vicinity of the catchment area. This station is Qaser Touba rainfall station. The long-term average rainfall (1976-2006) over the study area is about 50 mm. The maximum rainfall recorded during the period of records is 76 mm, whereas the minimum rainfall is 24.3 m. Table 1, represents the annual and monthly rainfall of Qaser Touba.

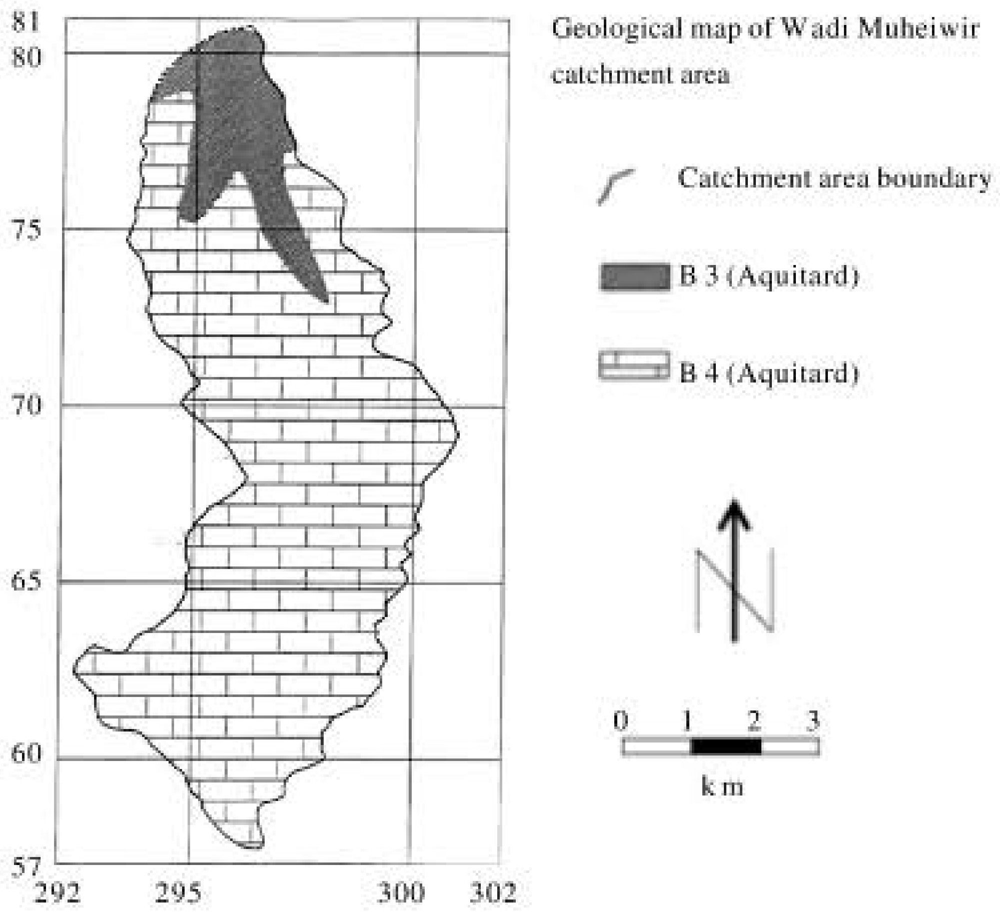

Fig. 2: Geological map of Wadi Muheiwir catchment area

Table 1: Annual and monthly rainfall for Qasr Touba station

	Months								
Water year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Annual (mm)
76/77	1.5	9.5	10.0	13.4	3.8	4.5	5.1	3.2	51.0
77/78	2.5	7.4	8.0	4.0	1.3	6.0	2.0	0.0	31.2
78/79	0.0	0.0	8.5	18.3	3.0	1.2	22.0	0.0	53.0
79/80	0.0	0.0	30.1	0.5	4.5	28.0	12.0	0.0	75.1
80/81	0.0	1.0	26.0	9.1	1.4	0.5	0.0	0.0	38.0
81/82	0.0	3.0	3.4	28.2	14.4	27.0	0.0	0.0	76.0
82/83	0.0	2.3	18.7	7.0	36.0	1.0	0.0	0.0	65.0
83/84	0.0	0.3	7.0	1.3	7.0	25.0	2.0	0.0	42.6
84/85	1.0	7.7	0.0	28.0	7.5	5.8	1.2	0.0	51.2
85/86	0.0	0.6	20.5	9.0	3.0	2.0	0.0	0.0	35.1
86/87	2.5	1.0	0.5	23.0	10.2	0.0	1.0	2.0	40.2
87/88	0.0	5.2	24.0	11.3	12.0	1.5	0.0	0.0	54.0
88/89	2.0	15.0	22.1	1.0	4.2	6.3	4.5	10.0	65.1
89/90	0.0	2.2	0.0	12.0	5.2	13.0	6.8	4.0	43.2
90/91	1.3	9.4	24.0	6.2	5.0	15.0	0.4	0.0	61.3
91/92	0.0	2.0	5.1	6.0	1.5	9.5	0.2	0.0	24.3
92/93	0.6	22.8	1.8	0.0	6.8	17.6	0.0	0.0	49.6
93/94	0.0	4.8	19.0	0.2	9.0	0.0	23.0	0.0	56.0
94/95	0.0	8.4	4.0	2.0	3.4	18.2	0.0	0.0	36.0
95/96	3.6	0.0	2.6	23.0	2.0	24.0	16.8	0.0	72.0
96/97	6.0	0.0	29.2	11.6	0.0	1.2	0.0	0.0	48.0
97/98	0.0	7.5	1.2	9.1	13.2	19.0	9.0	0.0	59.0
98/99	0.5	0.0	9.8	24.0	1.0	15.7	0.0	0.0	51.0
99/00	3.0	5.0	27.0	15.0	9.0	3.0	0.0	0.0	62.0
00/01	0.0	0.0	5.3	17.3	8.0	2.4	0.0	0.0	33.0
01/02	0.5	2.0	24.8	11.0	1.0	3.0	0.0	0.0	42.3
02/03	7.0	32.0	10.7	0.0	12.5	1.2	0.0	0.0	63.4
03/04	0.0	4.0	10.9	6.2	7.5	8.4	0.0	0.0	37.0
04/05	0.0	11.4	8.0	24.6	5.0	3.0	0.0	0.0	52.0
05/06	10.0	0.0	9.5	14.0	6.0	2.5	1.2	0.0	43.2
Average	1.40	5.48	12.39	11.21	6.81	8.85	3.57	0.64	50.36

Runoff: As mentioned previously, no gauging of wadi flow in Wadi Muheiwir conducted up to date. Runoff is estimated by 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 (Al-Zubi *et al*., 2006).

The Curve Number (CN), is calculated from the topographic maps, geologic map and land use map. There fore, the curve number 80 was found for Wadi Muheiwir catchment area. By applying Eq. 4, the potential abstraction was found as follows:

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

$$S = \frac{1000}{80} -10 = 2.5 \text{ inches} = 63.5 \text{ mm}$$

$$Ia = 0.2\ S = 0.2 * 63.5 = 12.7 \text{ mm}$$

Then, by applying the general equation relating the accumulated runoff to accumulated rainfall inserted below:

$$Q = (p -0.\ 25)^2/(p + 0.8\ s)$$

The runoff volumes for Wadi Muheiwir were calculated using the rainfall data of Qaser touba station. The results are listed in Table 2. The long-term average runoff is 0.063 million cubic meters (MCM). It ranges between zero and 0.544 MCM.

Flow frequency: The calculation of the flood volumes for wadi Muheiwir catchment area was determined. The flood (runoff) volumes were statistically analyzed by applying Gumble theory (distribution). The calculations are presented in Table 3 and the results are shown in Fig. 3. From this Fig. 3 the 10, 25, 50, 100 and 200 year return period were estimated. The runoff frequency for different return periods are shown in Table 3.

WATER HARVESTING CONCEPT

Water harvesting can be traced back to at least the Nabatens (B.C 300) but more recently the Frasier and FAO (1994) hosted an international workshop on water harvesting in the Middle East and North Africa and UNESCO for the Arab World (1986) and again in a smaller scale (UNESCO, 1986) as well as UNEP (1983) and various national and international bodies have funded the meetings of the International Rainwater. The emphasis here is upon water collection for agricultural purpose not

Table 2: Calculated annual runoff for Wadi Muheiwer in MCM

Water year	Rainfall MCM	Runoff MCM	Runoff coefficient (%)
76/77	5.1	0.0	0.0
77/78	3.12	0.0	0.0
78/79	5.3	0.064	1.49
79/80	7.51	0.001	0.01
80/81	3.8	0.020	0.53
81/82	7.6	0.032	0.42
82/83	6.5	0.279	4.29
83/84	4.26	0.146	3.43
84/85	5.12	0.00	0.0
85/86	3.51	0.011	0.31
86/87	4.02	0.0	0.0
87/88	5.4	0.021	0.39
88/89	6.51	0.247	3.79
89/90	4.32	0.0	0.0
90/91	6.13	0.544	8.87
91/92	2.43	0.0	0.0
92/93	4.96	0.015	0.30
93/94	5.6	0.052	0.93
94/95	3.6	0.0	0.0
95/96	7.2	0.015	0.21
96/97	4.8	0.054	1.13
97/98	5.9	0.016	0.27
98/99	5.1	0.077	1.51
99/00	6.2	0.047	0.76
00/01	3.3	0.0	0.0
01/02	4.23	0.0	0.0
02/03	6.34	0.172	2.71
03/04	3.7	0.026	0.70
04/05	5.2	0.034	0.65
05/06	4.32	0.018	0.42
Average	5.04	0.063	1.25

for domestic i.e., potable supplies. Water harvesting is an umbrella term describing a range of techniques for collecting, concentrating and conserving water from various sources for various purposes (Majed *et al*., 2000). Generally, these are based on the characteristics of the runoff producing and storage elements of the system. At the simplest level two groups can be identified:

- Within-field (site e.g., roof) methods in which the transfer of water takes place over a short distance (maximum 50-100 m) usually by sheet flow. This category includes micro catchment, natural-counter ridges, furrow dyking, strip planting and stone bunds
- External catchment in which runoff is collected from a catchments area at a considerable distance from the receiving area and is transferred by channel flow or overland flow. This category includes terraced wadi systems, hillside conduit system; dams used for recession planting, majaluba systems and Qaa systems (Eric Patrick, 2002)

Other important definitions related to water harvesting such as Run-off coefficient, which is the ratio of the amount of runoff water that leaves the catchment area to the amount of rainfall that caused such runoff. It is determined in the field for specific conditions. Also, Catchment Target Ratio, which is the ratio of the area of

Table 3: Distribution analysis: gumbel extremal type I

Point No.	Weibull probability	Actual value	Predicted value	Standard deviation
1	0.0313	0.0	-0.099	0.0242
2	0.0625	0.0	-0.0786	0.0217
3	0.0938	0.0	-0.0642	0.0202
4	0.125	0.0	-0.0524	0.0191
5	0.1563	0.0	-0.0421	0.0183
6	0.1875	0.0	-0.0327	0.0177
7	0.2188	0.0	-0.0239	0.0172
8	0.25	0.0	-0.0155	0.0169
9	0.2813	0.0	-0.0074	0.0168
10	0.3125	0.0	0.0005	0.0168
11	0.3438	0.01	0.0083	0.0168
12	0.375	0.02	0.016	0.017
13	0.4063	0.02	0.0238	0.0174
14	0.4375	0.02	0.0316	0.0178
15	0.4688	0.02	0.0396	0.0183
16	0.5	0.02	0.0477	0.0189
17	0.5313	0.02	0.056	0.0197
18	0.5625	0.03	0.0646	0.0205
19	0.5938	0.03	0.0736	0.0215
20	0.625	0.03	0.0831	0.0226
21	0.6563	0.05	0.0931	0.0238
22	0.6875	0.05	0.1037	0.0252
23	0.7188	0.05	0.1152	0.0268
24	0.75	0.06	0.1278	0.0286
25	0.7813	0.06	0.1418	0.0307
26	0.8125	0.08	0.1575	0.0331
27	0.8438	0.15	0.1758	0.036
28	0.875	0.17	0.1977	0.0395
29	0.9063	0.25	0.2255	0.0441
30	0.9375	0.28	0.264	0.0505
31	0.9688	0.54	0.3286	0.0616

Exceedence probability	Return period	Calculated value	Standard deviation
Predictions			
0.995	200	0.4968	0.091
0.99	100	0.4335	0.0799
0.98	50	0.3698	0.0688
0.96	25	0.3057	0.0577
0.9	10	0.2193	0.043
0.8	5	0.151	0.0321
0.667	3	0.0967	0.0243
0.5	2	0.0477	0.0189

First moment (mean) = 0.0632; Second moment = 1.288e-02; Skew = 2.731e+00

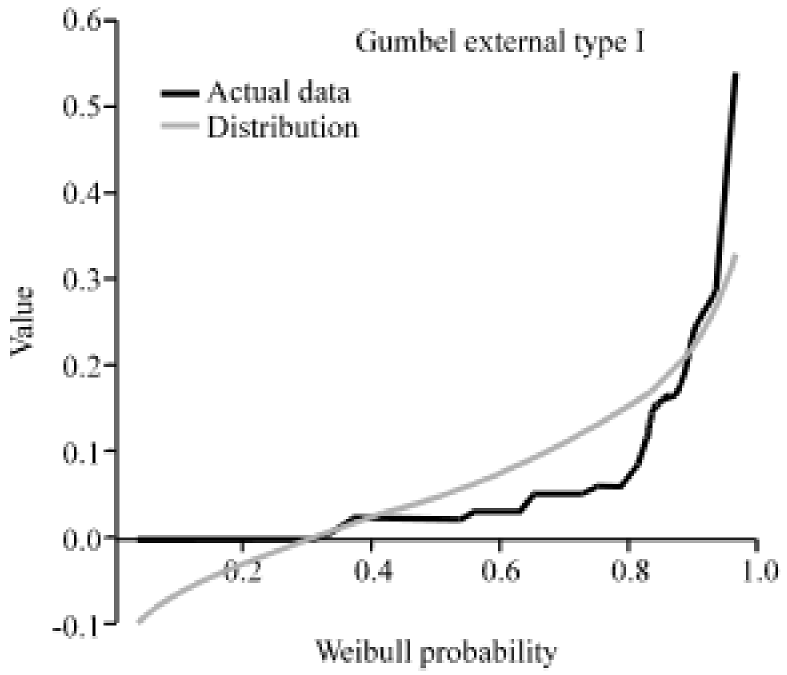

Fig. 3: Gumbel extremal type I

the catchment to the area of the cultivated land. This ratio is determined to insure sufficient amount of runoff to satisfy crop water requirements.

Water harvesting designs can increase the system efficiency in catchment hydrology by reducing conveyance losses by converting overland flow to channel flow. The nature of the surface materials and associated geology play a role in flow discontinuities in the catchment area. This is affected through changes in surface infiltration where the type and characteristics of the land surface are expected to exert significant influence upon the volume and duration of runoff. There are some techniques used in the Wadi as water harvesting systems such as runoff storage pond, contour tree bunds, contour ridges and semi circular earth bunds. These methods considered as small runoff storage work as micro-catchment harvesting system.

RESULTS AND DISCUSSION

Table 1 shows the annual and monthly rainfall for Qasr Touba station for the period (1976-2006). Monthly peak flow of each flood was selected in order to conduct the frequency analysis on monthly basis. Each monthly maximum series was analyzed individually using Storm Management and Design Aid computer package (Wanielista, 1996). Table 2 shows the calculated annual runoff for Wadi Muheiwir in MCM. The long-term average runoff is 0.063 MCM. It ranges between zero and 0.544 MCM. The Gumble Type (I) was applied for annual maximum series. As a result of distribution, the storm events for different return periods of the 2, 3, 5, 10, 25, 50,100 and 200 year are derived. The Gumble Type (I) show a good fitness of actual data to represent the runoff values for different return periods as shown in Table 3 and Fig. 3.

Runoff is a function of precipitation, soil, surface cover, elevation of the catchment and slope. Rainfall is the most variable factor. Shape of the drainage catchment also governs the rate of water enters the stream. Mainly, there are two types of catchments area, fan shape and fern leaf. The fan shaped catchments give greater runoff due to the fact that tributaries are smaller with the almost the same size and water enters at the same time. On the other hand, fern leaf catchments, tributaries are of different length and the time of concentration is more as the discharge has to travel longer. Due to the fact that Wadi Muheiwir catchment area is fern leaf shape and low rainfall amounts the generation of runoff will be affected and it is more likely to travel for shorter distance than feeding the stream.

CONCLUSIONS

Wadi Muheiwir is considered as a semi arid to hyper arid area. The calculations of flood have been estimated using the Curve Number (CN). Therefore, the curve number 80 was found for Wadi Muheiwir catchment area. The calculations of the flood volumes were determined and statistically analyzed by applying Gumble theory (distribution) for 10, 25, 50, 100 and 200 years return period. The long-term average runoff is 0.063 MCM. It ranges between zero and 0.544 MCM.

The monthly peak flow of each flood was selected in order to conduct the frequency analysis on monthly basis. Each monthly maximum series was analyzed individually using Storm Management and Design Aid computer package (Wanielista *et al*., 1996). The Gumble Type I was applied for annual maximum series. As a result of distribution, the storm events for different return periods of the 2, 3, 5, 10, 25, 50, 100 and 200 year are derived. The Gumble Type I show a good fitness of actual data to represent the runoff values for different return periods as shown in Table 3 and Fig. 3.

The flood frequency for 2, 3, 5, 10, 25, 50, 100 and 200 year return period was calculated and the values were 0.047, 0.097, 0.151, 0.219, 0.306, 0.369, 0.433 and 0.4968 mm, respectively.

During the period of records (1976-2006), the annual rainfall of the whole area showed a minimum value of 24.3 mm in the period 1991-1992 and a maximum value of 76 mm in the period 1981-1982.

Macro (small water ponds) and micro (farm level, Contour ridges and bunds) water harvesting techniques suitability for agricultural activity in Wadi Muheiwir were reviewed. Micro Water harvestings techniques will be more suitable to the study area as the rainfall is characterized by small amounts and sporadic during the rainy season. The catchments area shape is fern leaf and due to low rainfall amounts that will affect the generation of runoff to feed the stream. The importance and necessity of water encouraged people to think of many diverse ways and techniques to collect and keep water to be used later for many purposes. Water harvesting effectiveness has then been established as an effective strategy in semi-arid and arid years for agricultural activities.

More investigation and proper rainfall data collection should be carried out in the future as there is only one station in the study area.

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