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Availability of Surface Water of Wadi Rajil as a Source of Groundwater Artificial Recharge: A Case Study of Eastern Badia /Jordan

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ABSTRACT

Wadi Rajil catchment area is considered as one of the major wadis entering the Azraq Basin from the north. It is ungauged wadi and covers an area of about 3910km^2. The annual average rainfall on Wadi Rajil catchment area is about 126.6mm. Heavy thunderstorms occur in April and May, causing significant floods covering the area. The flood waters are not utilized, and a small portion infiltrates into the ground, where the great portion of these waters remain over Qaa' Azraqfew months before evaporation. Due to the absence of the hydrometric stream flow station, no data are available about surface water runoff in Wadi Rajil catchment area. Therefore, the first part of this study calculates the surface water potential of Wadi Rajil to be utilized for groundwater artificial recharge, applying the SCS curvilinear synthetic unit hydrograph method. The synthesis unit hydrograph of Wadi Rajil catchment is characterized by a peak value of 1146 m^3/s (4047 cfs) per one inch of rainfall excess. Flood hydrographs for 10,25,50, and 100 years return periods were derived and their peak flow are found to be 10,8,186,412, and 680 m^3/s, respectively and the corresponding flood volumes are 0.95, 16.53, 36.89, and 61.5 MCM, respectively.Groundwater artificial recharge conditions are suitably prevailing in the most northern and central part of the catchment area, whereas, geological, Hydrogeological, and water quality characteristics of the floodwater encourage artificial replenishment of the exploited aquifer in the study area.

Key words: Wadi Rajil, Hydrometric, Unit hydrograph, Geological, Artificial recharge.

INTRODUCTION

Azraq basin is located in the Northeastern part of Jordan and extends northwards into Syria and southwards into Saudi Arabia. The Azraq Oasis (called locally Sabkhah or Qa'a Azraq) which is located in the central part of the basin is at a distance of about 120 km northeast of Amman. Qa'a Azraq is a relative large mudflat located in the central part of the basin. Two villages are located on the western side of the Qa'a Azraq; these are Azraq Shishan and Azraq Druze. A well field called AWSA was established north of Azraq Druze Springs (northern springs) where about 15-20 million m^3 per year (MCM/a) of water is pumped to the capital Amman for drinking purposes since 1982. Farmers in the area are using around 45 MCM/a. Therefore, the total abstraction from the basin is about 65 MCM/a (El Naqa *et al.*, 2007).

The over-pumping from the shallow groundwater aquifers, the water level dropped dramatically and signs of salinization and depletion are starting to occur. Therefore, it is necessary to determine the location of this interface, since saline water, intrusion has started and is predicted to accelerate in the near future. (Bajjali, and Hadidi, 2005).

A number of major wadis drain radially into the Azraq depression. These wadis are characterized by wadis shallow flow-beds with relatively low slopes. None of the wadis within the basin is being gauged.Wadi Rajilcatchment area is considered as one of the most significant wadi draining the Azraq basin from its northern part. The general shape of Wadi Rajilcatchment area is trapezoidal, with its longer axis in general oriented NE-SW direction. The slope of the area is from NW to SE and the average slope of stream channels varies from 1% to 3% Elevation ranges from 1550 m above mean sea level (a.m.s.1) at Salkhad in Syria to 500 m a.m.s.1 at Qaa' Azraq. Considerable part of the drainage is nearly flat.

The main objective of this study is to estimate the peak discharge and the flood volumes for different return period in Wadi Rajil catchment area, and the potentiality of using this water for groundwater artificial recharge.

MATERIALS AND METHODS

Description of the study area

Wadi Rajil catchment area lies between 313 to 400 E and 138 to 228 N According to Palestine Grid, and it covers 3910 km^2, Figure 1.Intermittent flow in the wadi occurs in winter and drains into Qaa' Azraq, where it evaporates within a few months without utilization.

The climate in the Azraq Basin belongs to the Mediterranean bio-climatic region, which is characterized by dry hot summers and wet, cold winter. Most of the study area is arid and small portion can be considered as semi-arid. As in most arid and semi-arid areas, temperatures exhibit large seasonal and diurnal variations with absolute daily temperatures ranging from a maximum of about 46 ºC (January of 1993), (JMD, 2010).

The thunderstorm rainfalls from the great part of the total rainfall in the study area, which is characterized by irregular intensity and duration. The heaviest rainfall over 24 hours is usually recorded between December and March and no significant normal rainfall is to be expected in October and May. The average annual rainfall over the sub-catchment area is 126.6 mm and ranges between less than 50mm in the south to more than 300 mm in the northern part of the sub-catchment.

Geology

Azraq Basin in general and Wadi Rajil catchment area in particular is a part of the limestone plateau in east Jordan. The northern part of this plateau is covered by six basalt flows, tuff and volcanic eruption originated mainly in Jabel Arab in Syria and many other relatively small volcanoes in the area occurred during the Miocene-Quaternary. These flows overlie Tertiary rocks in the northern part of the catchment area.

The youngest sediments in the Qaa' consists of gravels and sands of fluviatile origin (NRA, 1992).The outcropping formations are, the Rijam and wadi Shallala in the central and eastern part of the basin, both of Eocene age.

The northern part of the Azraq basin is dominated by Miocene to Pleistocene basalt whereas to the west and south by Rijam and Muwaqqar formations of late cretaceous- Early Tertiary age. Regional distribution of the outcropping geological formations is shown in Figure 2.

The area as the whole of Jordan was effected by the transgressions and regressions that occurred during the time from Cenomanian until upper Eocene (NRA, 1992).

These transgressions and regressions are represented in the Azraq Basin by the changes of facies in the Ajlun Group (limestone, dolomite, marl, shale and dolomitic limestone) and Belqa Group (marl,limestone ,chert, silicified, limestone, dolomite and chalk),that crop out in the central, western and southern part of the basin. During the period from upper Oligocene and into the lower Miocene, the Azraq Basin has gone under erosion and tectonic activity,(Bender, 1974).

In the Azraq playa (wetland reserve), the basalt is missing. Upper Tertiary sediments (B5) (Wadi Shallala) are located in the structural depression zones. The (B5) Formation consists of Marly Clayey layers in the area of AWSA well field and acts here as an aquitard between the B4 (Rijam) and the Basalt aquifer. Towards the southeast, the B5 Formation contains more sandy layers and it is classified as an aquifer in this area. South of the basalt areas Paleocene and Eocene,marly limestone, chalks, and chalky limestone with chert layers of the B4 formation, dominate the landscape. The B4 formation is underlain by the Maastrichtian B3 (Muwaqqar) formation. B3 formation reaches a thickness of about 300 m and consists of marl and marly limestone with some gypsum and evaporite. The underlying Campanian to Turonian B2/A7 formations (Amman/Wadi Sir) is mainly formed by chert and limestone, (El Naqa, 2010).

Methodolgy

There are several methods for determining the peak discharge in un-gauged watersheds. In this study, the SCS-curvilinear synthetic unit hydrograph concept was applied to estimate the peak discharge for the un-gauged Wadi Rajil catchment area.

Derivation of the Unit Hydrograph

The most common method of deriving unit hydrograph synthetically is the soil conversation services (SCS) curvilinear unit hydrograph method, Chow, et al, 1988, Wanielista, 1990). The time to peak or the time required to reach the peak discharge (Tp) is defined as:

Tp=Dr/2+La ...(1)

Where,
Tp=is time to peak in hours
Dr= is the standard duration of rainfall
La= is the lag time

Table 1: Arrangements of incremental values of the storm of certain return period

Time Increment	Rainfall
T(1)	P(n)
T(2)	P(n-2)
.	.
.	.
.	.
T(n/2)-2)	P(5)
T(n/2)-1)	P(3)
T(n/2)	P(1)
T(n/2) +1)	P(2)
T(n/2) +2)	P(4)
.	.
.	.
.	.
T(n-1)	P(n-2)
T(n)	P(n)

The lag time (La) is calculated from the following formula;

La = Ct ((L* Lc)/√ (S_l) ^0.38 ...(2)

Where,
C_t, is aregional constant representing watershed slope and storage (Subramanya, 1984, Chow et al, 1988, Linsely, et al, 1988), L, is the hydraulic length, L_c,is the centroid length and S1 , is the slope.
The standard duration of rainfall (Dr) is calculated as:
Dr=La/5.5 ..(3)

The peak discharge (Qp) can be calculated using the SCS formula:

Table 2: Unit Hydrograph calculations of Wadi Rajil catchment area

T/T_P	T (hr)	Q/Q_P	Q (cfs)
0.0	0.00	0.00	0.00
0.1	1.83	0.015	607.08
0.2	3.65	0.075	3035.40
0.3	5.48	0.160	6475.52
0.4	7.31	0.280	11332.16
0.5	9.14	0.430	17402.96
0.6	10.96	0.600	24283.20
0.7	12.79	0.770	31136.44
0.8	14.62	0.890	36020.08
0.9	16.44	0.970	39257.84
1.0	18.27	1.000	40472.00
1.1	20.10	0.980	39662.56
1.2	21.92	0.920	37234.24
1.3	23.75	0.840	33996.48
1.4	25.58	0.750	30354.00
1.5	27.41	0.660	26711.52
1.6	29.23	0.560	22664.32
1.8	32.89	0.420	16998.24
2.0	36.54	0.320	12951.04
2.2	40.19	0.240	9713.28
2.4	43.85	0.180	7284.96
2.6	47.50	0.130	5261.36
2.8	51.16	0.098	3966.26
3.0	54.81	0.075	3035.40
3.5	63.95	0.036	1456.99
4.0	73.08	0.018	728.50
4.5	82.22	0.009	364.25
5.0	91.35	0.004	161.80

QP=(484/TP)*A ...(4)

Where, A, is the catchment area in (mi^2) and Qp in ft^3/sec (cfs).

Critical Arrangement of the storm

The incremental values of the storm of certain return period (e.g. 25-year), were arranged in descending order and re-arranged as shown in Table 1, below:

From this arrangement, it is indicated that T (n) is the last time increment in 24 hrs andP (1) is the first and consequently the maximum incremental rainfall. This is the critical arrangement of the storm, which produces maximum peak discharge in its flood, (Matthai, 1969).

Derivation of the Flood Hydrographs

The flood hydrograph of each frequency storm is derived by combining of the hydrograph obtained for each incremental net rainfall or runoff (r1, r2,……., ri). In this combination procedure, the shifting of the hydrographs according to its time increment should be considered, (Chow et al., 1988).

Estimation of peak discharge

In this study, the unit hydrograph approach is applied to determine the peak discharge values.The hydrologic characteristic of the drainage area such as the area of the basin(A),hydraulic length (L), centroid length (Lc) and the elevation deference between the highest point of the main stream and the outlet(H) are calculated from the topographic maps related to the

Table 3: Calculation of effective rainfall for Wadi Rajil Catchment Area for 10-year return period

Time (hrs)	Rainfall intensity (mm/hr)	Rainfall (mm)	Rainfall Increment (mm)	Critical Arrangement	($P-I_a$) (mm)	(P-Ia -f) (mm)	Effective Rainfall (inch)
1	10.25	10.25	10.25	0.14	0	0	0
2	6.72	13.4	3.15	0.22	0	0	0
3	5.00	15.00	1.60	0.41	0	0	0
4	4.10	16.40	1.40	0.54	0	0	0
5	3.52	17.60	1.20	0.65	0	0	0
6	3.14	18.84	1.24	0.70	0	0	0
7	2.75	19.25	0.41	0.70	0	0	0
8	2.50	20.00	0.75	0.71	0	0	0
9	2.30	20.70	0.70	0.84	0	0	0
10	2.13	21.30	0.60	1.20	0	0	0
11	2.00	22.00	0.70	1.60	0	0	0
12	1.88	22.56	0.56	10.25	0	0	0
13	1.79	23.27	0.71	3.15	0	0	0
14	1.70	23.80	0.53	1.4	0.71	0	0
15	1.63	24.45	0.65	1.24	1.24	0.24	0.00945
16	1.58	25.28	0.83	1.00	1.00	0	0
17	1.50	25.50	0.22	0.96	0.96	0	0
18	1.47	26.46	0.96	0.83	0.83	0	0
19	1.40	26.60	0.14	0.80	0.80	0	0
20	1.38	27.60	1.00	0.75	0.75	0	0
21	1.34	28.14	0.54	0.60	0.60	0	0
22	1.30	28.60	0.46	0.56	0.56	0	0
23	1.28	29.44	0.84	0.53	0.53	0	0
24	1.26	30.24	0.80	0.46	0.46	0	0

catchment.Whereas the Curve Number (CN) is calculated from the topographic maps, geologic maps and land use map available for Azraq Basin. The calculation of the unit hydrograph (UH) and the derivation of the flood hydrographs of 10, 25,50and 100years return period for Wadi Rajil catchment area were performed.

Unit Hydrograph of Wadi Rajil Catchment area

The calculation of UH of Wadi Rajil Catchment areawas done using the English unit, then the obtained peak discharge(Qp)values were converted to the metric units. The parameters taken from the topographic map were:

A=1527.3 square mile (mi^2)
L=118.75 mi
Lc= 59.38 mi
H=3444.9 ft

From Equation (2), the calculated lag time (La)is:

$$La = \quad 1.2((118.75 * 59.38)/\sqrt{29})\hat{}0.38$$

La = 18.35 hrs.

From Equation (3), the standard duration (Dr) is:

$$Dr = \quad 18.35/5.5$$

Dr = 3.34 hrs.

The La value is corrected for Dr = 1 hr. instead of 3.34hr, using Snyder's Formula:

$$L'a = 18.35 + (D'r - Dr)/4$$

$$L'a = 18.35 + \frac{1 - 3.34}{4} = 17.765\ hrs.$$

Table 4: Calculation of effective rainfall for Wadi Rajil Catchment Area for 25-year return period

Time (hrs)	Rainfall intensity (mm/hr)	Rainfall (mm)	Rainfall Increment (mm)	Critical Arrangement	(P-I_a) (mm)	(P-Ia -f) (mm)	Effective Rainfall (inch)
1	12.90	12.90	12.90	0.55	0	0	0
2	7.95	15.90	3.00	0.58	0	0	0
3	6.10	18.30	2.40	0.61	0	0	0
4	5.00	20.007	1.70	0.80	0	0	0
5	4.21	21.05	1.05	0.86	0	0	0
6	3.72	22.32	1.27	0.91	0	0	0
7	3.35	23.45	1.13	0.95	0	0	0
8	3.00	24.00	0.55	1.04	0	0	0
9	2.80	25.20	1.20	1.13	0	0	0
10	2.60	26.00	0.80	1.27	0	0	0
11	2.45	26.95	0.95	2.40	0	0	0
12	2.30	27.60	0.65	12.90	2.21	1.21	0.047
13	2.19	28.47	0.87	3.00	3.00	2.00	0.079
14	2.10	29.40	0.93	1.70	1.70	0.70	0.028
15	2.00	30.00	0.60	1.20	1.20	0.20	0.008
16	1.94	31.04	1.04	1.05	1.05	0.05	0.002
17	1.86	31.62	0.58	0.96	0.96	0	0
18	1.81	32.58	0.96	0.93	0.93	0	0
19	1.76	33.44	0.86	0.87	0.87	0	0
20	1.70	34.00	0.56	0.86	0.86	0	0
21	1.66	34.86	0.86	0.65	0.65	0	0
22	1.60	35.20	0.34	0.60	0.60	0	0
23	1.57	36.11	0.91	0.56	0.56	0	0
24	1.53	36.72	0.61	0.34	0.34	0	0

Where,

L'_a is the corrected lag time and $D'r$ is one hour duration. Then, theTp was calculated using formula (1):

$$TP = 1/2 + 17.765$$
$$TP = 18.265\ hrs.$$

Finally, the estimated Qp was obtained using Equation (4):

$$QP = (484/18.265) * 1527.3$$

= 40471.6 or 1146 m^3 / sec (cms)

The T/Tp and Q/Qp values of the generalized dimensionless UH of the SCS were used to derive the synthetic UH of Wadi Rajil catchment area. Table 2, shows the calculation of Wadi Rajil UH. The UH of Wadi Rajil is also illustrated in Figure 3.

Derivation of Wadi Rajil Flood Hydrographs

The intensity duration frequency curves (IDF) of Azraq rainfall station and the CN method mentioned previously, were utilized to calculate the effective rainfall (runoff). The IDF curves are shown in Figure 4.From these curves ,the 10 ,25,50 and 100 years return period rainfalls for duration of 24 hours were obtained hourly, the results of calculation are tabulated in Tables (3,4,5,and 6).These tables also show the critical arrangement of the incremental rainfall to obtain the maximum flood of 10,25,50 and 100 years return period storm.

Table 5: Calculation of effective rainfall for Wadi Rajil Catchment Area for 50-year return period

Time (hrs)	Rainfall intensity (mm/hr)	Rainfall (mm)	Rainfall Increment (mm)	Critical Arrangement	$(P-I_a)$ (mm)	(P-Ia -f) (mm)	Effective Rainfall (inch)
1	14.50	14.50	14.50	0.27	0	0	0
2	9.30	18.60	4.10	0.62	0	0	0
3	7.20	21.60	3.00	0.74	0	0	0
4	5.75	23.00	2.40	0.80	0	0	0
5	4.80	24.00	1.00	0.86	0	0	0
6	4.22	25.32	1.32	1.05	0	0	0
7	3.80	26.60	1.28	1.08	0	0	0
8	3.46	27.68	1.08	1.28	0	0	0
9	3.24	29.16	1.48	1.37	0	0	0
10	3.00	30.00	0.84	1.00	0	0	0
11	2.80	30.80	0.80	3.00	0	0	0
12	2.70	32.40	1.60	14.50	4.77	3.77	0.148
13	2.54	33.02	0.62	4.10	4.10	3.10	0.122
14	2.42	33.88	0.86	2.40	2.40	1.40	0.055
15	2.35	35.25	1.37	1.48	1.48	0.48	0.019
16	2.27	36.32	1.07	1.32	1.32	0.32	0.013
17	2.18	37.06	0.74	1.15	1.15	0.15	0.006
18	2.10	37.80	0.74	1.07	1.07	0.07	0.003
19	2.05	38.95	1.15	1.00	1.00	0	0
20	2.00	40.00	1.05	0.84	0.84	0	0
21	1.94	40.74	0.74	0.74	0.74	0	0
22	1.88	41.36	0.62	0.74	0.74	0	0
23	1.81	41.63	0.27	0.62	0.62	0	0
24	1.78	42.72	0.09	0.09	0.09	0	0

The incremental runoff values were applied to the UH with the time lag, and the individual hydrographs were obtained for each incremental runoff. The addition of these hydrographs give the total storms hydrographs .The application of the procedure to 10,25,50,and 100 years storms for Wadi Rajil catchment are shown in Table 7and the resulted flood hydrographs are illustrated in Figure 5. The calculated peak discharges were 10.8,186,412and 680 m^3/sfor the 10, 25, 50, and 100 year return period respectively. The calculated flood volumes were 0.95,16.5,36.9and 61.5 million cubic meter (MCM)for the 10,25,50,and 100 year return period respectively.

Possibilities of Artificial Recharge

As noticed from the previous section, the study area in particular as well as desert area in Jordan in general receive a low precipitation amount, where most of rainfall occurs in few storms of high intensity and short duration. Flush floods occur in desert areas, due to the low infiltration index. Most of the floodwater evaporates and very little amount for the time being has been utilized. Due to this, the ideal solution is the better management of such water by using it in the replenishment of the over pumped aquifer by artificial recharge techniques.

Artificial recharge is essential on enhancement of natural recharge ; therefore an understanding of the hydrologic cycle precedes developments of sites selection criteria .Five facets of the hydrologic cycle that need to be well understood(Chidly,1981). These are precipitation,

Table 6: Calculation of effective rainfall for Wadi Rajil Catchment Area for 100-year return period

Time (hrs)	Rainfall intensity (mm/hr)	Rainfall (mm)	Rainfall Increment (mm)	Critical Arrangement	$(P-I_a)$ (mm)	(P-Ia -f) (mm)	Effective Rainfall (inch)
1	16.20	16.20	16.20	0.68	0	0	0
2	10.30	20.60	4.40	0.74	0	0	0
3	7.90	23.70	3.10	0.90	0	0	0
4	6.40	25.60	1.90	1.00	0	0	0
5	5.50	27.50	1.90	1.13	0	0	0
6	4.87	29.22	1.72	1.22	0	0	0
7	4.38	30.66	1.44	1.39	0	0	0
8	3.92	31.36	0.70	1.50	0	0	0
9	3.70	33.30	1.94	1.72	0	0	0
10	3.48	34.80	1.50	1.90	0	0	0
11	3.24	35.64	0.84	3.10	0	0	0
12	3.08	36.96	1.32	16.20	9.68	8.68	0.342
13	2.90	37.70	0.74	4.40	4.40	3.40	0.134
14	2.78	38.92	1.22	1.94	1.94	0.94	0.037
15	2.67	40.05	1.13	1.90	1.90	0.90	0.035
16	2.59	41.44	1.39	1.50	1.50	0.50	0.020
17	2.46	41.82	0.38	1.44	1.44	0.44	0.017
18	2.39	43.02	1.20	1.32	1.32	0.32	0.013
19	2.30	43.70	0.68	1.20	1.20	0.20	0.008
20	2.26	45.20	1.50	1.10	1.10	0.10	0.004
21	2.20	46.20	1.00	1.00	1.00	0	0
22	2.15	47.30	1.10	0.84	0.84	0	0
23	2.10	48.30	1.00	0.70	0.70	0	0
24	2.05	49.20	0.90	0.38	0.38	0	0

Table 7: Flood hydrographs of 10, 25, 50 and 100 year return period for Wadi Rajil Catchment Area

T	Flood Discharge (cfs)				T	Flood Discharge (cfs)			
(hrs)	10 year	25 year	50 year	100 year	(hrs)	10 year	25 year	50 year	100 year
					50	40.8	756.0	1703.0	2866.0
0	0	0	0	0	51	36.4	700.0	1564.0	2611.0
1	2.2	10.8	34.0	78.7	52	34.3	641.0	1444.0	2420.0
2	7.1	50.5	139.1	287.8	53	32.1	598.0	1344.0	2258.0
3	11.5	123.0	284.8	526.5	54	30.5	562.0	1263.0	2122.0
4	34.0	288.0	727.5	1430.0	55	27.4	523.0	1168.0	1947.0
5	51.0	579.0	1322.0	2405.0	56	25.0	479.0	1071.0	1783.0
6	71.8	896.0	2016.0	3518.0	57	23.6	441.0	992.0	1663.0
7	98.3	1272.0	2853.0	4941.0	58	21.7	409.0	919.0	1540.0
8	124.7	1705.0	3800.0	6482.0	59	19.8	377.0	848.0	1413.0
9	162.5	2214.0	4968.0	8494.0	60	18.1	346.0	776.0	1297.0
10	207.9	2861.0	6411.0	10984.0	61	17.0	319.0	718.0	1203.0
11	229.6	3488.0	7674.0	12798.0	62	16.1	297.0	671.0	1126.0
12	260.8	3997.0	8844.0	14708.0	63	15.1	280.0	628.0	1055.0
13	298.6	4555.0	10133.0	16959.0	64	13.7	260.0	583.0	971.0
14	321.3	5105.0	11296.0	18752.0	65	12.5	239.0	534.0	888.0
15	346.0	5561.0	12330.0	20447.0	66	11.3	218.0	488.0	812.0
16	366.6	5977.0	13251.0	21983.0	67	10.5	199.0	447.0	704.0
17	374.2	6286.0	13905.0	22949.0	68	9.3	181.0	405.0	675.0
18	381.0	6470.0	14343.0	23671.0	69	8.7	164.0	371.0	622.0
19	380.3	6569.0	14566.0	24031.0	70	8.5	154.0	348.0	591.0
20	374.2	6565.0	14568.0	24019.0	71	7.8	145.0	326.0	547.0
21	355.8	6427.0	14241.0	23408.0	72	7.6	137.0	308.0	520.0
22	352.4	6239.0	13934.0	23088.0	73	6.9	129.0	288.0	481.0
23	334.5	6063.0	13497.0	22345.0	74	6.1	119.0	264.0	438.0
24	315.6	5791.0	12907.0	21337.0	75	5.7	108.0	242.0	403.0
25	300.5	5498.0	12285.0	20398.0	76	5.2	98.8	222.0	371.0
26	274.0	5168.0	11512.0	19038.0	77	4.7	90.5	203.0	339.0
27	253.2	4779.0	10685.0	17707.0	78	4.3	82.2	185.0	309.0
28	232.4	4406.0	9868.0	16404.0	79	4.2	75.9	172.0	290.0
29	218.1	4074.0	9161.0	15309.0	80	4.0	72.2	163.0	276.0
30	199.4	3776.0	8469.0	14144.0	81	3.8	68.9	155.0	261.0
31	185.2	3485.0	7828.0	13096.0	82	3.3	64.3	143.0	237.0
32	170.1	3221.0	7223.0	12084.0	83	2.6	56.1	123.0	200.0
33	160.6	2985.0	6719.0	11277.0	84	2.4	47.5	107.7	179.0
34	144.1	2763.0	6179.0	10310.0	85	2.4	43.2	98.9	169.0
35	135.1	2536.0	5705.0	9549.0	86	2.1	40.1	90.6	152.0
36	126.1	2357.0	5298.0	8889.0	87	2.0	36.9	83.4	141.0
37	115.3	2184.0	4900.0	8186.0	88	1.9	34.9	78.9	135.0
38	106.3	2012.0	4513.0	7547.0	89	1.9	33.8	76.0	129.0
39	98.7	1858.0	4174.0	6988.0	90	1.8	32.3	72.3	121.0
40	89.6	1711.0	3835.0	6401.0	91	1.6	30.2	67.3	111.8
41	86.0	1584.0	3575.0	6010.0	92	0.0	20.6	39.3	50.2
42	76.7	1472.0	3291.0	5494.0	93	0.0	6.7	17.4	25.8
43	70.7	1346.0	3019.0	5038.0	94	0.0	1.8	7.4	18.4
44	69.2	1254.0	2836.0	4789.0	95	0.0	0.3	3.9	11.5
45	60.3	1170.0	2608.0	4342.0	96	0.0	0.0	1.6	7.7
46	54.8	1058.0	2370.0	3941.0	97	0.0	0.0	0.5	4.5
47	50.6	963.0	2163.0	3623.0	98	0.0	0.0	0.0	2.1
48	46.1	880.0	1980.0	3312.0	99	0.0	0.0	0.0	0.7
49	43.5	810.0	1829.0	3078.0	100	0.0	0.0	0.0	0.0
Volume of flood water for different return periods in million cubic meter (MCM)						0.95	16.53	36.89	61.5

surfaceinfiltration, soilmoisture, surface runoff, interflow, and evapotranspiration. In addition to these facts, the following questions must be quantified concerning viable sites selection criteria(CGWB, 1994): how much rechargeable water is available? when and at what depth ?how will the quality of water change after recharge and how quickly will the aquifer plug due to chemical, physical or bacterial processes.

Applying these points on Wadi Rajil catchment, the different parameters of the hydrologic cycle are discussed in the previous section and the results are tabulated in Tables (3, 4, 5.6 and 7). From these tables the surface runoff in the area is available during the winter season.

The water quality of surface runoff of Wadi Rajil is considered to be of good quality,Table 8.whereas, the electrical conductivity (EC µS/cm) is considered low and highly appropriate since the water flows mostly on the basalt floes or the weathering products of the basalts or the volcanic ashes in most of the drainage areaand in general will not affect negatively the groundwater quality in the area after its percolation through the highly fractured basalt.

Talking into consideration the hydrological conditions prevailing in the Upper Aquifer Complex in the area, there is an enough space for ground water aquifer since it is all over the basin is over pumped as indicated from the groundwater withdrawals in the area of study, Figure 6. In addition, the hydraulic characteristics of the aquifer as indicated from the pump test analyses of the groundwater wells operating in the areaare as follows: the discharge, specifics capacities and transmissivities are ranging between 70-300m^3/hr,0.2-35200m^3/hr/m and 15-72300m^2/d, respectively, (El-Naqa and Al-Shayeb 2008).Therefore, the aquifer has a good potential to accept recharged water. Furthermore, the depth of the water table in the area is ranging between 20-70m from the ground surface.

As indicated from the above discussion on the situation of Wadi Rajil catchment, artificial recharge is considered of high potential to replenish the Upper aquifer. Concerning the technique of artificial recharge, which should be developed in the study area. It is suggested to use deep trench technique, Figure 7, whereas the course of Wadi Rajil itself as well as its tributaries are of wide type and under these circumstances check or desert dams are not feasible (Rimawi et al., 1995).

Table 8: Quality of Surface runoff and Groundwater of Wadi Rajil catchment area

Parameters	Flood Water			Groundwater
Date	14.3.2003	16.1.2006	25.2.2009	Representative
Temperature (ºC)	16.2	14.5	15.0	25.2
EC (µ/cm)	218	225	185	550
pH-value	7.5	7.7	7.8	7.9
Ca (meq/L)	1.18	1.12	1.06	0.92
Mg (meq/L)	0.25	0.21	0.18	0.72
Na (meq/L)	0.76	1.05	0.65	3.69
K (meq/L)	0.12	0.10	0.08	0.26
Cl (meq/L)	0.45	0.52	0.35	2.35
HCO3 (meq/L)	1.72	1.65	1.48	2.26
SO4 (meq/L)	0.12	0.4	0.10	1.08
NO3 (meq/L)	0.06	0.04	0.02	0.08
Turbidity	610	430	240	0.0
Color	18	12	8	0.0
TSS (g/L)	0.35	0.21	0.45	0.0

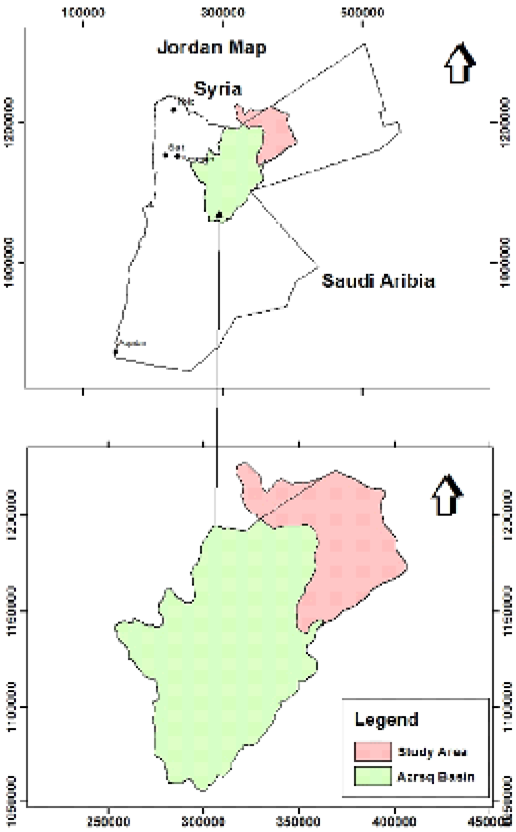

Fig. 1: Location Map of Wadi Rajil Area Catchment Area

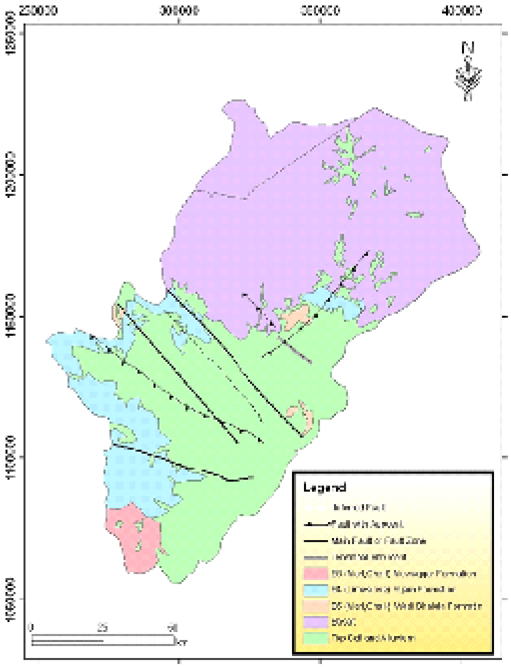

Fig. 2: Geological map of the Azraq Basin

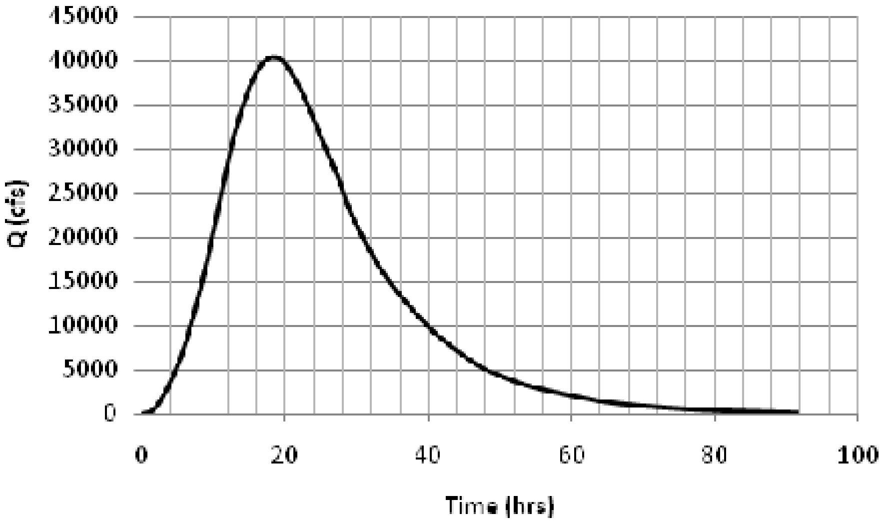

Fig. 3: Wadi Rajil Unit Hydrograph

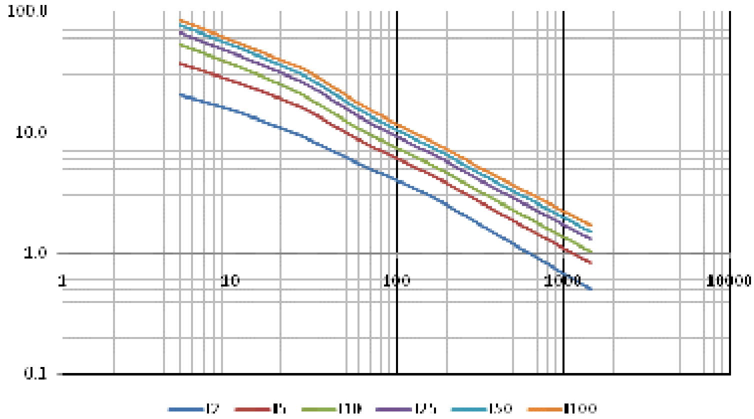

Fig. 4: Azraq Intensity Duration Frequency Curves, (Ta'any, 2002)

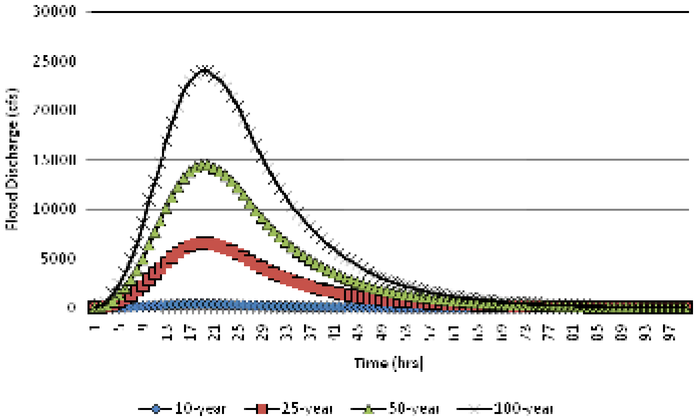

Fig. 5: Flood hydrograph of 10, 25, 50-and100 year return period for Wadi Rajil catchment area

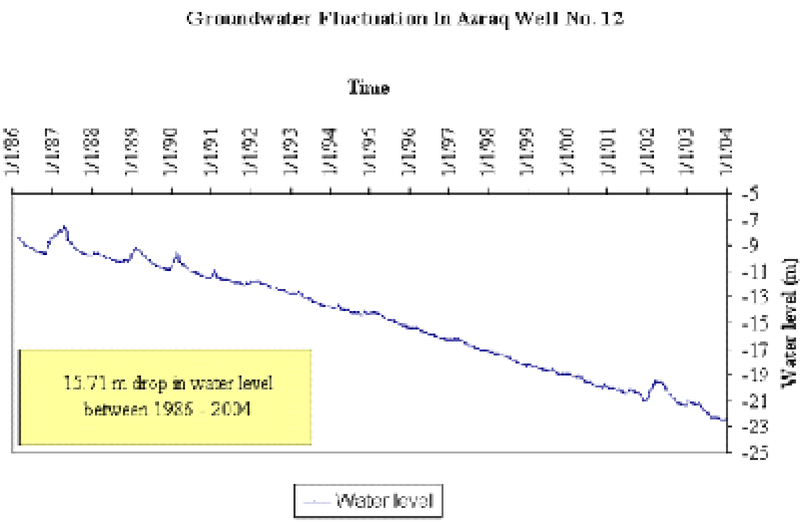

Fig. 6: Groundwater Fluctuation in Azraq – 12 Observation Well, (Bajjali, and Hadidi, 2005)

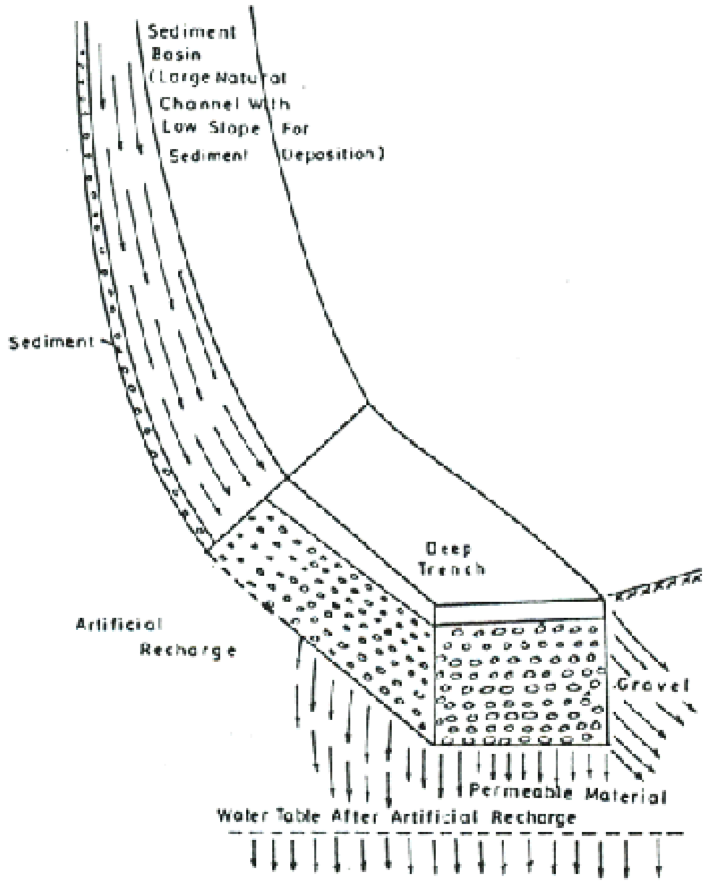

Fig. 7: Deep Trench for Artificial Recharge Purposes

The proposed technique is usually preferred by constructing successive trenches cross the wadi course.Trenches are filled with boulder, gravels and sands (volcanic ashes) in sequence from bottom to top. Using these techniques, the suspended mater will be removed and good water quality will reach the aquifer and no negative impacts will be expected in the groundwaterquality.

CONCLUSIONS

Generally, the northern part of the Azraq Basin receives higher rainfall amounts than the other parts of the basin and accordingly most of the groundwater resources are originated from north of the Azraq basin.The investigation of the availability of surface water and the prevailing conditions for groundwater artificial recharge for Wadi Rajil catchment area has led to the following results:

- The thunderstorm rainfalls from the great part of the total rainfall in the study area, which is characterized by irregular intensity and duration. The heaviest rainfall over 24 hours is usually recorded between December and March.
- The calculated peak discharges for the studied catchment area were 10.8,186,412and 680m^3/s for the 10, 25, 50, and 100 return period, respectively.
- The estimated flood volumes from the resulted flood hydrographs of Wadi Rajil catchment area were 0.95, 16.5, 36.9 and 61.5 MCM for the 10, 25, 50, and 100-year return periods, respectively.
- Geological, hydrogeological and

waterquality offloodwater are found to be highly suitable for artificial recharge of the Upper Aquifer System.

´ Deep long narrow trenches refilled with the available basalt boulders, gravels as well as volcanic ashes will be the appropriate method to be used for artificial recharge in Wadi Rajil catchment area .

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