HIGH QUALITY WATER USING ZERO ENERGY AT URBAN AREAS OF JORDAN

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Abstract **-Water budget of Jordan is about one billion cubic meters with domestic water more than 40%. The quality of water is low in general due to the water shortage at all levels. The drinking water as well is of bad quality and high in dissolve solids little less than 1000 ppm as reflect of water scarcity. The solution could be the reverse osmosis (RO) but it is required energy. The energy consumed is high at main cities of Jordan just for drinking water since household RO is very common at every house and office. The attractive solution can be rainwater harvesting using no energy out of houses roofs. The only extra infrastructure required is a storage tank, which must be feasible economically or otherwise will be wasting energy. Building large storage tank for no rainwater to be stored is the waste. This practice is common as a result of wrong interpretation of rainfall measurements. Rainfall records of nine major cities in Jordan are investigated and average annual rainfall-runoff coefficients are developed to guide the sizing of the storage tanks. The selected rainfall stations are of average annual rainfall of as low as 40 mm per annum at Ma'an city up to 625 mm per annum at Ajloun city. The resulted average annual runoff coefficients are very low for Ma'an about 5% but high at Ajloun about 50%. Power equation is developed to estimate the runoff coefficient for paved roof out of the average annual rainfall with estimated error at ± 10%.**

Keywords- Rainwater Harvesting, runoff curve number, annual rainfall, annual runoff, runfoo coefficient.

I. INTRODUCTION AND STUDY AREA

Jordan is a quite small country with a total area of 89,342 sq km. Although mostly desert, within its compact area, there are three different climatic zones; the Jordan valley, Mountain Heights and the Desert area, which constitutes 75% of the total land area of Jordan. The weather is almost entirely dry and sunny from May to October, where there is hardly any rainfall. Most of Jordan's desert receives less than 120 mm of rain per year, while the average rainfall in the mountain heights ranges between 300 and 600 mm per year. The rainy season begins at the end of November and continues till the end of March. Nonetheless, rainfall is periodic and chance of rain drops substantially from April onwards [1].

Jordan is classified among few countries of the world with limited water resources and it is one of the lowest on a per capita basis. The available water resources per capita are falling as a result of population growth. They are projected to fall from less than 160 m^3/capita/year (2006) to about 90 m^3/capita/year (2025) according to report out of MEnv and UNDP; this is putting Jordan in the category of an absolute water shortage. The scarcity of water in Jordan is the single most important constrains to the country growth and development because water is not only considered a factor for food production but a very crucial factor of health, survival and social and economical development. Water resources consist mainly of surface and ground water, with reclaimed wastewater being used at an increasing scale for irrigation [2].

Jordan is one of the Middle East countries which suffer from water scarcity as its water resources have been extensively exploited to cover the increasing demand. Supply and demand were examined to identify new supply resources and the potential for savings in the demand that can be implemented [3]. Jordan is suffering from an immediate and rapidly growing deficit. The water demand is exceeded the supply at all levels of consumption and specially the domestic use. The rainwater harvesting could be an attractive option to be implemented in order to close the deficit gap of the drinking water.

Water budget of Jordan is about one billion cubic meters with domestic water more than 40%. The quality of water is low in general due to the water shortage at all levels. The drinking water as well is of bad quality and high in dissolve solids little less than 1000 ppm as reflect of water scarcity [4] [5]. The alternative solution could be the reverse osmosis (RO) but it is required energy. The energy consumed is high at main cities of Jordan just for drinking water since household RO is very common at every house and office [6].

The attractive solution can be rainwater harvesting using no energy out of houses roofs [7] as mentioned earlier. The rainwater harvesting is ancient practice in Jordan and the region [8]. The Nabataeans practiced rainwater harvesting at 1st century AD; more than 2,000 years ago. The rainwater is harvested for agricultural and domestic usages. The agricultural demand is supply completely out of rainwater at mountain and hilly areas [9]. The domestic demand is supplied partially from rainwater at different levels of practices [10]. The most common practice is using rainwater to make a nice cup of tea in Jordan and the region.

The climate in study area varies from dry sub-humid Mediterranean in the northwest of the country with rainfall of about 630 mm to desert conditions with less than 50 mm over distance of only 100 km. This climatic variety is reflected in rainfall patterns across the country where rainfall decreases from north to south, west to east and from higher to lower altitudes [11].

The study area is covered by nine rainfall stations along Jordan as shown in "Fig. 1". The concentration can be the north and middle parts of the kingdom to follow the high density of population areas. Most of the rainfall stations are in the northern and the middle part of the country since population intensity is higher as discussed. The high number of population leads to high water demand, which needs to be addressed. At same pattern, the rainfall is higher in those cities, which is more than the southern part of the country. Nevertheless, the country is divided into three parts, which are the north with two stations at two major cities; Ajloun and Jarash, the middle part with four stations at the two largest cities in the kingdom; Amman and Zarqa, and the south part with three stations at three major southern cities.

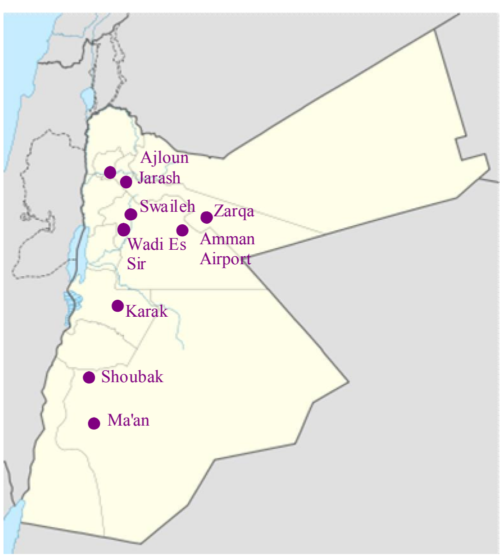

Figure 1: Rainfall Stations at Major Cities of Jordan.

II. METHODOLOGY AND RESULTS

Complete daily rainfall data for each station for twenty years of 1982 to 2002 are used to represent the rainfall phenomena. Longer daily rainfall records are reviewed and tested for consistency in order to find the proper continuous period of records. The period between 1982 and 2002 is found consistent and continuous for the nine rainfall stations. The monthly and annual rainfalls are developed at each station. "Fig. 2" shows the sample of the annual rainfall for four stations with annual average rainfall to present the trend of the annual rainfall. The average annual rainfall almost presents the records for all stations with couple of spikes.

The method developed by Soil Conservation Service (SCS) (1972) [12] for computing abstractions from storm rainfall is used to find the runoff for different curve numbers based on the three Antecedent Moisture Condition (AMC) classifications, as explained by [13].

Curve number for different roofs sizes and hydrologic soil group are presented in Table I below for urban district. For example CN 95 is used for commercial and business lots for hydrologic soil group D [14]. "Fig. 3" presents water year annual runoff for different stations and couple of curve numbers as an example. SCS method is well known as abstracting procedure to obtain the runoff out of the rainfall using storm-by-storm analysis, which can be one of the reliable procedures [15]. The runoff at each storm is developed according to SCS method, which leads to the monthly and annual runoff for five different curve numbers. Accordingly, the runoff coefficients are estimated.

TABLE I. RUNOFF CURVE NUMBER FOR URBAN AREAS.

Cover Type and Hydrologic Condition	CN for Hydrologic Soil Group
Commercial and Business	95 D
500m^2 or less (Town House)	85 B and 90 C
Residential of lot size 2000m^2	80 C and 85 D
Residential of lot size 1000m^2	75 B

Ajloun rainfall station receives the highest annual rainfall with an average of 627mm, while Ma'an gets the lowest of 41mm. Relationship between rainfall and runoff with different curve number values are investigated for each rainfall station. As an example, "Fig. 4" shows annual rainfall versus annual runoff at Ajloun using two different curve numbers; 95 and 85, respectively. The trend of the relationship is differing according to the curve number due to the abstracting depth differences.

On the other hand, the storms' numbers per year are affecting the annual runoff since the annual rainfall will be distributed among the storms. Therefore, higher number of storms will lead to less annual runoff for the same annual rainfall. "Fig. 5" presents the relationship between storms' numbers per year versus annual runoff for two different curve numbers with respect to different ranges of annual rainfall. Two extreme curve number values are used in the comparison to reflect the differences in the relationship strongly.

The runoff values increase when rainfall values do, nevertheless, in some cases runoff values do not correspond with rainfall values' increment such as in Ajloun, Shoubak and Karak. "Fig. 5" is backing up this remark and shows Ajloun storms' numbers and runoff per water year relationship with respect to curve number and four rainfall intervals. The runoff values resulted from the interval (500-650) mm of rainfall are higher than those resulted from the interval 650-680 mm of rainfall when the curve number is CN 75 and vice versa for CN 95. The figure shows the same results for Karak rainfall station.

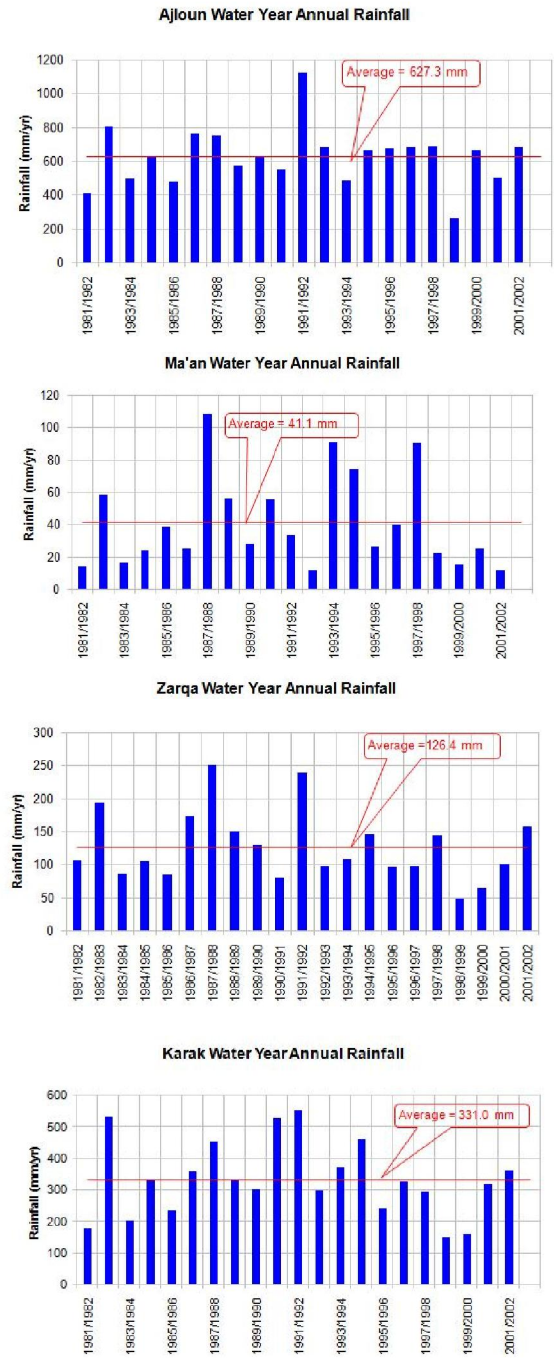

Figure 2: Annual Rainfall with Average at Major Cities for 20 Years (1982-2002).

CN = 90 CN = 95

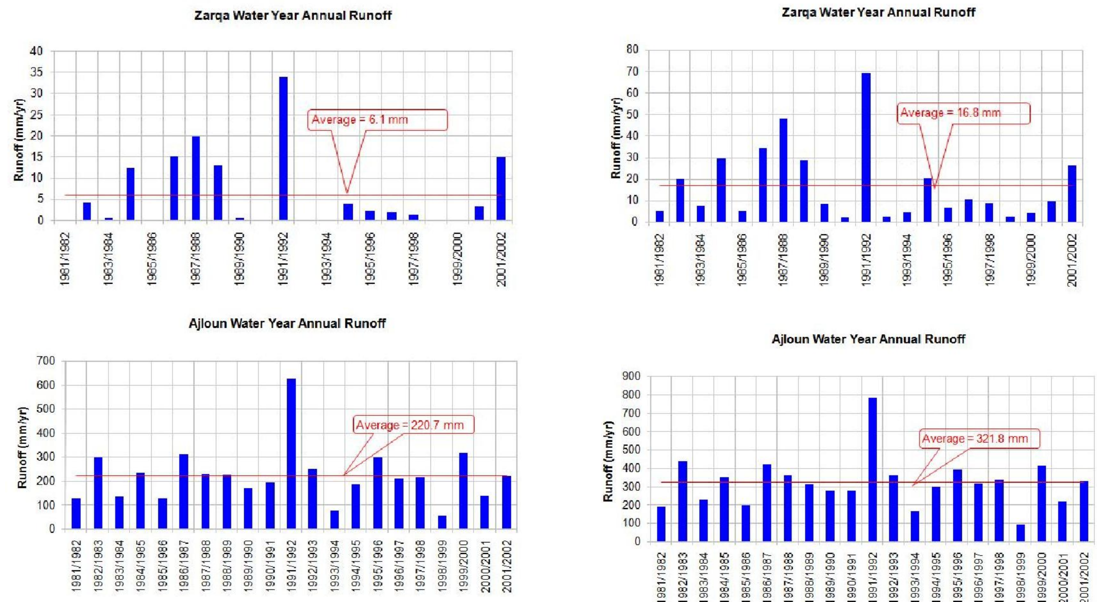

Figure 3: Annual Runoff as sample for three Stations with different Curve Numbers.

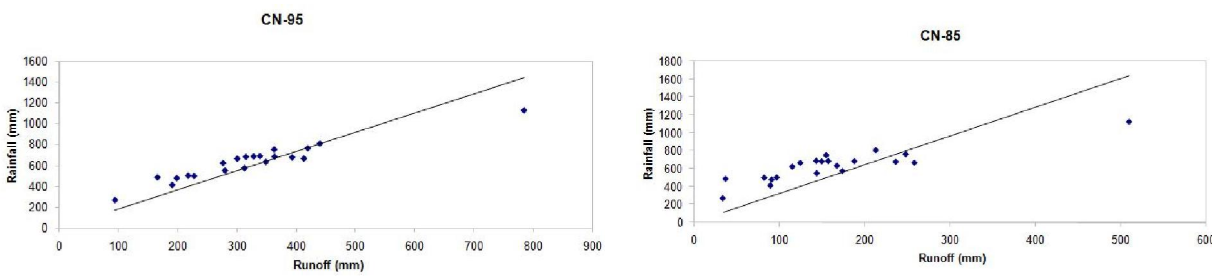

Figure 4: Annual Rainfall vs. Annual Rainfall for Ajloun at CN-95 and CN-85.

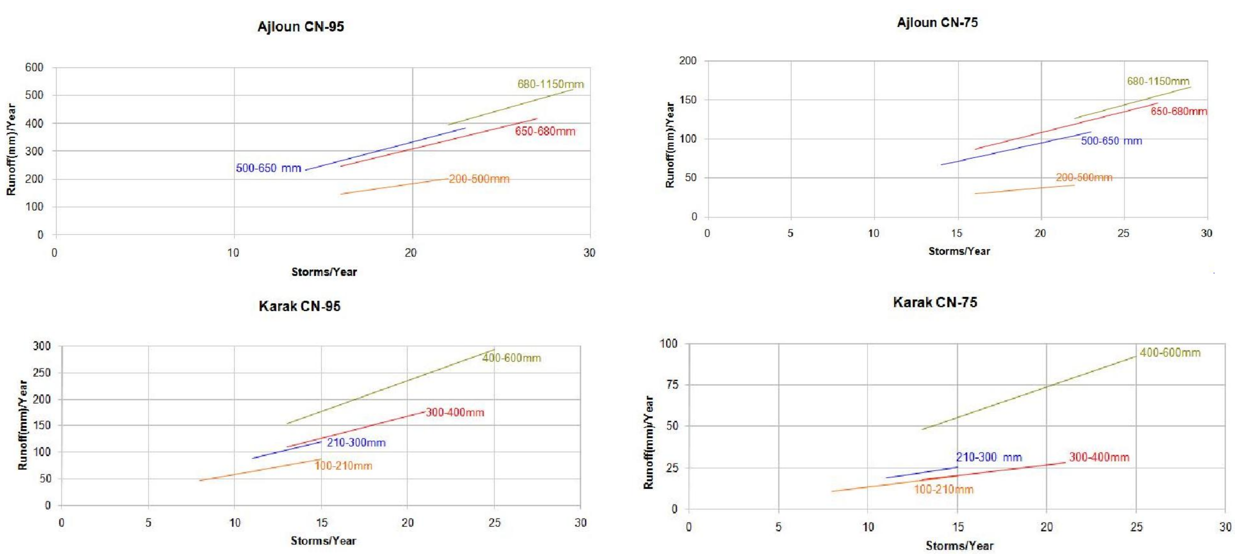

Figure 5: Annual Runoff vs. Annual Number of Storms at Different Ranges of Annual Rainfall.

III. DISCUSSION AND RECOMMENDATION

The selected nine rainfall stations are at seven major cities in Jordan, as shown in "Fig. 1". The major population intensities are in Amman and Zarqa and the rest divided into two parts one at north and the other at south. The intensity at north is higher than at south. The north cities are Ajloun and Jarash while the south cities are Karak, Shoubak, and Ma'an. These seven cities contain more than 85% of the Jordan population.

The data used is out of nine stations to represent mostly all different conditions of rainfall in Jordan from north to south. The area of relatively high rainfalls is presented by three stations, which are namely; Ajloun at north, Wadi Es-Sir and Sweilih at Amman in the middle of the country. The semi dry area is presented by four stations, which are one at north, one at middle and two at south. Jarash and Amman Airport are at north and middle, respectively, while Karak and Shoubak are at south. The dry area is presented by Zarqa at middle and Ma'an at south. The daily runoff should be used to generate the annual runoff out of storm-by-storm analysis but in this research the average annual runoff coefficients are developed for different curve numbers at all nine rainfall stations over Jordan, as shown in Table II. The runoff coefficients can be used for different surface or roof covers starting from paved roof down to permeable surfaces. This will help in estimating the runoff out of a certain type of surface using the average annual rainfall. As an example, the CN for commercial $100m^2$ paved roof located at Sweilih is 95, and by using the average annual rainfall of 485mm/yr for Sweilih the amount of annual runoff that can be harvested out of this roof will be about $21m^3$/year. On the other hand $0.21m^3$/year can be harvested from the same roof if it was located at Ma'an. This leads to unfeasible construction of rain water harvesting system at areas of low precipitation.

The runoff coefficient for paved roof is highly correlated to the average annual rainfall with correlation coefficient of 0.934. A power equation is developed to solve for the runoff coefficient for paved roof out of the average annual rainfall at the area with coefficient of determination at 0.960. The maximum error is not more than ± 25% with average error around ± 10%. The parameter of the equation is 1.932×10^{-3} and the power is 0.8866. "Fig. 6" shows the paved roofs runoff coefficients in relationship with the average annual rainfall at the major cities of Jordan.

TABLE II. RUNOFF COEFFICIENT ACCORDING TO STATIONS AT DIFFERENT CURVE NUMBERS

Station	Av Rainfall (mm/yr)	Runoff Coef*	Curve Number (CN)				
			95	90	85	80	75
Ajloun	625	0.500	0.496	0.334	0.244	0.185	0.143
Jarash	350	0.355	0.352	0.205	0.134	0.092	0.065
Zarqa	125	0.115	0.112	0.037	0.017	0.009	0.005
Amman Airport	240	0.240	0.238	0.115	0.067	0.043	0.029
Sweilih	485	0.430	0.427	0.268	0.184	0.132	0.097
Wadi Es-Sir	450	0.460	0.457	0.295	0.207	0.150	0.111
Karak	330	0.445	0.442	0.283	0.198	0.144	0.107
Shoubak	275	0.320	0.315	0.166	0.098	0.061	0.039
Ma'an	40	0.055	0.053	0.015	0.006	0.002	0.001

* Runoff coefficient for paved impermeable roofs (CN=98).

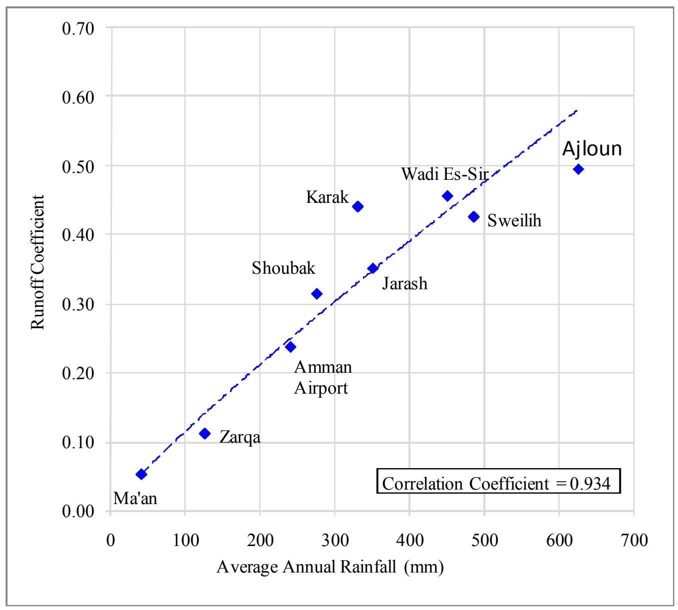

Figure 6: Runoff Coefficient vs. Average Annual Rainfall at Major Cities of Jordan.

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