

Urban Rainwater Harvesting: An Approach for Water Provision for Cities in Semi-Arid Regions: The Case of Um Uthaina Neighbourhood in Amman - Jordan

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Abstract

This study aims to investigate the feasibility of an urban water harvesting system at Um Uthaina neighborhood located in Amman city, the capital of Jordan in order to meet its future water demands and to reduce its increasing water costs due to the fact that Jordan is one of the most water-scarce countries in the world. The country's renewable water supply currently only meets about half of the population's water demands, with groundwater being used twice as quickly as it can be recharged. In order to accomplish this, different rainfall aspects were investigated and the potential runoff from the roofs and ground surfaces was calculated. This was done through calculating the precipitation concentration index (PCI) and the seasonality index (SI) in addition to the abstraction from the storm rainfall and the flood volume. The results show the amount of water that could be harvested in the study area and they reflect the high potential for rainwater harvesting application in Um Uthaina and other neighborhoods and districts in Amman city.

Keywords: rainwater harvesting, renewable water supply, rainfall, precipitation concentration index, seasonality index

1. Introduction

Jordan is one of the most water-scarce countries in the world. The country's renewable water supply currently only meets about half of the population's water demands, with groundwater being used twice as quickly as it can be recharged (Hadadin et al., 2013). The high rate of population growth and the influx of refugees due to regional conflicts put additional strain on an already diminished supply of safe drinking water. In addition, there is limited water for irrigation which is a central component for food production and economic growth. Sustainable and inclusive access to water is critical for the country's long-term stability and prosperity (Water Resources & Environment, USAID).

Rainwater harvesting is in general an old concept for collecting and storing rainwater for later use. It was used by the old civilizations for drinking water supply and for irrigation (Pereira, 1996; Oweis et al., 2001). Nevertheless, it is traditionally still in practice in some rural and urban parts worldwide. Recently, this technology has gained more interest as water conservation and management method (Pereira, 1996). Simplicity of installation (Prinz and Singh, 2000; Şen et al., 2011) and low maintenance and energy costs (Prinz and Singh, 2000; Şen et al., 2011; Van Steenberg et al., 2011) make rainwater harvesting systems attractive to be adopted in the urban and rural regions in the arid climate. Rainwater harvesting system in these regions could be an efficient tool for managing water shortage and mitigating drought (Pereira, 1996; Tabatabaee et al., 2010). The concept of rainwater harvesting (RWH) has been proven a promising potential alternative water source for domestic use in areas with scarce and/or contaminated water (Islam et al., 2010). It has also been shown that a significant percentage of the non-potable water needs of multifamily residential buildings, such as flushing toilets, irrigating gardens, and topping off air-conditioner, can be supplied with rooftop harvested runoff (Basinger et al., 2010).

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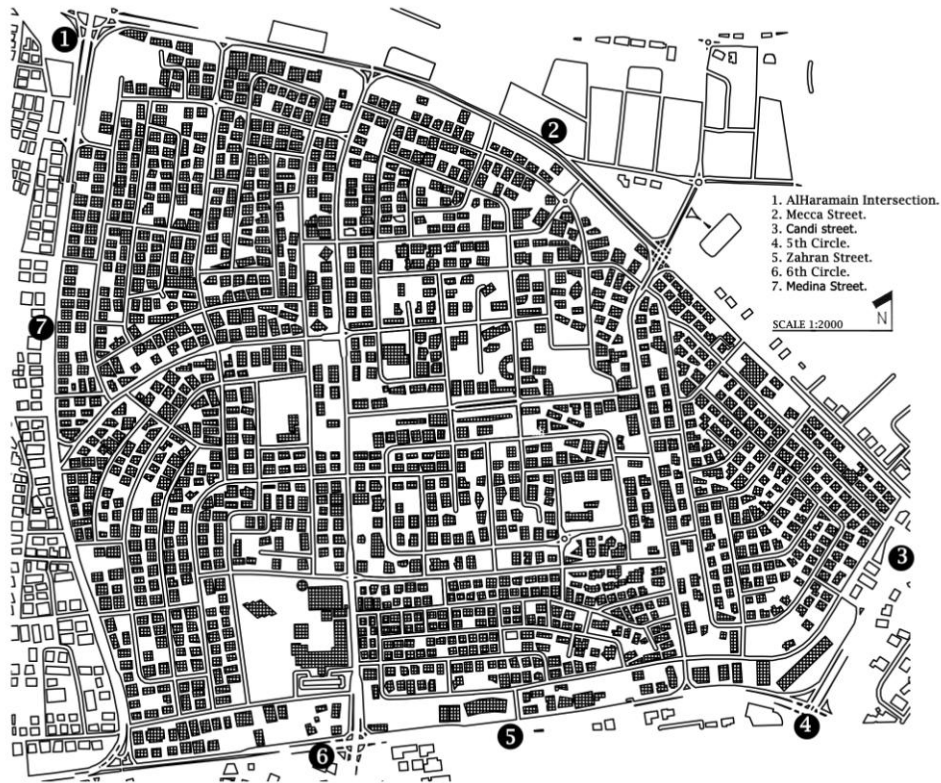
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In Barcelona, RWH has been imposed as a non-conventional water resource since a decade in a residential area; a single family house should install a 10 m³ storage capacity tank for toilet flushing and garden watering (Domènech et al., 2013). The same obligation is found in Jordan, where a potential of annual 15.5 million m³ rainwater (representing about 5.6% of the total household water supply of the year 2005 from groundwater) can be harvested from the roofs of the residential buildings (Abdulla & Al-Shareef, 2009). For a family of five members living in the semi arid rural of Brazil, a volume of 16 m³ of harvested water could meet the consumption demand for drinking and domestic use for about three quarter of a drought year (Gomes et al., 2012).

This study aims to investigate the feasibility of an urban water harvesting system at Um Uthaina to meet its future water demands and to reduce its increasing water costs.

2. Study Area

The study was conducted in Um Uthaina which is one of the neighborhoods of Zahran district located in the southwestern area of Amman city, the capital of Jordan. The area is surrounded by Mecca Street to the south and Zahran Street to the north and adjacent to the neighborhoods of Sweifieh and Abdoun. The average annual rainfall is about 464 mm. The average maximum temperature during summer is + 28°C while the average minimum temperature in winter is + 2°C.



Um Uthaina neighborhood

ethodology

To accomplish the objectives specified, it was necessary to obtain annual rainfall data and total area of building rooftops and streets in the study area.

In this study, different rainfall aspects were investigated, including variability, number of rain days, distribution over the season, probability of daily rainfall and maximum rainfall recorded in one day and deficit/surplus of rain through time. The precipitation concentration index (PCI) proposed by Oliver (1980), the seasonality index (SI) designed by Walsh and Lawler (1981) and the contribution index (CI) (Elagib and Abdu, 1997; Elagib & Elhag, 2011; Sulieman & Elagib, 2012) of daily, monthly and seasonal rainfall to the total amount of rain received per annum were used to assess the aspect of seasonality/irregular distribution of rainfall over the year. The PCI and SI are computed respectively as follows:

$$PCI = 100 \times \frac{12}{n} \times \frac{X_{n=1}}{X_{n=12}} \times \frac{R_2}{R_{12}} \quad (1)$$

$$SI = \frac{1}{R_{12}} \times \frac{12}{n} \times \frac{X_n}{R_{12}} \quad (2)$$

Where X_n = rainfall of month(n) and R = annual rainfall. The contribution index is evaluated as the daily, monthly or seasonal rainfall expressed as percentage from the total annual rainfall.

To calculate the potential runoff from a rainstorm, the rainfall–runoff Natural Resources Conservation Services (NRCS) equation was applied. The equation was developed in 1972 by the United States Department of Agriculture (USDA) and was previously known as the Soil Conservation Service (SCS) method for calculating direct runoff from rainstorm (Yevjevich, 1988; *National Engineering Handbook*, 2004). It is considered as a deterministic or a probabilistic model. The former is applied when a runoff depth is to be estimated from a certain storm event while the latter is applied to derive a flood with a specified return period from a design rainfall with similar return period (Hoesein et al., 1989). It excludes time as variable and ignores rainfall intensity (*National Engineering Handbook*, 2004) This makes the application of the method optimal for the study area since the rainfall data were available for this study only as daily rainfall time series. The model involves the relationship between the land cover, the hydrologic soil group (HSG) and the curve number (CN). High CN values indicate an impermeable soil class and consequently a higher runoff than infiltration:

$$Q = (P - I_a) \frac{2P - I_a + S}{2P + 0.8S} \quad (3)$$

Where Q is the runoff(mm), P is the rainfall(mm), S is the maximum retention after runoff has begun (mm) and I_a is the initial abstraction (mm) – normally taken as $0.2S$. S is given by the following equation

$$S = 25,400 \text{ CN} - 254 \quad (4)$$

The potential maximum retention following the onset of runoff is related to the soil and land use/vegetative cover characteristics of a watershed. It is a function of CN, and represents the runoff potential of the land cover/soil complex. CN values can be determined depending on the hydrological soil class A, B, C, or D, where A and D classes are the ones with maximum and minimum infiltration capacity, respectively (Table 1). By defining the soil group and the land cover, the values of the CN for the moderate soil antecedent moisture condition (AMC II) can be obtained from the table for the runoff curve numbers developed by soil consevtaion services in 1986 as provided by Chow et al. (1988). A weighted curve number (CN_w) was calculated considering the land-use categories of the study area as follow:

$$\text{CN}_w = \frac{\sum \text{CN}_i w_i}{100} \quad (5)$$

where CN_i is the weighted curve number of the individual land cover. According to Richard and Sorrell (2010), the application of NRCS method is limited by the basin area (maximum 2000 acre, i.e. 8 km²) (SCS, 1973), high rainfall depth, and low infiltration capacity. Although the method is suitable for ungauged watershed (Richard and Sorrell, 2010), the accuracy of the estimated runoff value is highly dependent on the CN value; therefore, CN values must be calculated using actual locally measured rainfall and runoff data of a watershed, especially for design purposes (Hoesein et al., 1989; Hawkins, 1993). The Rational Method (Wilson, 1990) was applied to calculate the potential runoff from the roofs and ground surfaces of the selected complexes as follows:

$$Q_v = C \times i \times A \quad (6)$$

where Q_v is the runoff volume (m³), C is the runoff coefficient, I is the rainfall (mm) and A is the catchment area (m²). In general, runoff coefficients for dry-land areas are in the range of (0.8–0.95).

Many factors control the rainfall–runoff relationships. Some relate to the meteorological characteristics (e.g. rainfall intensity, duration, evaporation, etc.) while others relate to the physical characteristics of the surface receiving the rainfall (e.g. imperviousness and slope). These factors contribute to the partial or complete absorption of the rainfall depth by the atmosphere, surface ground, or both. Runoff coefficients were developed to determine the runoff that could be generated from a specific rainfall depth. These coefficients represent the proportion of the rainfall depth to be deducted and considered as loss to runoff.

4. RESULTS AND DISCUSSION

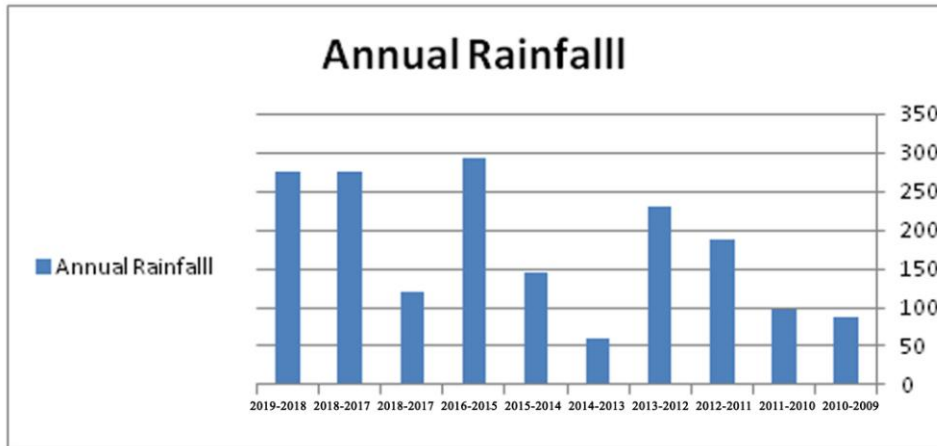


Fig .A. Annual rainfall period (2010-2019). (weatheronline.com)

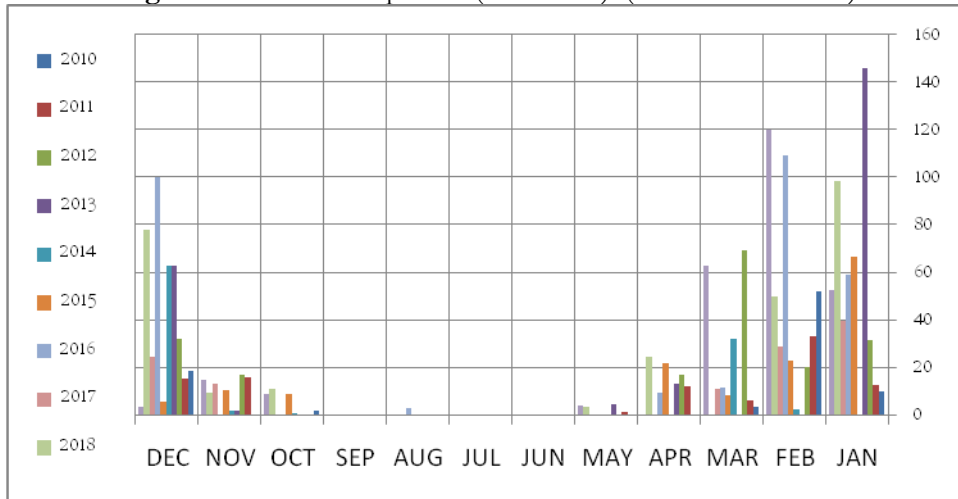


Fig .B. monthly rainfall during the period (2010-2019).(weatheronline.com)

Fig.A. shows that the rainfall in Amman is highly irregular through the last ten years, where the highest rainfall was recorded in 2016. Fig.B. shows the monthly rainfall in Amman, the highest rainfall was recorded during the three months of December, January and February.

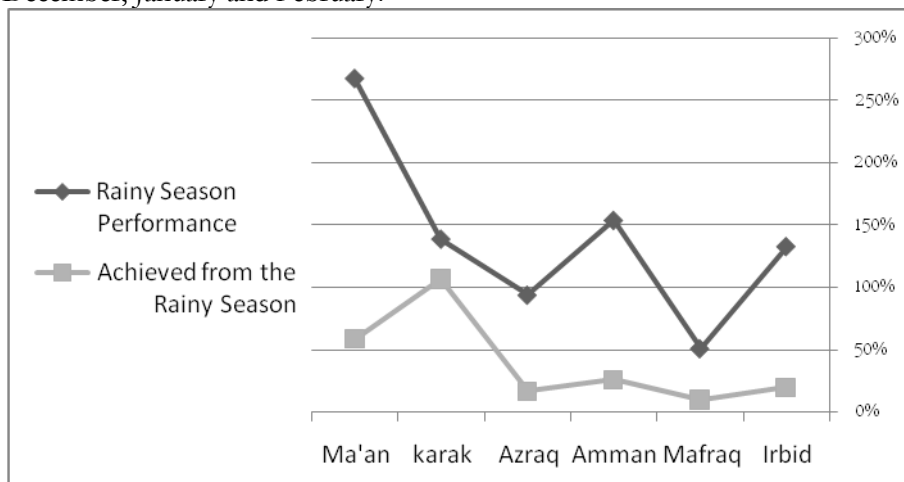


Fig .C. Rainy Season performance and what is achieved from the rainy season (2018-2019). (The Department of Meterology)

Fig.C. shows that the difference between the rainy season performance and what was achieved during the last season (2018-2019), As this difference represents the amount of wasted water that has not been utilized.

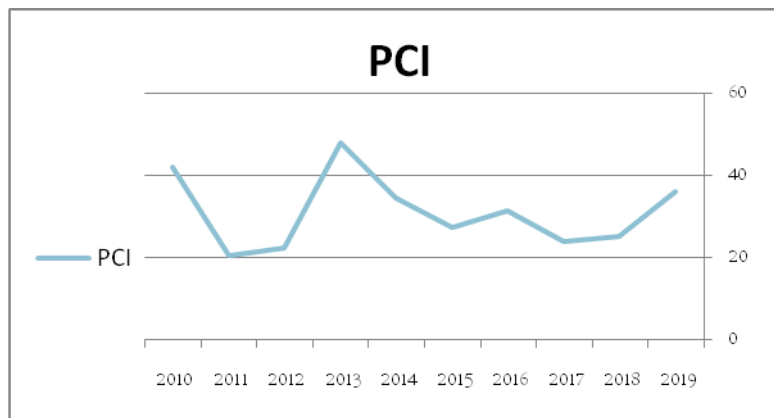


Fig .D. Rainfall seasonality and concentration using (D) precipitation concentration index.

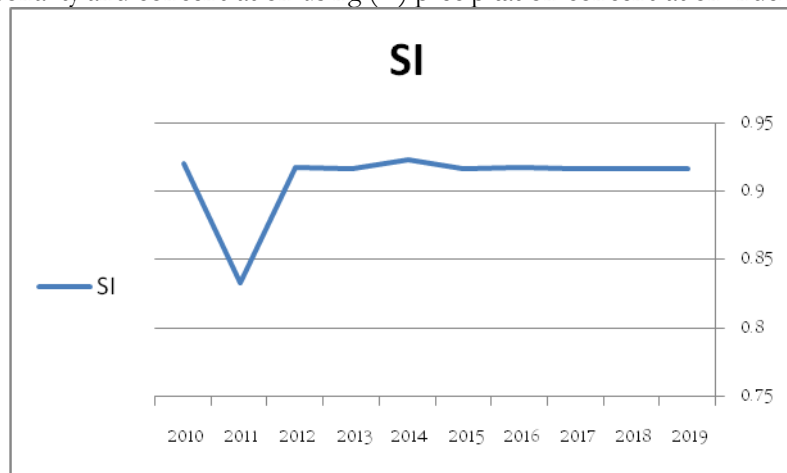


Fig.E. Seasonality index. Average percent contribution to annual rainfall.

Year	PCI	SI	CN	S	Ia	Q
2019	36.27721	0.916557	75	3	0.6	2.72
2018	25.1305	0.916666	75	3	0.6	2.72
2017	23.8469	0.916666	75	3	0.6	1.15
2016	31.458	0.91752	75	3	0.6	2.9
2015	27.2819	0.91666	75	3	0.6	1.4
2014	34.7622	0.922838	75	3	0.6	0.57
2013	48.11049	0.9164	75	3	0.6	2.26
2012	22.3391	0.91698	75	3	0.6	1.83
2011	20.5234	0.833333	75	3	0.6	0.96
2010	42.0782	0.919874	75	3	0.6	0.83
						Avg=1.736

Table.1. The abstraction from the storm rainfall and the flood volume.

Harvesting Area	Area (m ²)	The amount of water that could be harvested (m ³)
Buildings Rooftop	523126	218373.7
Streets	446340	619876.992
Total	969446	838250.692

Table.2. The amount of water that could be harvested.

The above calculations show that considerable water conservation gains are possible in Amman through rainfall-runoff water harvesting from building roofs and streets. Table. 2. indicates that the amount of rainwater that can be harvested from rooftops of houses in Um Uthaina with an approximate area of 523126 m² is 218373.7 m³. Furthermore, rainwater that can be harvested from streets with an approximate area of 446340 m² is 619876.992 m³. This reflects the high potential for rainwater harvesting application in Um Uthaina and other neighborhoods and districts in Amman city.

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