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# Urban Rainfall Harvesting to Alleviate Water Shortages and Combat Desertification in the Arid Land of Jordan

**Majed ABU-ZREIG*[1], Ayat HAZAYMEH[2]**

**Abstract:** Water harvesting can alleviate the chronic water supply shortages in Jordan, increase cropping land area, improve the livelihood of population and eventually combat desertification. A systematic study was undertaken to evaluate the use of rooftop rainfall harvesting in urban areas, study the socioeconomic value, determine the optimum rainfall collection tank volume and the potential contribution of rainfall harvesting to the national domestic water supply budget. The potential water supply volume from rooftop rainfall harvesting can reach 14.7 million $m^3$/year, comprising of about 6% of the domestic national water supply. Analysis of domestic water supply rate in relation to average rainfall depth and number of cisterns in each governorates indicated that the public water supply rate decreased in governorates with high rainfall depth and large number of cisterns. Cistern number among governorates increased with rainfall depth indicating a good adaptation behavior to water shortages. Optimum cistern volume charts were constructed for some governorates as a function of family consumption rate and house roof area. These charts can be used as tool to determine the optimum rainfall cistern volume as related to consumption rate and rooftop area. An immediate and nationwide awareness and legislative program is needed to spread rooftop rainfall harvesting among the whole population of Jordan and region with similar climates.

**Key Words:** Rooftop rainfall harvesting, Tank size and water supply

## 1. Introduction

The increasing need to provide potable water due to urbanization and population increase demanded development of nontraditional water resources for domestic uses. As such, rooftop and open yard rainfall harvesting is gaining a lot of interest recently not only in arid countries such as Jordan, Tunisia but also in humid countries like Germany, Japan, Sweden and Brazil to reduce urban runoff, improve water self dependent facilities and reduce the cost of water (Chisi, *et al*., 2007; Kahinda *et al*., 2007).

In arid climates rainfall harvesting can be the only sources of potable water in some cases. Until the development of well drilling and piping, which started in 1940 for wealthier families, the whole population of Jordan was totally dependent on rainfall harvesting for domestic uses (Nydahl, 2002). In 1991, the public water supply network has reached about 97% of households in Jordan due to intensified urbanization. While population increases, water demand also increases due to the increased standard of life style and the dependence on easy accessed water supply. However, the traditional in house rainfall harvesting systems became more and more ignored.

Very few studies have focused on rooftop and court yard rainfall harvesting systems (Abdullaa and Al-Shareef, 2009). But their study used was limited to technical aspects and used the average annual rainfall in each area and without considering the low-depth rainfall events that often produce no runoff. The objective of this paper is to analyze the current notions and practices of the Jordanian population to rooftop rainfall harvesting, estimate the potential resources from in-house rainfall harvesting at the national level, determine the optimum volume of rainfall harvesting tank in some areas and identify methodologies to reinitiate and promote rooftop rainfall harvesting among Jordanians.

## 2. Materials and Methods

Information about type and area of houses, main sources of drinking water and number of cisterns for each governorate in Jordan were collected from the Department of Statistics in Jordan (DOS, 2004). The average rainfall depth and water supply rate in various governorates was taken from the Meteorological Department and the Water Authority, respectively.

The potential volume of rainwater that can be collected from each governorate based on the average rainfall and the total roof of individual houses and apartment building were calculated. The potential volume of rooftop rainfall

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* Corresponding Author: majed@just.edu.jo
P.O.Box 3030, Irbid 22110, Jordan
1) Professor of Water Resources and Environmental Engineering, Civil Engineering Department, Jordan University of Science and Technology
2) Graduate Student ,Water and Environmental Engineering ,Civil Engineering Department, Jordan University of Science and Technology, Irbid, Jordan.

harvesting for the whole country is calculated simply by adding up the volume of water that can be collected in each governorate.

Rooftop rainfall volume *RRV* for each governorate can be calculated from the following equation

$$RRV = C \cdot Re \cdot A/1000 \qquad (1)$$

Where *RRV* is the annual roof rainwater volume that can be collected from each governorate ($m^3$), $R_e$ is the effective average annual rainfall (mm), ($R_e$ is equal to the annual rainfall excluding small rainfall events less than 2 mm that produce no runoff); *A* is the total roof area of individual house and apartment buildings in each governorate ($m^2$), *C* is the runoff coefficient; and 1000 is a conversion factor.

An appropriate runoff coefficient, *C*, must be determined. The runoff coefficient lump sums the proportion of losses and it depends not only on the type of roof but also on the amount of rainfall. Since almost all roof areas are made of concrete *C* was fixed at a value equal to 0.8. Many other researchers used a runoff coefficient of 0.8 for concrete roofs (Abdullah and Al-Shareef, 2009; Ghisi *et al*, 2006). However, Li *et al.* (2004) reported that the runoff coefficient of concrete surface varied from 46 to 70%. Nevertheless, a loss of 20% in rainfall and *C* value of 0.8 seemed to represent roof systems in Jordan.

## 3. Results and Discussion

### 3.1 Sizing of rainwater collection tank

The high cost of rooftop rainfall harvesting systems comes mainly from the cost of collection tanks or cisterns. The most common types of tanks in Jordan are made of reinforced concrete. Therefore, an attempt was made to determine the cost of reinforced concrete tanks based on the market prices of concrete, steel and labor. The result of this analysis is shown in **Figure 1** at which the tank cost was shown as a function of volume and water depth. As shown in the figure, the cost increases with volume in nonlinear fashion and also with water depth. It seemed that 3 to 3.5 tank depth is practical and results in the lowest cost. As the cost increases with volume, one should determine the optimum volume that can satisfy this need.

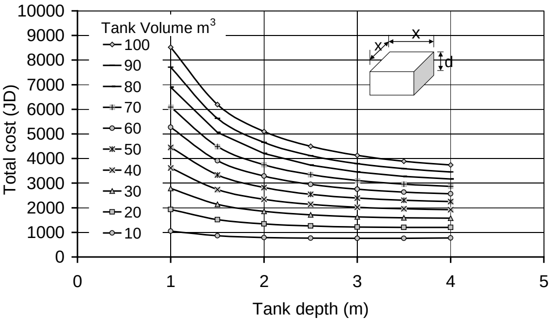

**Fig. 1. Relationship between the cost, volume and depth of square reinforced concrete tank.**

Therefore, many efforts have been made to design an optimum tank size that can accommodate supply and demand with cost (Anonymous, 2001)

Several methods were used to estimate the required storage tank capacity that varies in their complexity. One of these methods depends on the demand of households. The tank volume is simply equal to the cumulative demand volume needed by a household in a given period of time. This method is suitable in high rainfall regions where rainfall is not a limiting factor. The other method depends on the supply side, which in turn depends on the volume of rainfall that can be collected from a specific area in a specific period of time. This method is used in arid and semi-arid regions where rainfall depth is the limiting factor. The tank volume calculated from rainfall and rooftop area during period of time represents the maximum tank volume possible for that case.

However, the optimum, tank volume depends on the supply or rainfall volume rate and demand, the consumption rate. Mass curve analysis can be used to calculate the optimum size of a tank for a supply and demand series with either graphical or analytical techniques. The amount of storage that must be provided is a function of the expected inflow, supply, to the tank and outflow, demand, from the tank. Mathematically, this may be stated as follows:

$$\Delta S = O\text{-}I \qquad (2)$$

Where $\Delta S$: change in storage volume during a specified time interval; *I*: total inflow volume during this period; *O*: total outflow volume during this period. The cumulative deficiency between outflow and inflow (*O-I*) is calculated over a preselected time series. The maximum cumulative value would be the required storage to mach supply with demand in that specific period.

Thirty years of monthly rainfall data, from 1976 to 2005, were used to determine the optimum rainwater tank volume for Irbid governorate. However, this volume should not exceed the maximum total volume of rainfall that could be collected from a given roof or yard area. The optimum tank volume for various combinations of roof area and demand rate was calculated for each Irbid governorate and the result is shown in **Figure 2**. The maximum tank volumes that should not be exceeded, based on rainfall supply volume, are also shown in the figures. Using such figures, one can determine the optimum tank volume that would probably meet the demand rate for the wet 8 months for a given rooftop area. The Figure also shows clearly the influence of demand rate and rainfall volume and pattern in Irbid governorate. Tank volume increases with an increase in the demand rate and rainfall depth.

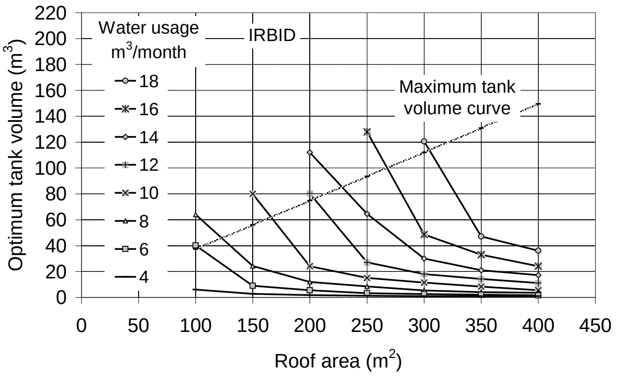

**Fig. 2. The optimum tank volume in relation to rooftop area and water usage; Irbid governorate.**

The optimum tank volume charts are being constructed for the whole of Jordan and on finer grid to cover various parts in each governorate. As an Example the rainfall depth and pattern in Mafraq governorate varied widely from about 200 mm to as low as 50 mm per year and calculating the tank volume based on the average rainfall depth results in large error. Therefore, the Government of Jordan should adopt a systematic program to promote rainfall harvesting and publish design pamphlets to be used by local people and contractors.

Rooftop rainfall harvesting is being practiced widely in Irbid and the number of cisterns is about 27 000 which is far higher than any other governorate. This is followed by Ajloun, 2650 and Amman with only 600 cisterns as shown in **Table 2**. This seemed to be illogical since Amman should have much higher number of cisterns due to its high population density and high living standards compared to other governorates that can afford the cost of rainfall harvesting system. However, the public water network in Amman covers most of the population and is the most reliable among all other water networks in Jordan. Therefore, residents of Amman feel safe in terms of water supply and lack the motivation to build an in-house rainfall collection system. Immense awareness and legislative efforts should be made to promote in-house rainfall harvesting systems among the population of Jordan in general and Amman residents in particular.

### 3.2 Potential water supply from rooftop rainfall harvesting

The national total water supply from rooftop rainfall harvesting can be estimated from the total areas of houses, villas and apartment buildings and the average effective rainfall over each governorate and a runoff coefficient of 0.8. The potential rooftop water harvesting for Jordan is about 14.8 million cubic meters comprising about 6% of the total domestic water supply in Jordan (**Table 1**). About 64% of the rainwater is collected from the Amman and Irbid governorates due to their high population, housing density and high rainfall depth. All other governorates contribute about 35% of the total harvested rain. Therefore, efforts should focus on Irbid and Amman residents to promote in-house rainfall harvesting.

**Table 1. Potential volume of harvested water in the twelve governorates of Jordan.**

| Governorate | Total area ($m^2$) | Average rainfall (mm) | Effective+ rainfall (mm) | Potential runoff++ harvested ($m^3$) |
|---|---|---|---|---|
| Amman | 17672244 | 490 | 441 | 6,234,768 |
| Irbid | 11018556 | 411 | 370 | 3,260,611 |
| Mafraq | 3725944 | 169 | 152 | 453,373 |
| Ajloun | 1343588 | 645 | 581 | 623,962 |
| Jerash | 1796600 | 352 | 317 | 455,330 |
| Zarqa | 5907619 | 136 | 122 | 578,474 |
| Balqa | 3784513 | 624 | 562 | 1,700,306 |
| Madaba | 1572025 | 339 | 305 | 383,700 |
| Karak | 3045775 | 359 | 323 | 787,272 |
| Tafileh | 971713 | 270 | 243 | 188,901 |
| Ma'an | 1297056 | 43 | 39 | 40,157 |
| Aqaba | 883681 | 35 | 32 | 22,269 |
| TOTAL | | | | 14,729,122 |

+ Rainfall events of depth<5 mm were not included. ++ Runoff harvested = Total area ($m^2$)*Effective rainfall (m) * 0.8

**Table 2. Summary of cisterns, consumption rate and average rainfall for Jordanian governorates.**

| Governorate | Number of cistern | Water supply rate (l/c-d) | Average rainfall (mm) |
|---|---|---|---|
| Amman | 612 | 163 | 480 |
| Irbid | 26941 | 97 | 427 |
| Mafraq | 136 | 187 | 161 |
| Ajloun | 2641 | 71 | 582 |
| Jerash | 802 | 76 | 436 |
| Zarqa | 242 | 133 | 144 |
| Balqa | 1538 | 155 | 530 |
| Madaba | 69 | 127 | 320 |
| Karak | 162 | 148 | 350 |
| Tafileh | 14 | 112 | 242 |
| Ma'an | 47 | 208 | 42 |
| Aqaba | 25 | 228 | 32 |
| TOTAL | 33229 | | |

Analysis of the relationship among number of cisterns, public water supply rate and average rainfall in each governorate, shown in **Table 2**, gives an insight on the population behavior and management actions of the water sector in Jordan. Analysis may clarify the reason of decreasing water supply rate for governorates with high rainfall depth. Water supply rates for governorates seemed to

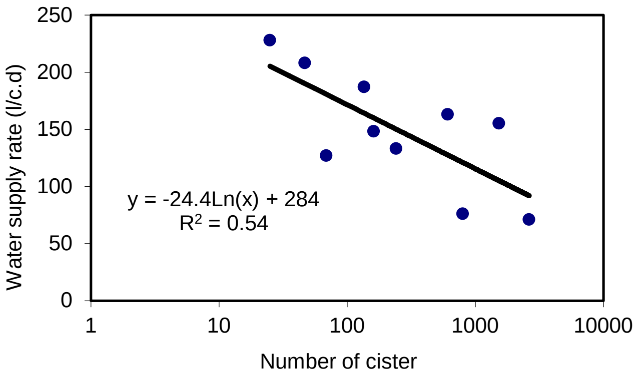

**Fig. 3. Relationship between average public water supply and number of cisterns for Jordanian governorates.**

decrease with the number for cisterns logarithmically as shown in **Figure 3** reflecting the conception of government dependence on cisterns as a source of domestic water supply for the population. This may also be affected by population behavior towards water needs. A population with cisterns may feel more secure and less dependent on public water supply thus reducing people's demands for more water supplies. This result showed clearly that spreading and renewing the culture of rainfall harvesting among the population of Jordan will ultimately reduce the need for additional domestic water supplies in the whole country.

The number of cisterns increased with average rainfall depth in the Jordanian governorates. The population seemed to evaluate the economical efficiency of rooftop rainfall harvesting internally and therefore respond in building more cistern in high rainfall areas compared to low rainfall areas. The authors believe that governments should invest urgently into more awareness, legislative and financial and technical support programs to spread rooftop rainfall harvesting among Jordan population and that the population of Jordan will respond positively.

## 4. Conclusion

This research has shown the importance of rooftop rainfall harvesting and analyzes the needs to adopt an integrated approach to spread its use at the national level. Rooftop rainfall volume can increase domestic water supply by about 14.7 $m^3$/year comprising 6% of the domestic national water supply. Analysis of the number of cisterns, rainfall depth and public water supply among governorates have shown that people have developed adaptation behavior and self-reliance for water supply as the public water supply seemed to decrease in high rainfall governorates having a high number of cisterns. Water managers also seemed to rely on population judgment to secure their own water supply as they decrease the supply rate for governorates of high rainfall and high number of cisterns.

A technical chart to determine the optimum size of rainfall harvesting tank has been developed for various governorates. Such charts will help people to build the most economical water harvesting tank that satisfy the needs for their house. Under the current water crises, the government of Jordan should move ahead with intensive awareness, financial, and technical programs to spread the use of rooftop rainfall harvesting in the country.

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