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Rainwater harvesting in North Africa: A novel method for reservoir sizing

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Abstract

In North Africa water is becoming a scarce resource, fragile and unevenly distributed across different areas. Because of economic and human growth considerations, water demand is continuously increasing. Johns Hopkins University, USA, states that in 2025 the annual quantity of water per person in Algeria will be less than 500 m^3; hence the need to seek new resources to substitute or complement existing ones. Unconventional resources are positioned well as possible solutions. These include groundwater recharge, desalination of seawater, water recycling, reuse of treated wastewater, and rainwater harvesting. Rainwater harvesting is an old method used almost anywhere in the world. The main drawback of this method is the calculation of the reservoir volume, which is approximate at best. This article presents a novel approach for the estimation of required reservoir volume as a function of roof surface area, number of household inhabitants, and rainfall distribution.

Keywords: rainwater harvesting, unconventional resources, water scarcity, Souk-Ahras,

Introduction

Rainwater harvesting is an old method used almost anywhere in the world. It is applied in a traditional way in some parts of Algeria. It attracts more and more attention in several countries as an excellent practice of sustainable water management. In most cases rainwater is stored in à reservoir or a tank constructed using various materials such as concrete, polypropylene, polyethylene, fiberglass, or metal.

Current approach to sizing storage reservoir uses one of two methods (Sprouse (2005); Baillieux et al (2004); Krishna (2003), and the Texas Water Development Board (2005)). The first method is simple and produces a rough estimate of the tank. This method is popular among professionals and consists of sizing a reservoir to cover household needs during a full season; that is to say, a quarter of the year. The following equation estimates the volume of the tank that covers the needs of R day of the year

$$V = A \times P \times C \times \frac{R}{365}$$

where V: is the volume of the tank; A: horizontal projected surface area of the collection roof; P: mean annual rainfall precipitation depth; C: runoff coefficient, and R the number of days the reservoir is supposed to cover the household occupants water needs. For R = 120 days, the reservoir should cover the needs for one third of the year. This approach produces an expensive system because of the large storage volume it produces.

The second method uses monthly water balance. The collected water volume over a month is added and water used is subtracted from the previous balance of the tank. Here, water demand per capita is assumed. In this study water demand per capita is assumed to be between 100 to 150 l/p/d.

Both two methods have some shortcomings including:

- They don't take into consideration the cost aspect. Indeed, water price and rainwater harvesting system cost are inversely proportional. The lower the tap water price the higher resulting long term cost of rainwater harvesting system.
- Rainfall distribution over time impact availability of rainwater for storage and therefore its use. Longer dry periods over the year favor the design of larger reservoirs. On the other hand, short dry periods favor smaller reservoirs.

Most rainwater harvesting system design is governed by the traditional and approximate Texas method (Texas Water Development Board, 2004).

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Data

The aim of this work is to present a new design method that addresses the previous shortcomings by taking into consideration the followings:

- Analyze the way rainwater is both stored and used over a long period of time.
- Propose a new method, which calculates the optimal volume of the storage tank based on actual rain and demand.
- Develop a graphical method that is direct and easy to use. This method is particularly applicable to North African conditions.

To illustrate the approach, the case of "Quouicem" urban neighborhood, Souk-Ahras, northeast of Algeria, is illustrated. The latter includes 240 houses, with roofs of up to 200 m^2 in area. The analysis takes into account water losses though evaporation and leaks from the transport and distribution systems. We used different rainfall series of the study areas: Sfax, east of Tunisia, Tebessa and Souk-Ahras east and north-east of Algeria, respectively. The rainfall record extends over a ten-year period from September 1969 to August 1979. The annual precipitation in the study areas varies between 216 and 500 mm/year. The authors believe that the rainfall distribution in the study area is representative of both rainfall variability and rainfall volume observed in east North Africa.

Results and discussion

The new method presented in this paper provides solutions to the limitations of existing methods. It uses the daily balance (Figure 1) of water use per dwelling. It also uses the total cost during the life cycle of the structure using the life cycle analysis approach as shown in Figure 2 (Guebail and Djebbar, 2008). Our approach will be illustrated using practical graphs, which are developed with a set of computer programs.

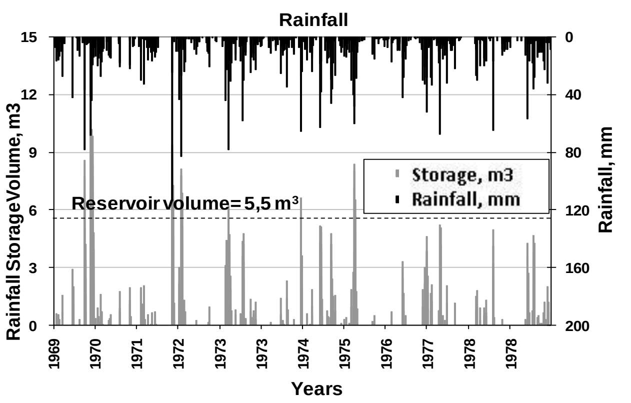

Figure 1: Water volume in the reservoir using 11-year rainfall record (1969 - 1979) Sfax region, collection foof of 100m² for 7 persons.

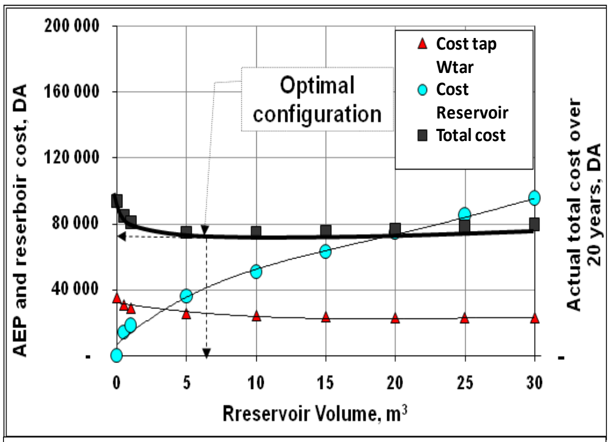

Figure 2 : Variation of reservoir+Tap water cost with the volume of reservoir, Sfax region, dwelling of 100m² and 7 inhabitants.

It is a well entrenched belief that it is necessary to use larger tanks to substantially increase the duration of coverage during which stored rainwater rather than tap water is used. This is generally not true due to the nature of precipitation and its variation in time. In addition, economic considerations do not justify such large expenditure related to the construction of large reservoir, especially where water prices are heavily subsidized by the state. This problem has not been reported in previous studies. Indeed, there is not always a solution, i.e., a reasonable reservoir volume, for any desired coverage period.

To calculate the costs associated with rainwater harvesting system, we used two variants. In the first, we used the administrative water price of 0.26€/m^3 as applied by "Algérienne des Eaux" (ADE), the Algerian public organism responsible for water distribution. In the second variant we used the real actual cost of water which is estimated by Bukhari et al (2008) to be 1.25€/m^3. We used a conversion factor of 100 DA to 1€. It was assumed, all along in this study, that people continue to use, at all conditions, tap water for drinking purposes, which is estimated to be 5 l/p/d. The remaining water needs will be covered by stored rainwater if available, otherwise tap water will be used. To find the optimal volume of the tank, the method of net present value (NPV) as shown in Figure 2 is used (Djebbar and Kadota, 1998). The result of this analysis is shown in Table 1.

This simple exercise doesn't include the saved cost of postponing resource and infrastructure upgrades in the system resulting from increased demand; since water harvesting reduces the demand by more than 35% as will be shown.

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It is obvious that with the administered water price of 0.26€/m^3, rainwater harvesting system cannot be economical at the user level. One of the two following options may be adopted:

- Increase water prices
- Design economic incentives, which will pay for the whole or part of the rainwater harvesting system.

Table 1 : Comparison between the NPV of different systems with the indicated water prices

Designation	Tap water, €	Reservoir, €	Total, €
Tap water at 0.26€/m^3	580	0	580
Tap water at 1.25€/m^3 without reservoir	2 786	0	2 786
Tap water at 1.25€/m^3 with reservoir	2 068	624	2 690

Increasing water prices at a level where these systems become economical may not be a popular or socially accepted solution, at least at this stage. Therefore a combination of the two options is the best solution.
Incentive mechanisms that motivate individuals to adopt rainwater harvesting systems should be designed. For example, in Belgium, rainwater tanks have become mandatory for new buildings. In Texas, USA, legislative means along with some taxes exemptions are put in place to encourage the construction of rainwater harvesting systems.

Algeria needs sustainable solutions to address the alarming future scenarios of water availability. It is time, and even urgent, to consider objective measures to finance rainwater harvesting systems.
The proposed method is more exact and more convenient compared to traditional ones. Figure 3 shows a comparison between the proposed method and the traditional ones. With the new method a large reduction (50%) in reservoir volume required is obtained. The extra volume proposed by the traditional method will not be used by the hypothetical house for which it has been calculated.
Based on the previous results a series of simulations have been conducted using scenarios of different roof collection surface areas, number of inhabitants, and regions. Exemple of the result of the optimization exercise is shown in figures 4.

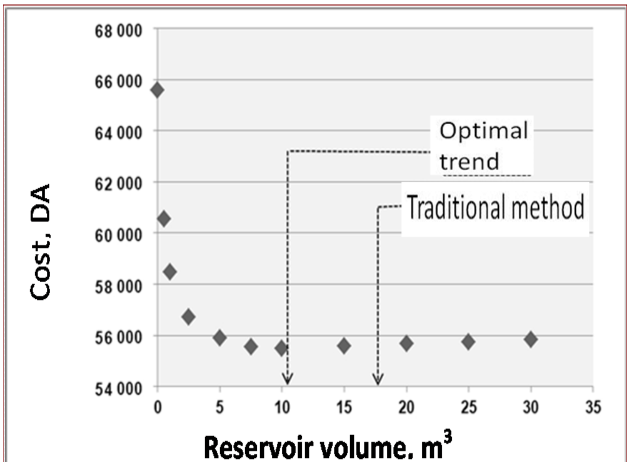

Figure 3: Typical representation of optimal tendency of NPV using water real cost (case of Souk-Ahras, 100m², 7 persons).

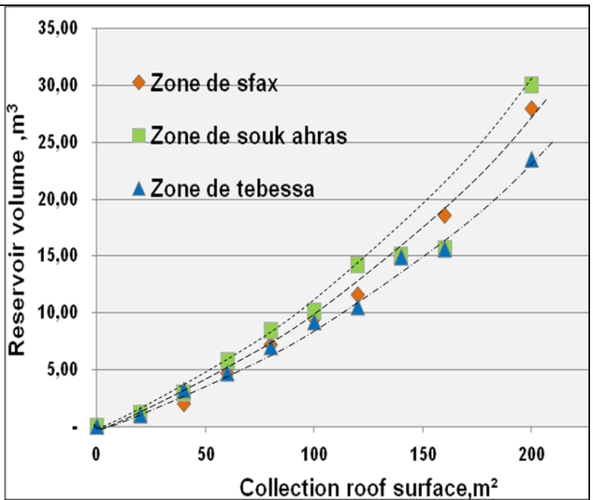

Figure 4: Graphical representation showing reservoir volume as a fu of surface area and region for a 7 inhabitants dwelling.

This graphic representation of the results enables the designer to rapidly estimate the reservoir volume for the specified conditions, number of inhabitants, collection roof surface area, and the region.

Finally, and based on the results of Figure 5, rainwater harvesting system in the case of Quouicem neighborhood (240 houses) reveals very interesting and ecological results.

The 240 houses can collect and use about 10 000 m^3 of rainwater. If this volume is supplied by ADE, the latter would have produced an extra 4 000m^3 of water to be lost through leakage, and another 10 000 m^3 of extra water for evaporation.

Therefore, rainwater harvesting system would save more than 20 000 m^3 (tap water, leak, and evaporation), which could be used to cover other needs, such as irrigation.

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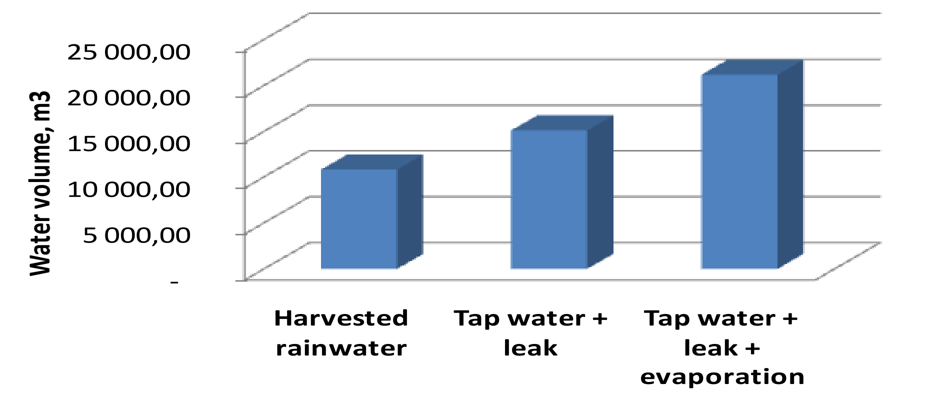

Figure 5 : Comparison of harvested water volume as compared to related equivalent tap water, leak, and evaporation four 240 dwelling unit 100 m² in average and 7 inhabitants each, Souk-Ahras region.

Conclusion

This paper presents a new method for designing the reservoir of rainwater harvesting system. It yields a system that is cheaper and specific to the study area conditions. It produces the optimum tank volume with the minimum cost. It has been shown that for the conditions of Souk-Ahras, this method produces the followings:

- A savings of more than 30% on total real cost of water.
- A savings of 50% on water volume at source.
- In addition to other benefits such as a flood control and impact reduction mean, environmental stewardship, this method is an excellent solution to the water availability problem in Algeria.

In order to introduce and generalize the use of rainwater harvesting in Algeria it is necessary to support this action through law enforcement and financial incentives or supports.

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