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Investigations of Rainwater Harvesting System From Rooftop Catchment (Case study: Babolrood Catchment)

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Abstract

Unfortunately, in Iran and other countries in the Middle East region, water becomes scarcer than ever before, and over the last decades, the demand for domestic water has increased due to population and economic growth. Although rainwater harvesting is considered to be a safe and reliable alternative source for domestic water, the inconvenience or impracticalities related to the cost and space needed for the construction of ground or underground storage tanks makes this practice not widely common in rural areas and rarely implemented in urban cities. This paper introduces a new technique to rainwater harvesting which can be easily used in both rural and urban areas; it collects and stores rainwater directly from rooftop catchments and not necessarily in the special ground or underground ones. This system was examined in one of villa garden of Mazandaran province (Babolrood catchment) to provide the irrigation water for one-hectare citruses garden, this villa garden has one two-story building that the second floor is to settlement and the first floor is a water storage with 100 m3 capacity that each time 26 m3 and during the year 52 m3 water is stored and transfers from storage to pool of gathering water and then it is transferred by Hydration pipes through gravity as drip irrigation to the foot of the trees and consuming water has been estimated for each hectare to irrigate 19 m3, and in a normal water year 3-5 years old trees need 2-3 irrigation that mostly is 50-57 m3 water. Therefore harvesting water is a suitable method to meet water of one-hectare citrus grove by floor insulation levels, and also it needs 4-5 irrigation courses in the drought times. We usually encounter to drought period every ten years, we need to advance the floor insulation levels and if the area of the garden is increased we must increase our floor insulation levels. If widely adopted in Iran Particularly in Mazandaran province, this technique could help in: (1) collecting around 70 % of the current deficit in the domestic water supply) of rainwater (2) saving around 7 % of the amount of electric energy usually needed to pump water from an aquifer well and ground or underground tank, and (3) considerably reducing the rate of surface runoff of rainwater at the hill area where rainwater is not captured at all and ultimately goes to the sea.

Keywords: *Rooftop catchment, Garden citruses irrigation, Rainwater harvesting system, Villa gardens, Babolrood catchment.*

1- Introduction

Since human being lives in arid and semi-arid and cultivates the agricultural crops, he has been used a water harvesting system. Thousands of years ago people of arid and semi-arid had used water of temporary rivers that caused the establishment of towns in desert areas (Khalili, 1992).

The water harvesting system most probably was used for once in million hectares of lands in arid areas of the world for various reasons. Due to technical development in Europe since 1850, more areas were under classic irrigation methods and less traditional irrigation and small-scale irrigation. So water harvesting systems are used in arid and semi-arid regions, where there is not enough rainfall and rainfall is irregular and there is a very high-risk agricultural product, water harvesting technique can significantly increase crop production in arid areas by focusing rainwater, on the other hand, runoff in a part of the total basin area.

Harvesting water is practically based on local precipitation and using surface runoff, so it needs runoff and a place where water can be stored. Basically, the water is being used it is prepared from the rainwater harvesting in small areas from the same place as the method of roof surfaces, but the water of flooding recovery methods is provided from basins outside the area such as floodwater spreading projects in a place and small-scale, generally. This paper attempts to identify methods of water harvesting to use in the arid and semiarid areas (Sepaskhah, 1992).

In regions with an annual rainfall of 100 to 700 mm, low-cost method of extracting water will have a significant capable of producing runoff. If another source of irrigation water is not readily available or is too expensive, this method can provide suitable water for daily use, plants and animals. At least rainfall for water harvesting should be at least 200 mm per year in areas with summer precipitation. In areas with more rainfall from 600 to 700 mm per year, the season of producing crops can be prolonged with harvesting water. Compared to pump water, recovered water preserves energy and the value of water.Of course, this is reversed with the uncertainty of rainfall, but this problem can be partially adjusted by temporary storage of rainwater in tanks (reservoirs, small reservoirs, etc.) by calculating the probability of precipitation and runoff (Khalili, 1992).

Water scare city is a global problem. Not only 30 Asian countries and African are involved in drastically reducing the water resources, but also countries like the United States, Belgium, Singapore and Netherland (poster, 1992) have encountered with water shortage. Today, 26 countries which totally have a population of about 230 million people are among the arid areas. In the plateau of Iran, a lot of droughts that occurred in people's lives have left painful traces, especially in the past times. Based on famines that occurred in Iran in the 1860s and 1880s and by comparing the situation in Iran with India Andre Ace and Ashtoulz (1885) concluded that drought is renewed once at any period of 10 to 11-year. Meanwhile, this eleven-year period is also matched with the eclipse. Also, Bruckner has concluded that every 35 years the Iranian plateau climate bears some changes. This 35-year-old alternation has been recorded as Bruckner in the Meteorological literature.

1. Materials and Methods

2-1 Study area

The study area is located in Babol rood catchment and in the central part of Mazandaran province. Overall, the study area has a temperate and wet climate and general characteristics of the project area are as follows, Figure (1-1) shows a part of the villa and roof surfaces rainwater harvesting.

- **The physio-topography of the area:**

The average height of the project site is located between 650-1300 m above sea level. The slopes of the hill (steeps) are between 20% - 40%.

- **The soil of the region:**

The area is mostly hilly and has deep to semi-deep soils are formed from a type of Randzine or brown limestone soil. The direction of the slope the dominant slope direction of the project site is in north and northwest.

- **Economic and social position:**

The six villages with an average population of 46,000 people are located in the project site that mainly has a villa.

- **Weather and climate:**

The mean of annual temperature is17 ° C and mean annual rainfall is 840 mm and the distribution of precipitation is 28% in autumn, 38% in winter, 19% in the spring and 15% in summer. The Potential of annual average evapotranspiration is 702 mm; relative humidity has been measured maximally 82.4%, in average 73.3% and at least 64.9%.

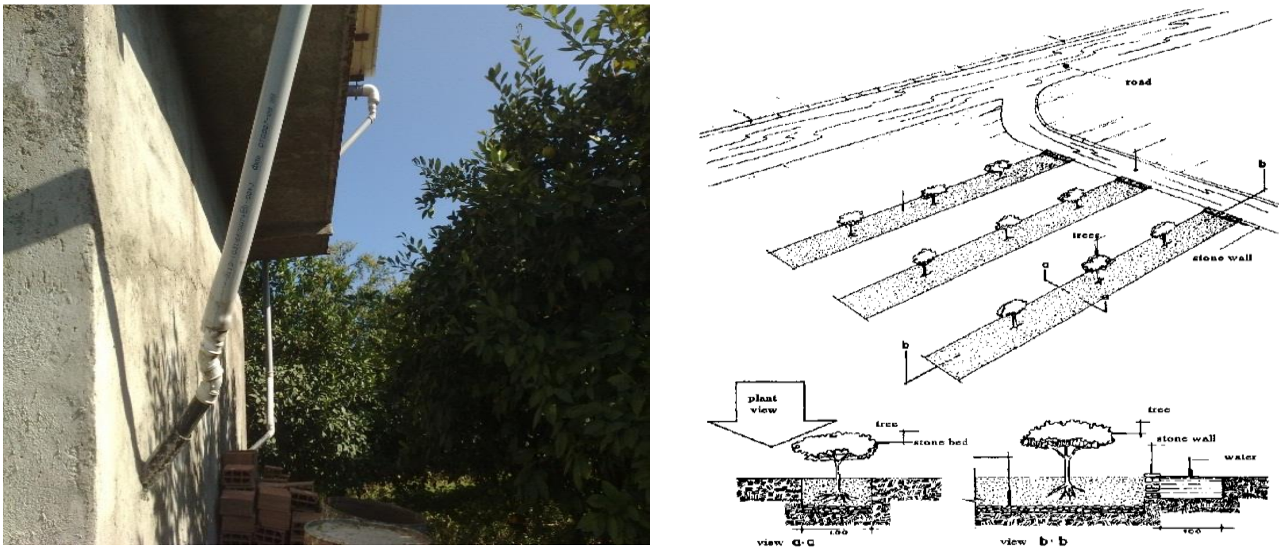

Fig. 1. It shows a part of rainwater roof top system and villas in the foothills land in the study area.

2-2 Definitions:

In general it has been offered multiple and different definitions for water harvesting by experts, term water harvesting for the first time is used by (Geddes, 1963) and (Nessler& Evenarim, 1986), so it emphasizes that the term water harvesting cannot be limited to certain specific types of surface runoff and aim. Therefore it seems due to great controversy in defining water harvesting, we cannot offer a general definition for this term that can include all different aspects of water harvesting about collecting, storing and using water harvested. Undoubtedly, it is necessary to consider specific definitions for water harvesting that it depends on the origins of surface runoff and how it has been produced.

Pacey and Callis (1986) offered an especial definition through water harvesting limited to collect rainfall and their runoffs by establishing small pond that rainfalls are gathered in them directly (Gholami, 2000). Therefore accordingly definition of rainfall is collecting and storage rainfall in ponds to supply water for different consumption.

By providing a similar definition F.A.O (1987) has considered harvesting water as a method to supply and conserve water in the pond of gathering rainfalls and in the first steps of forming surface runoff. In some definition provided for water harvesting, controlling, collection and water storage using a variety of pond levels have been proposed for harvesting rainwater, runoff and harsh waters and floods as water harvested (Bruins, & Haefner, 1986).

Geddes (1963) assert that surface runoff as key in water harvesting and other factors included in the definition, such as the origin of surface runoff, the formation of these runoffs and the way of using water harvested and method of collecting and water storage are considered the main factors. So words like, "rainwater harvesting", "rainfall collection", "the flood"," harvesting fog and dew", "collection of surface runoff in the early stages of formation", and finally "total small ice and snow " are basically hydrological terms in the form of water harvesting word.

2-3 Introducing and select the type of rain aggregator system:

Rain Water Harvesting is applicable even in areas with average annual precipitation only 50 to 80 mm. it seems as the lowest amount of rainfall but in a watershed in Israel, only 24 mm annual rainfall could be produced a useful runoff (Mahdavi, 1992). There are many examples are available among the different methods used in making plans for collecting rain, (Mahdavi, 1992). Common methods for collecting rain in the watershed are following as:

- **Collecting rainfall by the way of changing the land surface.**

These systems are simple. In some cases just need to make streams with rock walls along the contours of the hills to collect and transfer runoff. For improving to transfer of surface runoffs between rivers or the contour line, we can implement several operations such as a) removing the surface, b) using vegetation and c) using mechanical operation.

- **collect rainfall by the method, "adding chemicals to the soil surface :"**

Sometimes due to good soil conditions and the presence of chemical facilities, this method will be affordable. The system is tried to decrease soil permeability so that the maximum surface runoff flows. Soil permeability can be made by spreading soil colloid with hydrophobicity (water repellency) treatment, or both together (Valentien, J.F.1967).

- **collecting rainfall through method, "the soil covering system:"**

In this system, some materials can be used to prevent water from reaching the soil or to form a non-permeable layer. In fact, there is as a thick or thin layer on the soil surface that collects rainwater and lead to the pre-designed point. They are facilities such as; bitumen coating, making the concrete surface, plastic, putting fiberglass and nylon plate (Sepaskhah, 1992).

- **collect rainfall by the insulation plates system:**

Constructing the insulation system is very simple and does not require high cost; they are categorized into two systems: (a) the roof insulation level system of buildings and plants, (b) The insulation level system of land surface, the first one is used in the present study (Figure 1-2).

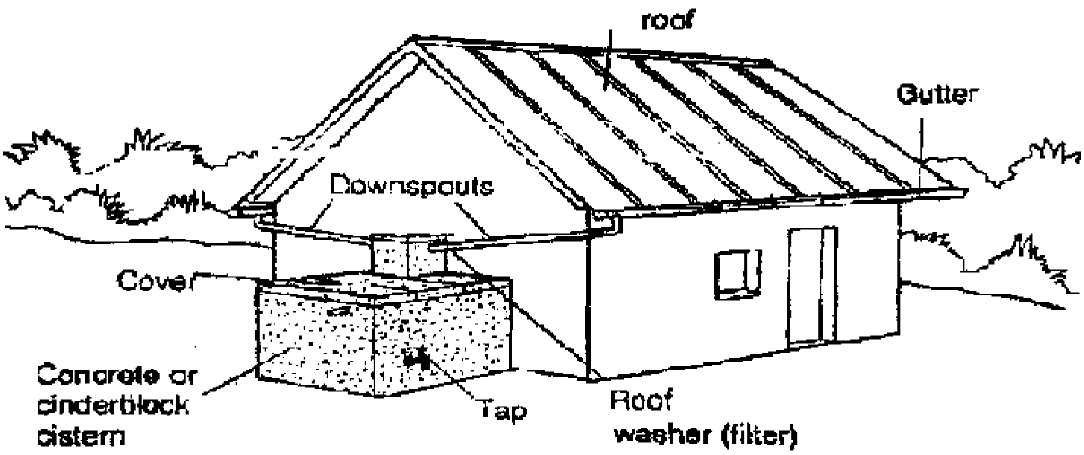

Fig. 2. shows the design of a building roof insulation level system (by Pacey, & Cullis, 1989)

i) The site for constructing the roof insulation levels:

The first thing in building insulation levels is to select its site and the most important problem, in this case, is to study a bearish pattern. In general, the factors influencing the choice of location can be summarized as follows, so the rainfall pattern is mentioned as the major issue. (Sepaskhah, 1992).

ii) -Determining the rainfall pattern of the area:

The intensity of the shower especially rainfall intensity is an important hydrological factor that has a significant effect on determining the place of insulation level. Determining the rainfall intensity is very difficult in a short-term, especially in mountainous regions that measure facilities is not provided or is rare. In developed countries, organizations and forecasting agencies calculate meteorological rainfall intensity frequencies at different times and it is accessible to the public. But in Iran, this is still not the case. Therefore, theoretical methods should be used. In Iran, the universal formula Bell or Vaziri and Ghahramani's method is used to obtain shower intensity that it is not possible to provide its full description in this paper.

iii) Calculation of collecting rain and water storage tank volume:

The second issue in the construction of insulation levels is to calculate rain storage aggregator level, especially volume of the water reservoir. The reservoir dimension depends on the collector surface area of rain (watershed), and the annual volume of waste from the area (Va) can be calculated from the following equation (Gholami, 2000).

$$Va = a\,(1 - ny/Pa)\,A\,(1 - B) \times Pa)$$

Where,

Pa is annual rainfall in mm.

A is the collector surface area of rain in m2.

B is a constant coefficient that depends on physical characteristics of surface area or rain collector (1>B>0).

a is the ratio of annual wastewater to annual rainfall $\frac{R}{P}$.

NY is receiving precipitation factor by the insulation level (if the insulator surface is against the wind is given (0-0.5) and otherwise (1- 0.5)).

iv) Other factors affecting the system:

The direction of roof level: it is clear that direction has the basic role in collecting rainwater. The direction of the roof surface effect on harvesting the highest rainfall.

Therefore, in this study direction of roof level is northwest to south-east due to the prevailing wind.

Type of vegetation: it has an important role in determining the insulation level. In this study, the type of vegetation is to plant citrus trees throughout the 1.2 hectares, which include 320 orange seedlings, 320 Thomson orange trees, and 320 orange trees.

- **Method for estimating ET0:**

Previous rules were provided by FAO in publication No. 24, irrigation networks and drainage. These four methods are following as improved Bellini Criddle, radiation, modified pan and Penman's evaporation. Modified Penman was selected as the best way among these four methods, the latest assessment by Mr. Johnson in his publication entitled "evapotranspiration and water requirements" (ASCE, 1990).

- **Rain estimation method:**

Regional climate can be classified as semi-humid to wet with an average annual rainfall varies between 600 and1100 mm, so rainfall in the winter is about 55 to 70% (Non - agricultural season) and the rest occurs in the summer.

The trend of rain decreasing has been shown 75 to 5 mm for Gharakhail station and for Babolsar 58 to zero mm from March to August. During the remaining seven months, namely September to February, rainfall is between530 to 780 mm. Diagram 1-3 shows monthly changes in rainfall for Gharakheil stations in the wet and dry year and average annual changes for Gharakheilin the period of 28 years. Positions station is close to the investigation place.

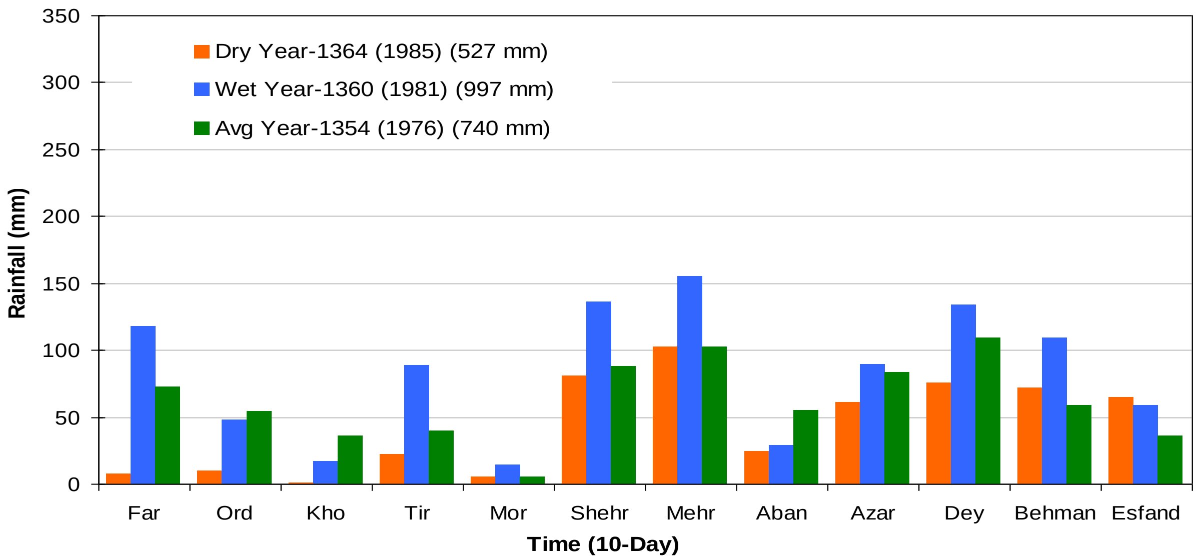

Fig. 3. Monthly changes in rainfall for Gharakheil stations in the wet and dry year and average annual changes for Gharakheil in the period of 28 years.

Methodology

1- Selecting the project location:

Selection of the project location is one of the important parameters in collecting rainwater, but in this research, the choice of the location of the project is optional, that is, the location of the project is a villa garden, (Figure 1). For watering the garden, the water required for the plan should be provided. If we want to develop this approach in the region or there are similar conditions in the region, the present plan is a practical and academic experience that provides irrigation water for the garden.

2- The pattern of raining in the project area:

According to the results of the project area, the average annual rainfall is determined 850 mm that the roof insulation levels can collect rainwater over the years. In this regard, the type of raining effects on planning the water storage pool and aggregators surface, based on climate studies in the region, two kinds of rainy weather is defined in this region:

The first type of rainfall is with maximum intensity and with irregular distribution rainfall, but the second type is low-intensity and with regular distribution rainfall and region of the project has the annual precipitation in the second kind.

3- Design and construction of roof insulation levels or levels of collecting rain:

Level of collecting rainwater is an important factor in increasing or decreasing the rainwater, and three parameters have important effect on designing and constructing the insulation level, including coefficient factor C, the dimension of plate (length and width of the roof) and the structure of insulated surface that is usually selected in type Plate or Iranit to construct the building roof. (Husseini A.S.1992)

Now the roof structure has selected the plate that the coefficient C is considered one in this type of roof. C= 0.7-1 (Mahdavi, 1992), the dimension of Roof surface equals $S = 8 \times 9 = 72$ m2, that the ceiling on the horizontal surface is 72 square meters, but in the steep area, its area is estimated 80 square meters. The steep surfaces are bilaterally, and they are made in the northwest and southeast directions.

4- Constructing rainfall storage pools:

According to Figure (1-3) storage pool of rainwater has been embedded in the ground of building, the volume of collecting water on the roof level is calculated 26 m 3. Remarkable factors for designing the storage pool, the height of freeboard and the overflow height. To prevent possible water leakage, the impenetrable material has been used, and then these materials have been used inside the wall of foundation and 15 cm in the body wall. Sometimes polyethylene is used as a cover inside the pool. The foundation surface is used the bar, and diameter of the bar has been selected about Φ=16 mm. The rainwater has been stored during a year in two pools that one is used till mid spring and the other is used till mid of summer to irrigate citrus trees, in total, $37 \times 2 = 74$ cubic meters of water will be saved.

5- Assessing irrigation water demand and mid-irrigation of citrus trees:

The area under cultivation of citrus is 2 ha that was chosen as a pilot in this study. The trees of the garden include different varieties of citrus trees, including Thomson orange, Onsho, and Tanjylatangerine.

Irrigation period has been suggested, the water requirement of citrus trees was determined based on studying a comprehensive plan of irrigation and equipping modernization of cultivation land by the (World Bank 2010, Agricultural Jihad Organization of Mazandaran province). Irrigation is done using drip irrigation methods in the normal water year. a maximum of 60 liters is used per tree during the three intervals but in the wet years, 2 times a year and for periods of drought 4 times a year).

2. Discussion and Conclusion

According to the results, from the level of the gable of a villa equal to80 m² is collected 60 m3 of rainwater in two periods of time. The coefficient of the gable of the roof is estimated equal to 0.95, and for one hectare of citrus gardens of 3-5 years old is required an average 50-57m3 irrigation water, during a normal aquatic year for during the 2-3 years. Therefore, the water requirement for one hectare of citrus gardens is complete can be supplied, through rainwater harvesting with the method of the gable of roof insulation, and there is no problem. But, in the drought period, is required irrigation periods for 4 to 5 times. Usually in each period of ten years may occur, a drought period so, you should increase the gable of roof insulation. Thus, if anyone wants to have a villa with green garden, is no need for urban water. in such a situation, and

Instead of that, it can be used rainwater harvesting through the gable of the roof insulation method for irrigation, which is a cheap and low-cost method.

This research has been done during 2013-14 years, that it was a normal aquatic year, and in the course of the study, has occurred six storms with 12-hour duration with an average intensity was 6.92 mm per hour. In this regard, the rain intensity factor has not been affected on the amount of rainwater harvesting in the unit area, but the direction of precipitation and the slop gable roof of collector have played a significant role. (The slope of gable roof was 30%), but the slope of a surface with the intensity of rainfall is directly related to the amount of collected rainwater. In this regard, the wind intensity has only affected on the variation in the amount of rainwater harvesting (the wind intensity was predominantly in the south-western direction at 11 km/h).

It is worth noting that in this research, the type and direction role of gable roof in the collection of rainwater has been considered and it has had a great impact, thus it should be investigated further.

It seems that the rainwater has better quality than surface waters, because in old time, Water consumption particularly, it had been a lot of advocators for cooking rice, washing, and drinking, so it is necessary to investigate further.

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