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Economic Study of the Rainwater Collection System in Drought Conditions

Payam Ebrahimi[a*] and Mohsen Mohseni Saravi[b]

[a]Assistant Professor, Forests, Rangelands and Watershed Research Department; Sistan Agricultural and Natural Resources Research and Education Center; AREEO, Zabol, Iran.
[b]Professor Retired, University of Tehran, Iran

[*]Corresponding Author, E-mail address: p.ebrahimi@areeo.ac.ir

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Abstract

Collecting rainwater is one way to make life easier for local communities during periods of drought. The lack of uniform distribution of rainfall in all seasons makes it necessary to store the water needed by households. Iran is one of the arid and semiarid countries facing water scarcity problems, but in the city of Taleghan, average annual rainfall is above the national average. The roof surfaces were used to measure the quantity of water stored. The surface which can be created on the roofs of houses has been calculated using the SPOT 5 satellite. It has a total accuracy and a kappa coefficient of 91.2 and 88.5, respectively. While there are many benefits of the rainwater collection system, the results of this study showed that the economic benefits are different. If the estimated life of the rainwater collection system is 10 years and annual inflation increases at least 41% each year, this system is not economic. The initial capital requirement for a rainwater collection system was estimated at $ 679 ± 278. The results show that the costs of setting up a rainwater collection system and at least the 18% yearly financial interest on bank deposits are not equal. Besides the results show that the high cost of building the rainwater collection system is linked to the storage tank and it needs the government's financial support.

Keywords: Drought, Economic Estimation, Rainwater collection system, Taleghan.

1- Introduction

Rainwater harvesting is one of the most important rainwater management techniques to address water scarcity, which is rapidly developing in areas facing water scarcity (Alim et al, 2020; Barbosa de Jesus et al, 2020). The basis of this method is to allocate an area of land to collect rainfall and then store it for use at the required time. Because of the variety of methods for harvesting rainwater, the appropriate method should be chosen. Characteristics such as the amount of rainfall and distribution, soil, topography, soil type, soil depth, economic and social factors of each region are important (Boers and Ben-Asher, 1982). The problem of water scarcity in arid and semi-arid regions is due to low precipitation and inadequate distribution, which has made farming in these regions uneconomic. Conventional water sources in these regions, such as wells, are often overused and decisions have to be made to compensate for economic and social impacts (Chiu et al. 2009). The results of the design and implementation of a pilot project for rainwater collection in arid and semi-arid regions using runoff from a plastic-coated surface demonstrated that in areas with moderate precipitation, plantation operations can be economically viable (De Sá Silva et al, 2022). Modern methods for extracting water have been successful in many countries (Imteaz and Shadeed, 2022); however, its economic viability has to be assessed (Marinoski et al, 2018). The most important issue for comprehensive watershed management is reducing the availability of water resources. In many countries, the overall management of water resources is central to the decisions and actions of public authorities and local and national institutions. This kind of management requires efficient harvesting practices and alternative water resources. These resources facilitate local government management during a drought (Latif et al, 2022). An alternative water source makes it easier critical situations. These resources are approved by many farmers and increase the amount of water available (Aly et al, 2022). Most stakeholders and watershed experts realize the benefits of collecting rainwater. However, social conditions and economic efficiency are two factors that prevent the use of new rainwater collection technologies (Abdulla and Al-Shareef, 2009). Under the comprehensive watershed management approach, one of the water supply programs required is the use of rainwater stored on the roofs of homes (Singh, et al, 2022). The goal of a comprehensive watershed management is to reduce the pressure on surface and groundwater resources, and this goal may not be economically viable for community use. Two factors influence the unpopular use of rainwater collection methods in Iran. Both of these are the distribution of non-monetary subsidies on resources such as water, gas, electricity and equipment costs. In other words, although the goal of a comprehensive watershed management is to use modern methods of rain water extraction (Thomas et al, 2014) in the current situation, this goal is not being achieved. Factors that affect the price include distance or proximity to the tank manufacturer, the price of the metal or pipe used, and the area of use. The use of economic valuation methods to depreciate rainwater collection facilities and the initial costs of constructing a catchment system can strengthen the comprehensive management attitude (Mini et al, 2015). If the results are cost-effective, rainwater collection techniques may be encouraged. Unfortunately, despite the crisis of water scarcity, particularly in Iran, rainwater harvesting and activities in this area are very limited. Generally, the high initial cost is due to the components of the treatment system and the comparison of cost-effectiveness with other long-term investments (Ammar et al, 2016). A study of subscriber water prices in Iran shows that the amounts received are very low and insignificant in the rural area. This increases consumer pressure in rural and urban areas with access to potable water regulated by drought conditions. Due to the fact that the cost of drinking water used in gardens, summer gardens, small garden, roof garden, car wash, and other uses are very inexpensive. As a result, there is no economic justification for the rainwater collection system for subscribers. Increasing the cost of water and supporting the rainwater collection system and the provision of facilities by the government will encourage more households to use the rainwater collection systems. Rainwater collection for agriculture is much less used by government, the private sector and public assistance because of the high volume of water needed (Campisano et al, 2017). But to use this system for domestic use, drinking water subscribers pay more attention to the economic benefits of the plan. One way to figure out how many facilities the government needs is to look at the cost of building a rainwater collection system. This cost is measured against the cost of drinking water. In order to protect water resources under drought conditions and to optimize the use of annual precipitation, reserves of water resources are required (Aladenola and Adeboye, 2010). Consequently, in this study, the net present value of rainwater extraction systems on the roofs of homes for domestic use was used. Due to the lower quality of water extracted as drinking water, this water is used for irrigating gardens, washing cars and gardens, flash tanks, fire extinguishers and swimming pools. One of the areas that has the conditions to establish a rainwater collection system and its precipitation is approximately 400 mm is the Taleghan watershed. The volume extracted from this area is appropriate for normal household use, but accurate determination of its economic efficiency requires system design and operating costs. This study examines the economic reasons for the non-use of rainwater collection systems by local communities in the Taleghan watershed.

2- Materials and Methods

2.1. Case study

The Taleghan Watershed is one of the branches of the Sefidrood Watershed, located on the southern slope of the Alborz Mountain Range, northwest of Tehran (Figure 1). That basin is situated at 36 degrees and 12 minutes north latitude and 50 degrees and 47 minutes east longitude. It covers an area of approximately 111231.27 hectares and is located 105 km from the center of the province (city of Karaj) and 120 km northwest of Tehran. There are 2 districts, 4 rural districts and 75 villages. The climate type is varied Mediterranean-humid Domarten method and the altitude is from 1260 to 4125 meters. This city has three parts: Lower Taleghan, Mid Taleghan and Upper Taleghan. It is connected to Kelardasht, Alamut and Manjil of the north and to the western ocean. It is linked with Qazvin, Abik, Hashtgerd and Karaj in the south and Kandovan and in the east. The city of Taleghan is located in the Taleghan watershed and roofs of houses that may build a rainwater collection system have been used.

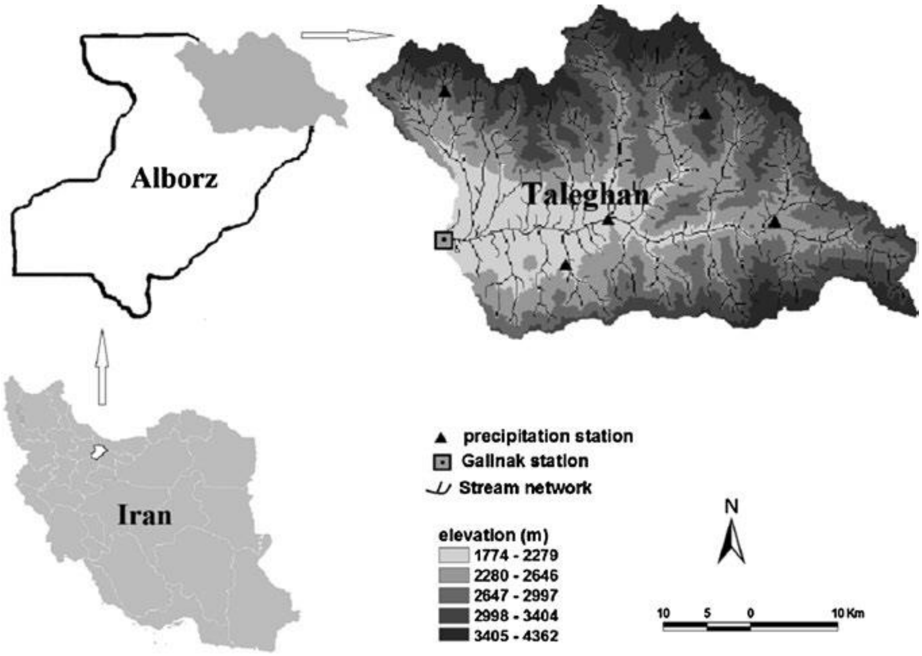

Fig. 1. Study area (Taleghan watershed)

2.2. Methods

In order to evaluate the proposed system of catchment surfaces, the technical and economic specifications of the roof system must be determined. Using this method, the amount of investment in the system creation phase through to the equipment life phase is examined. The best way to evaluate the economic value of rainwater collection projects is to use techniques that calculate the economic value relative to inflation (Nouri et al, 2013). There are a lot of variables which is affected in storm water collection. In this study, Walsh et al. (2014) have been used. These variables include: Average annual rainfall of Taleghan watershed (mm/year), average levels of roofs (m^2), runoff coefficient of roofs and potential for rainwater production per cubic meter. In addition, to determine the optimum storage capacity according to the roof level of the houses in the city of Taleghan, geographical information system was used. The required reservoir volume and then per capita household consumption in the unconventional consumption section was evaluated. Within this study, conventional consumption is linked to drinking water. Because of the importance of the treatment system and the pump for drinking water consumption, only part of the unconventional consumption is examined. Unusual uses include the bath, the toilet, washing machine or by hand, washing dishes, the pool, irrigation of the garden (Lopes et al, 2017). Satellite imagery from SPOT 2022 was used to determine the roof area of houses. The pre-processing of this image included atmospheric and geometrical

corrections in the ENVI environment and the area of each roof was calculated in the SIG environment (Zhong et al, 2022). Field visits were used to monitor ground locations. A way to decide on the classification of each pixel or desired area of the roof of each home is to use the maximum probability method. This method has more precision than the others (Ortegón et al, 2022; Alfano and Adeboye, 2018; Levine and Herman, 1987). The variance and spectral correl
regions with appropriate distribution at the post-processing stage of classification were determined by the maximum likelihood method (Ennenbach et al, 2018). This is one of the more accurate ways to classify basic pixels (Kidd and Levizzani, 2022). The overall accuracy of the images exceeds the kappa coefficient and indicates that the roof areas of the houses have been estimated with acceptable accuracy (Liu et al, 2017). The values of the overall accuracy are usually greater than the actual value, while the kappa coefficient evaluates the accuracy of a random classification (Lu and Weng, 2007). Overall accuracy is the mean of classification accuracy, which is relative to pixels classified at the sum of knew pixels, and is computed as follows:

$$\mathrm{OA} = \frac{\sum_{K=1}^{N} a_{kk}}{\sum_{i,k=1}^{N} a_{ik}} = \frac{1}{n}\sum_{K=1}^{N} a_{kk} \tag{1}$$

Where OA is the total accuracy and N is the total number of pixels categorized. Also $\sum_{K=1} a_{kk}$ is the sum of the pixels of the original diameter of the error array.

The kappa value computes the accuracy of the classification with respect to a random classification. In other words, the kappa value is the accuracy of the classification compared to the case that the image is classified completely at random. The value of this factor is obtained from the next equation.

$$\text{Kappa} = \frac{P_o - P_\theta}{1 - P_o} \tag{2}$$

where Po is the relative observed agreement among raters, and P_θ is the hypothetical probability of chance agreement, using the observed data to calculate the probabilities of each observer randomly seeing each category.

To determine the amount and distribution of precipitation, the long-term average of precipitation data from 8 stations (Ange, Golirud, Skranchal, Gotehdeh, Armut, Jostan, Dehdar and Zidasht) from 1966 to 2022 was used (Mohseni Saravi et al. 2017). In this research, cost-benefit approaches were employed, the following equations (Zangeneh et al. 2010; Frej et al. 2021):

$$BCR = \frac{|\, PV[\text{ Benefits }]\, |}{|PV[Cost]|} \tag{3}$$

where PV is present value.

The average inflation rate over 10 years was used to determine the inflation rate. This is the equation of the mean rate Increases the construction cost of a rainwater collection system in the first and tenth years.

$$\ln x10 = \ln x1(1+i)^{10} \tag{4}$$

3- Results and Discussion

Using the precipitation stations at Ange, Golirud, Skranchal, Gotehdeh, Armut, Jostan, Dehdar and Zidasht, the average annual and monthly precipitation in millimeters is shown in Figure 2. The location of the stations and the city of Taleghan are given in Figure 1.

According to the research (Norman et al. 2019), SPOT images as well as field visits were used to determine the levels of rainwater uptake. During a site visit using the point and line method, Taleghan's houses were surveyed on a case-by-case basis (Chen et al. 2019) (Figure 3). Total roof levels for cityhouses were monitored by the ENVI software and calculated by examining the maximum pixel similarity (Table 1) (Baby et al. 2019).

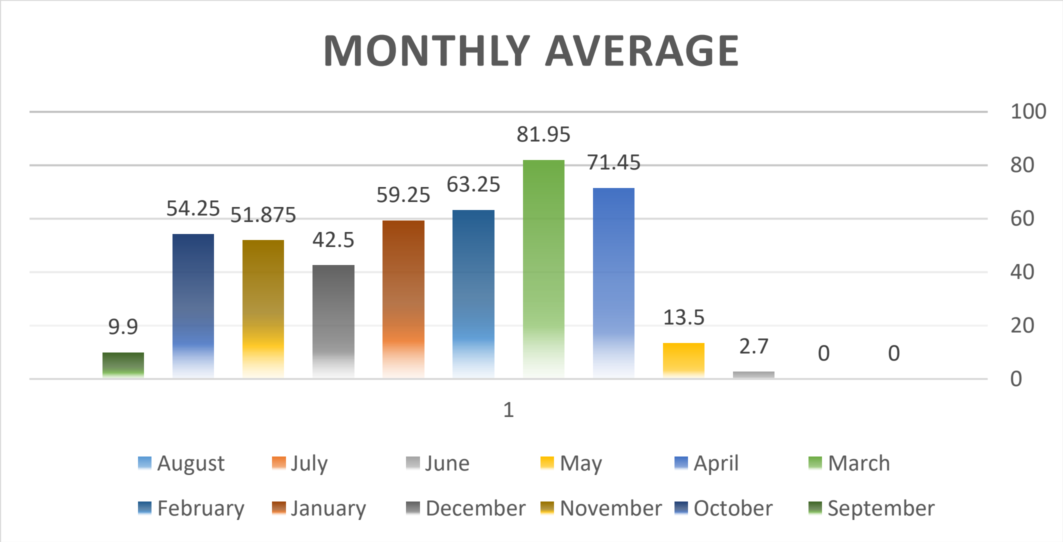

Fig. 2. Chart of monthly rainfall changes in study stations

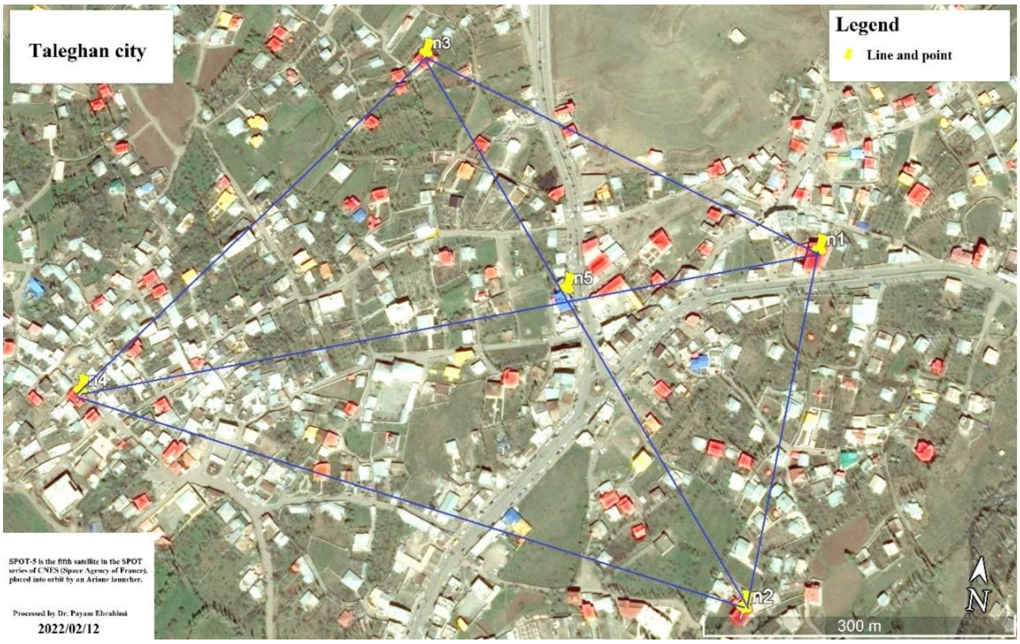

Fig. 3. Linear and point study in Taleghan town

Table 1. Kappa coefficient and Overall accuracy

Kappa coefficient %	Overall accuracy%	Satellite	Year
88.5	91.2	SPOT	2022

Through field surveys, only about one-third of the total roof of houses in the city had rainwater collection conditions. These conditions include a galvanized, sloping and efficient surface, the ability of the building to be fitted with a rainwater collection system. The usability of urban drinking water and the interviews conducted in the study area show that the use of rainwater for drinking is expensive and difficult to use. The use of rainwater in a manner collected without the use of the pump and chlorination costs can be considered in a cost-effective set. As a first step, through library studies, the economic system with the lowest cost with the necessary equipment was examined. On the basis of the storage of rainwater for non-potable use, a profitable and standard tank, necessary designs and estimates have been made.

The volume of the tank was determined by its usage in different months. Amount of rainfall and consumption is different, and according to the frequency of consumption and emptying. Consequently, the volume of the tank was determined on the basis of the water consumption collected in the last 3 to 4 months of consumption of 5000 liters. The proposed system components include: 1- Gutter or prestige 2- Primary filter 3- Pipes 4- Plastic tank 5- Galvanized tank 6- Seepage tank (Figure 4).

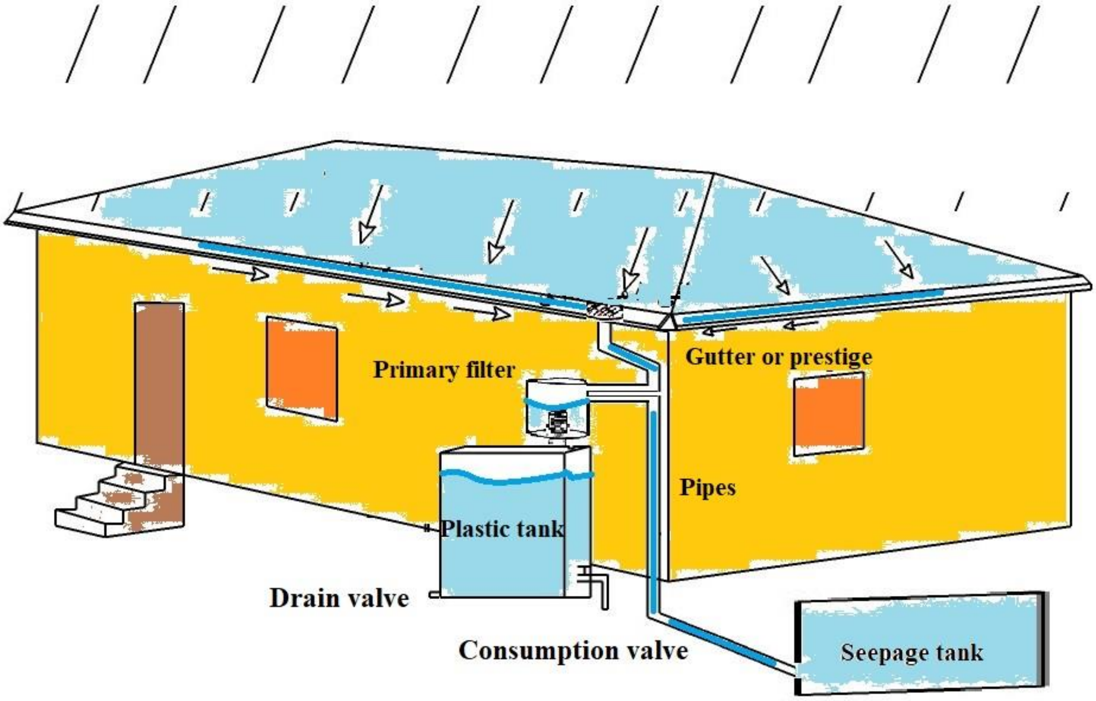

Fig. 4. Rainwater extraction system without pumping and purification system (NIT Campus, 2016)

Most houses had no gutters, and an appropriate slope was required that led to gently sloping gutters around the roofs of the houses to the exit. In the next step, the rain water at the beginning of the inlet into the collector pipe passes through a filter with the ability to pass particles of a size of 5 mm. This filter prevents the entrance of objects greater than 5 mm.

It is then guided through a pipe to a galvanized reservoir and the water is raised to a certain height so that particles less than 5 mm can be deposited. After settlement, water is directed and stored in plastic reservoirs. Excess water is also carried through the return pipe into the seepage tank and into the soil. Assuming the desired system, the coverage areas of the houses were calculated using GIS software and equivalent to one-third of the houses in the Taleghan (Figure 5). Satellite imagery was processed and after 4 months of the wet season, the points were monitored by field visits.

The average roof surface of the houses is 180 m^2 and the lifetime of the polyethylene tank with guarantee is 10 years. The cost of water uses in one year and up to a total of 10 years was calculated based on the useful life of the parts, in particular tankers. The average level of the gutter was used with a slope of 30 degrees and a runoff factor of 1 per rainfall event. About 7 months of the year, precipitation is perceptible and about 60 percent of precipitation accumulates as snow. As a result, the tank will be empty until the snow melts, and in case of excessive accumulation due to the slope, it will be out of range and melt. Therefore, the volume of rainfall that may be extracted as rainfall is introduced as the volume of the proposed tanker.

The tank capacity requirement is indicated in Table 2. In addition Table 3, the equipment price through to the end of 2021 is calculated in $. Table 3 shows the cost of building a water intake system from the rooftops of urban houses in the city of Taleghan will be $ 679 with IRR 280000 exchange rate. Due to changes in equipment prices, the final price will be 41 percent above or below the advertised price level. Furthermore, on the basis of the annual inflation rate, the cost of constructing the rainwater collection (2011) is equivalent to $ 1416 with IRR 12000 exchange rate. The average rate of increase in rainfall collection system prices ($1) over the past 10 years:

$$
\begin{aligned}
& ln\,280000 = ln\,12000(1+i)^{10}\,. \\
& anti\,log(12.54-9.39) = 10\,log(1+i) \\
& i = 1.41-1 = 0.41 \\
& i = 41\%
\end{aligned}
\qquad (5)
$$

The initial cost of using this reservoir in residential spaces is high. Therefore, conventional 5000-liter tankers are used in the research.

In the following phase, the cost of water and waste water disposal in Taleghan was considered. Because of the lack of a wastewater drainage system, the cost of wastewater was ignored. According to information obtained from Taleghan Urban Water and wastewater Affairs, this city is one of the cities of fewer than 20,000 inhabitants. The price of water in this group was reviewed. The average cost per cubic meter of drinking water is $ 0.017 to 0.025 in 2021, and an average family of four consumes 45 to 60 m^3.

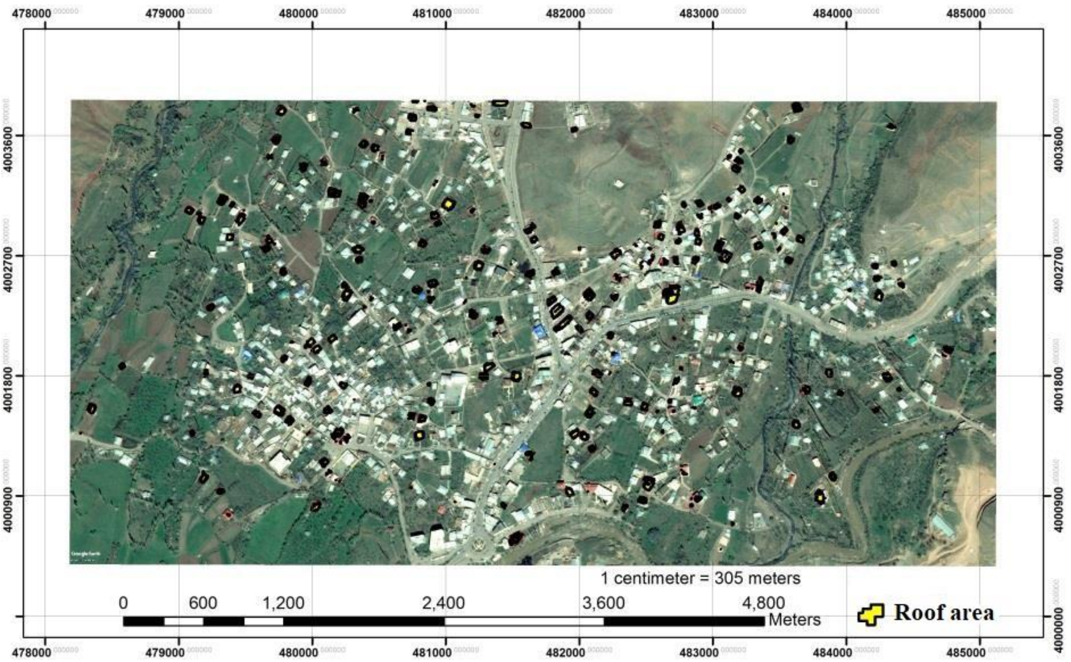

Fig. 5. Catchment areas for houses that have the lowest cost of rainwater extraction

Table 2. Water storage tank

Average annual rainfall (mm)	Average roof catchment (m^2)	Total volume of extractable water (m^3)	Converted to liters	Number of months with significant and economical rainfall	Capacity of the tanker for total precipitation (lit)	
540	180	97.2	97200	7	40% Rain	60% Snow

- **The volume requirement is 38880 liters. But the price of a 38,000-litre reservoir is $ 3035[1].**

[1] makhzaneab.com

Table 3. Shows the cost of building a water intake system from the rooftops of urban houses in the Taleghan town

Row	Product name	Specifications	Unit	Required quantity	Total price ($) (2021.11.08)	Online market address
1	Polyethylene pipe	Outer diameter 125 mm	On average in meters	20 m	46.42	abrahpipe.ir
2	Polyethylene tanker	Three antifungal layers, vertical and long	1 x	5000 lit	392.85	www.makhzaneab.com
3	Galvanized tank	0.40 mm sheet	1 x	3 m^2	12.5	Polad.ir
4	Polyethylene fittings	Fittings	On average	10 pieces	16.07	www.ahmadipe.com
5	Transportation	Once from Tehran to Taleghan	A truck	1 x	71.42	fullwork.ir
6	Gutter construction fee	Per meter	M2s	23 m^2	53.57	Local technician
7	Gutters	0.40 mm sheet	50 by 0.4 meters	20 m^2	53.57	Polad.ir
8	Construction fee for galvanized tank	Fits inlet and outlet pipes	number	1	14.75	Local technician
9	Installation fee	once	Sealing	1	7.14	Local technician
10	Unforeseen cost	-	-	-	10.71	-
-	Total	-	-	-	679± 41%	-

The average cost is $ 1.10 per household, plus other bill costs such as subscriptions, value added and development in other areas. Water consumption volume equal to 20 cubic meters or $ 0.78 in 2021 is spent for non-conventional uses, such as washing the yard, car and irrigate the garden. Considering the 10-year useful life of the equipment and the annual inflation rate of 41%, the total cost of a household in the unusual sector was determined. The results show that in the current situation, the water price for a family living in Taleghan is between $ 1.60 and $ 2.5 (average $ 2.05) (Table 4). If the rainwater extraction system is considered the cheapest price without a pumping and purifying system, its construction cost is equal to $ 679. By the end of the 10th year, rainwater collection equipment will depreciate and require repair. In order to increase price risk, the upper price limit was used (Table 5). Against the deposit advantage of the $ 679 between the beginning of 2022 and 2032 is $ 639.68. This means that we have assumed that the annual benefit is the minimum amount and it is 18%. The total cost of water usage in the unconventional sector is $291.3. While the yearly price of water will be 41 percent higher than the previous year.

Finally, $ 76048 is needed for 112 residential roofs suitable for a rainwater collection system. This quantity corresponds to the capacity of the 5000-litre reservoir (Table 6).

Table 4. The price of water for a family of 4 persons per year and the proportion of non-conventional water consumption

Basic city	Type of use	4 consumers	Cost of drinking and washing dishes in the kitchen and bathroom ($)	Costs related to unconventional use (yard washing, small garden irrigation, car wash, carpet, etc.) ($)	Annual water price for a family (4 persons) in an unconventional section ($)	Inflation rate
Taleghan	Household and fair consumption	1	2.05	0.78	9.37	41%

Table 5. Annual profit, cost of rainwater harvesting system and cost of water in unconventional consumption

Row	Year	The cost of annual water consumption of the non-conventional sector cumulated with an annual rise of 41% inflation	The price of the rainwater collection system ($)	The money invested in the rainwater collection system for an annual benefit of 18%
1	2022	9.37	679	122.22
2	2023	13.21	-	144.22
3	2024	18.63	-	170.18
4	2025	26.27	-	200.81
5	2026	37.04	-	236.96
6	2027	52.22	-	279.61
7	2028	73.63	-	329.94
8	2029	103.82	-	389.33
9	2030	146.38	-	459.41
10	2031	206.40	-	542.10
11	2032	291.03	-	639.68
Total	10Years	291.03	679	639.68

Table 6. Total costs invested by households

Number of houses capable of extracting rainwater	Area (m^2)	Total costs invested by households with a capacity of 5000 liters ($)
112	21037	76048

4- Conclusion

The study of the economic efficiency of collecting rainwater in the Taleghan has shown that with the least equipment of this system, the rate of return on investment is not appropriate. Despite the use of low-cost facilities in the rainwater collection system, this approach has no economic justification for the home-based consumer. The cost of approximately $ 679 at the start of the project and the current water pricing does not justify the use of this system. With an inflation rate of 41% annually over 10 years, this project will be a failure. According to research findings, it is the economic factor that has the greatest effect on the acceptance of the rainwater collection system (De Sá Silva et al. 2022). This study confirms their findings and suggests to governments to invest in this field. Given the use of potable water for the green space sector in the Taleghan and its cost, one of the drought management options cannot be rainwater use. The initial amount of investment for the construction of a rainwater collection system is at least 10 years of household water use in the non-conventional water sector. Due to the cost of building the annual rainwater collection system, at least

110% should be added to the total water price to make the system profitable. Furthermore, the volume of the storage tank is very small and it is not possible to store all the runoff from each roof. One-tenth of the extractable volume of rain water costs $ 679 and the storage cost of 38,880 liters requires at least $ 3035. The government should cover 50% of the cost of setting up a rainwater collection system through low-interest loans to extract rainwater. Subsequently, in this case, the Taleghan rainwater extraction system will be considered by the households.

5- Acknowledgements

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6- Conflicts of Interest

No potential conflict of interest was reported by the authors.

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