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Research Article

Rainwater Harvesting for Lawn Irrigation: A Case Study in Diyarbakır Province

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ABSTRACT

The prevalence of water stress is on the rise due to the confluence of population growth and industrialization. The utilization of potable water for non-potable applications such as irrigation and cleaning places considerable strain on freshwater resources, underscoring the growing importance of alternative water management strategies such as rainwater harvesting (RWH). This study investigates the potential of rooftop RWH to mitigate water stress in Diyarbakır, Türkiye, by supplying irrigation water for lawns area. The research calculates the volume of rainwater that can be collected, filtered, and stored for irrigation, comparing it with the water needed to irrigate the lawn. This study evaluates the feasibility of RWH systems for irrigation, focusing on water savings, economic performance, and payback periods. The findings indicate that irrigating a 100 m² lawn area with rainwater harvested from 350, 400, 450, and 500 m² roof areas can provide 56%, 64%, 71%, and 78% of annual water saving, respectively, with larger roof areas providing greater savings. Subsidy mechanisms significantly reduce the payback period while a 400 m² roof area emerges as an optimal size balancing cost and benefit. In the case that the storage tank and pump, which constitute the initial capital costs, are provided free of charge with the subsidy, net present value (NPV) is positive from the first year onwards. The study demonstrates that interest rates, inflation, water prices, initial investments and operating costs are significant factors influencing the economic viability of the RWH system. In countries where the price of water is low, the economic feasibility of RWH systems may be compromised. Nevertheless, in countries where water is scarce, it is essential to consider the economic and environmental benefits simultaneously and to implement incentives to facilitate the implementation of such systems.

Introduction

As of 2023, the global population surpasses 8 billion, with projections indicating it will approach 10 billion by 2080 [1]. An increase in population results in an increased demand for food and raw materials in agricultural and industrial activities [2-3]. Consequently, water demand in urban, agricultural, and industrial sectors escalates [4]. Worldwide, 70% of freshwater utilization is allocated to agriculture, whilst industrial operations account for less than 20% and urban applications approximately 12% [5]. The rising demand for water and issues stemming from global climate change are leading to water scarcity or stress in numerous countries [6]. A nation is deemed to experience water stress when the yearly renewable freshwater availability per capita falls below 1,700 m^3 [6]. Moderate water shortage is characterized by a per capita renewable fresh water availability of less than 1700 m^3 annually, whilst severe water scarcity is defined as a per capita availability below 1000 m^3 [7]. Currently, it is reported that almost 4 billion individuals experience significant water scarcity for at least one month year [8]. Figure 1 demonstrates that the city of Diyarbakır is currently experiencing high water stress, with forecasts predicting a substantial increase to an extremely high level by 2050 [9]. Goal 6 of the Sustainable Development Goals, released by the United Nations in 2015, entitled ‘Clean Water and Sanitation’, establishes significant objectives for access to water and wastewater services. The objective is to guarantee universal access to clean water and sanitation services by 2030 [10]. The World Health Organization report indicates that 2.2 billion individuals lack access to safe drinking water [11]. The current global situation demonstrates that more efforts and effective solutions are needed to reach these goals.

The southern and western regions of Türkiye have a Mediterranean climate, while the inland and eastern areas have a continental climate [12]. The southeastern and eastern Anatolia regions of Türkiye encounter considerable short-term drought, whereas the coastal areas exhibit a reduced risk of drought [13]. Based on data from 1991 to 2020, Türkiye's mean annual areal precipitation is 573.4 mm, while Diyarbakır's mean annual areal precipitation, at 492.6 mm, falls below this national average [14]. The General Directorate of Meteorology indicates that Türkiye experiences an average of 100.3 rainy days annually. The years 2008, 2013, 2017, 2020, 2021, and 2022 rank among the driest in Türkiye over the past two decades [15]. Annual precipitation fluctuates yearly, with certain years experiencing aridity while others may exceed average levels. This circumstance exacerbates the issue of water stress during arid years.

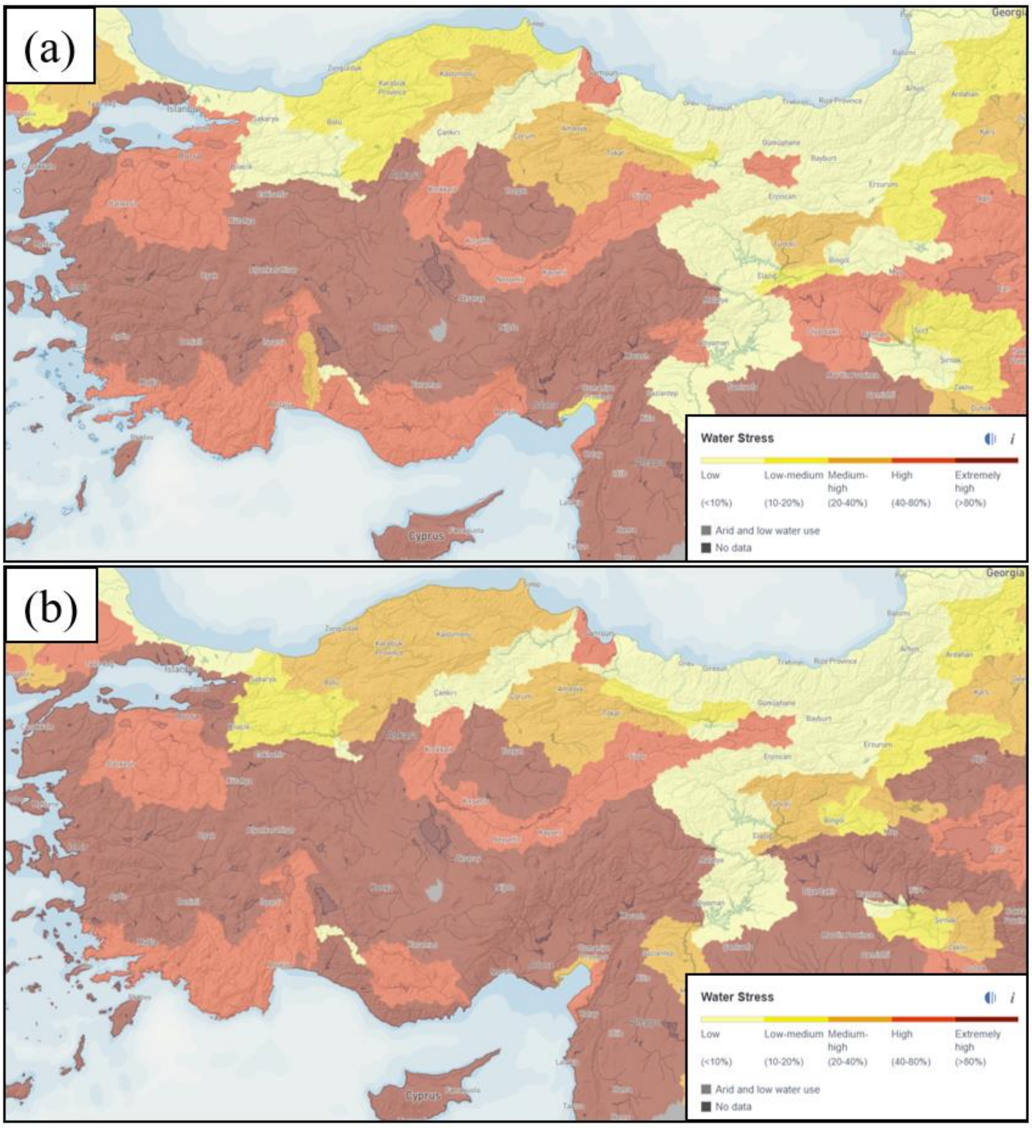

Figure 1. (a) Water stress level in Türkiye in 2024, (b) Estimated water stress level in Türkiye in 2050 [9].

Drinking water quality is unnecessary for agricultural purposes [16]. The parameters for the reuse of treated wastewater for irrigation in Türkiye are outlined in Annex 7 of “Atıksu Arıtma Tesisleri Teknik Usuller Tebliği”. This regulation categorizes irrigation water into two classifications: Class A and Class B, based on quality and recovery type. Given that agricultural and urban irrigation comprise over 70% of global water consumption, and that potable water quality is unnecessary for irrigation, utilizing alternative water sources in lieu of freshwater resources is deemed an effective strategy to mitigate water stress [17].

Rainwater harvesting (RWH) serves as an alternate water resource for irrigation and mitigates water stress [18-19-20]. RWH involves the comprehensive procedure of collecting rainwater from impermeable surfaces, such as rooftops and rain gardens, for storage and eventual use for many applications [21]. RWH is a technique that aids in water conservation, diminishes reliance on traditional water delivery systems, and alleviates the impacts of water scarcity [19].

In recent years, the severity of drought has been increasing in Diyarbakır. Şarlak et al. conducted a study indicating that water levels in Devegeçidi Dam had diminished, necessitating supplemental water from Tigris Dam due to insufficient storage for agricultural irrigation [22]. The reason for the decrease in fresh water in the dam lakes is the low rainfall and high agricultural water use. Furthermore, analyses of data from 2008 to 2021 in other studies employed drought assessment methodologies, including the Palmer Drought Severity Index (PDSI) and the Standard Precipitation Index (SPI), in conjunction with precipitation data, revealing intermittent occurrences of drought [22], [23]. Furthermore, the Diyarbakır province experienced a prolonged period of drought between 2007 and 2010, which significantly affected agricultural activities. It is noteworthy that the droughts that occurred during 2008-2009 were particularly severe. The droughts compelled the rural population to migrate to urban areas, leading to a significant increase in both the population and the population growth rate in Diyarbakır [22].

To meet the growing water demand and protect existing freshwater resources, RWH is proposed as a solution [18]. In urban areas, RWH involves the collection of water from impermeable surfaces, such as roofs and terraces, followed by its storage for non-potable applications, including irrigation [24]. Residential complexes and their associated lawns are common features in the Diyarbakır province. The objective of this study is to assess the economic viability of RWH from buildings in Diyarbakır for the irrigation of lawns. Considering the rising water demand and increasing risk of drought, the potential of RWH to conserve water and reduce reliance on the municipal water distribution network is examined. Furthermore, a cost analysis and payback period for the system have been calculated, and its suitability for implementation in water-stressed regions such as Diyarbakır has been demonstrated.

Material and method

Water Saving Calculations

This study quantifies water conservation by utilizing rainfall harvested from the roof of a building in Diyarbakır province for lawn watering (Figure 2). Typically, precipitation is inadequate to satisfy the watering requirements of lawn areas, necessitating supplementary irrigation alongside rainfall. The requisite water for irrigating lawn areas ranges from 2.5 to 7.5 mm/day/m^2 [25]. In another study, the amount of water required for lawn irrigation is recommended at 5 l/day/m^2, which equates to 5 mm/day [26]. In this study, the water requirement for lawns was established at 5 mm/day/m^2 (g).

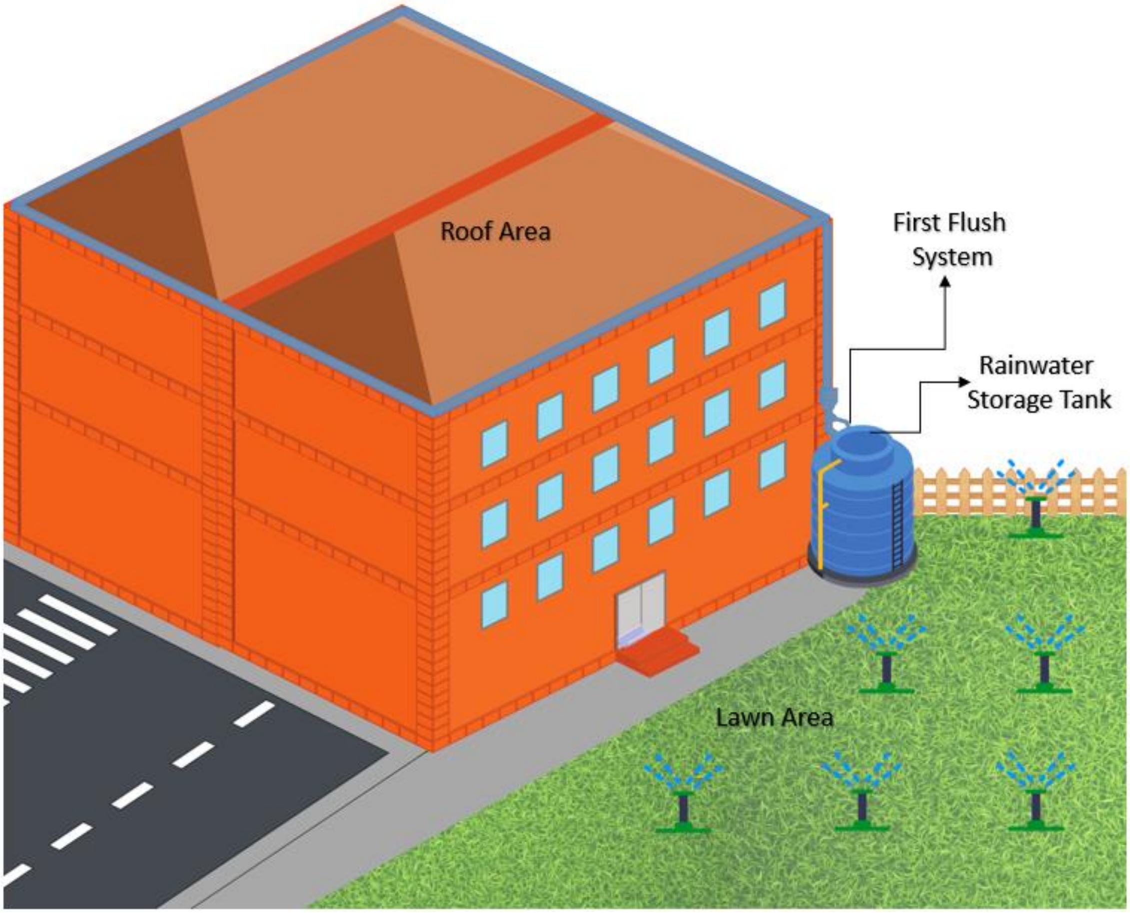

Figure 2. Demonstration of RWH system and irrigation area

The General Directorate of Meteorology of Republic of Türkiye Ministry of Environment, Urbanization and Climate Change presents data on the average temperature, sunshine length, and number of rainy days in Diyarbakır from 1929 to 2023, as illustrated in the Table 1. In this study, the values of the number of rainy days were rounded to ensure that the first flush calculations were whole numbers. In RWH applications, some of the rain falling on the roof is collected depending on the structure of the roof. In periods without rainfall, only potable water supplied by the municipal water distribution network will be used for lawn irrigation. In periods of rainfall, potable water and collected rainwater will be mixed in a common storage tank and irrigation will be done with the mixed water.

Table 1. Average temperature, sunlight duration and number of rainy days in Diyarbakır [27]

Month	Average temperature (°C)	Average duration of sunlight (hours)	Average Number of Rainy Days
January	1.8	3.9	12.25
February	3.7	4.9	11.32
March	8.3	5.6	11.82
April	13.8	7.2	11.21
May	19.3	9.6	8.73
June	26.1	12.1	2.63
July	31	12.4	0.46
August	30.5	11.6	0.32
September	25.1	10	1.07
October	17.6	7.5	5.74
November	9.8	5.5	8.19
December	4.1	3.9	11.49
Annual average	15.9	7.9	85.2

In this study, the roof coefficient is assumed to be 0.8, similar to the study of Çakar (2022) [28]. In addition, the collected water will be passed through a coarse filter before entering the storage tank. It is foreseen that some of the water will not be able to enter the storage tank due to the losses in coarse filter. Therefore coarse filter efficiency coefficient is assumed to be 0.9 [28]. The monthly precipitation height values (r) and number of rainy days (c) of Diyarbakır were obtained from the Turkish State Meteorological Service website [27]. Collectible rainfall volume was calculated by multiplying the roof area by the rainfall height. The amount of water separated by the first flush (b) was selected as 1 mm using literature data [18]. The volume of the storage tank was selected as the amount of water harvested in December, the month with the highest rainfall. In Equation (1), the net collected rainwater (a) is calculated by assuming that 80% of the rainwater is lost (roof coefficient) on the roof and 90% is lost while passing through the filter (filter efficiency coefficient). Equation (2) demonstrate the monthly amount of rainwater separated by the first flush (d) multiplied by the number of rainy days (c) and the first flush amount (b). It is assumed that the first flush should be used for each rainy day. In Equation (3), water remaining after the first flush (e) is calculated by subtracting the amount of water separated by the first flush (d) from the net collected rainwater (a). In Equation (4), the monthly rainfall per 100 m^2 of lawn (h) was calculated by multiplying the water remaining after the first flush (e) by the lawn area. In Equation (5), the monthly amount of irrigation water required for the lawn (j) is calculated by subtracting the monthly rainfall (h) from the monthly water requirement (g) for the lawn. In Equation (6), the monthly amount of water required to be supplemented from the the municipal water distribution network (m) is calculated by subtracting the volume of water collected in the storage tank (l) from the monthly amount of irrigation water required for the lawn (j). The monthly saving percentage (n) from the the municipal water distribution network is shown in Equation (7).

$$a = r \times \text{roof coefficient} \times \text{filter efficiency coefficient} \tag{1}$$

$$d = b \times c \tag{2}$$

$$e = a - d \tag{3}$$

$$h = e \times \text{lawn area} \tag{4}$$

$$j = g - h \tag{5}$$

$$m = j - l \tag{6}$$

$$n = (j - m) \div j \tag{7}$$

Cost Calculations

According to the official data of the Diyarbakır Water and Sewerage Administration, the water tariff for parks, gardens and communal areas in Diyarbakır is 28.4 TL per cubic meter of water used [29]. However, calculations were made based on a USD/TL rate of 34. The initial capital cost (ICC) of rainwater storage tank and water pump were taken from local market in Türkiye [30]. It should be noted that roof construction is not included in the ICC. The rainwater storage tank volumes vary according to the roof area. As the roof area increases, more rainwater is collected. Consequently, the ICC is observed to increase in accordance with the expansion of the storage tank volume. Annual inflation and interest rates are difficult to predict as they depend on many factors. In this study, annual interest rate is selected as 2% and annual inflation rate are accepted as 16,73% which is last 20 years avarage inflation rate in Türkiye [31], in order to calculate the cost calculation and to calculate the depreciation period of the system. Annual cost for cleaning and maintenance of the system are assumed to be approximately 70 USD. Based on the electricity price in Diyarbakır and the power of a pump that can be sufficient for this system, the cost of the consumed electrical energy is calculated as 9 USD. In the calculation of the energy consumption of the pump, it is assumed that irrigation will be done for 1 hour a day, the pump will operate on the days when the storage tank is full, that is, the pump will operate for 156 days. The storage tank is empty in July, August and September and it is assumed that it will remain empty in other months of the year when there is no rainfall. It is assumed that irrigation water will be supplied from the municipal water distribution network during the periods when the storage tank is empty. Thus, total operation and maintanance (O&M) cost is calculated as 79 USD. Water price is assumed to increase according to inflation. Equation (8) shows the annual cash flow calculation. Net present value (NPV) is calculated in Equation (9). Table 2 shows the parameters and their values used in cost calculations.

$$\text{Annual cash flow} = \text{Cost of water saved} - \text{Operating cost} \tag{8}$$

$$\text{NPV} = \sum_{t=1}^{n} \frac{\text{Annual cash flow}}{(1 + r)^t} - \text{Total initial investment cost} \tag{9}$$

Table 2. Parameters used in cost calculations

Parameters	**Value**
Annual interest rate (r) (%)	2
Annual inflation rate (%)	16.73
Current unit water price (USD/m^3)	0.8
ICC of RWH system incluede 350 m^2 roof (USD)	2050
ICC of RWH system incluede 400 m^2 roof (USD)	3680
ICC of RWH system incluede 450 m^2 roof (USD)	4680
ICC of RWH system incluede 500 m^2 roof (USD)	6210
Current O&M cost (USD)	79
Annual water saving (m^3)	968

Result and Discussion

In this study, the storage of harvested rainwater (HRW) for irrigation purposes after passing through first flush and coarse filtration units was examined. It was determined that irrigating a 100 m² lawn area with rainwater collected from a 350, 400, 450 and 500 m² roof areas could save 56%, %64, %71 and %78 of the annual water consumption from the municipal water distribution network, respectively. As this roof:lawn area ratio decreases, the water savings also decline. The primary reason for this reduction is that as the lawn area increases, the water required for irrigation grows proportionally. The results in this study are consistent with the results in the literature. Studies in the literature report that non-potable water savings for domestic use through RWH systems range from 29% to 62%, depending on the characteristics of the buildings [32]. In a study conducted in China, the use of rainwater for irrigation was investigated, and it was shown that a well-designed RWH system could achieve up to 54% water savings from the municipal water distribution network [33].

Comparision of economic and environmental impacts of the RWH system for different roof areas (350 m², 400 m², 450 m² and 500 m²) according to the incentive rates (25%, 50%, 75% and no incentive) were demonstrated in Figure 3. It is evident that the annual water savings (m³/year) exhibit a notable increase with an expansion in roof area, thereby substantiating the assertion that larger roof areas exert a direct influence on the RWH capacity. To illustrate, 100 m³ of water can be saved with a roof area of 350 m², while this value reaches 141 m³ with a roof area of 500 m².

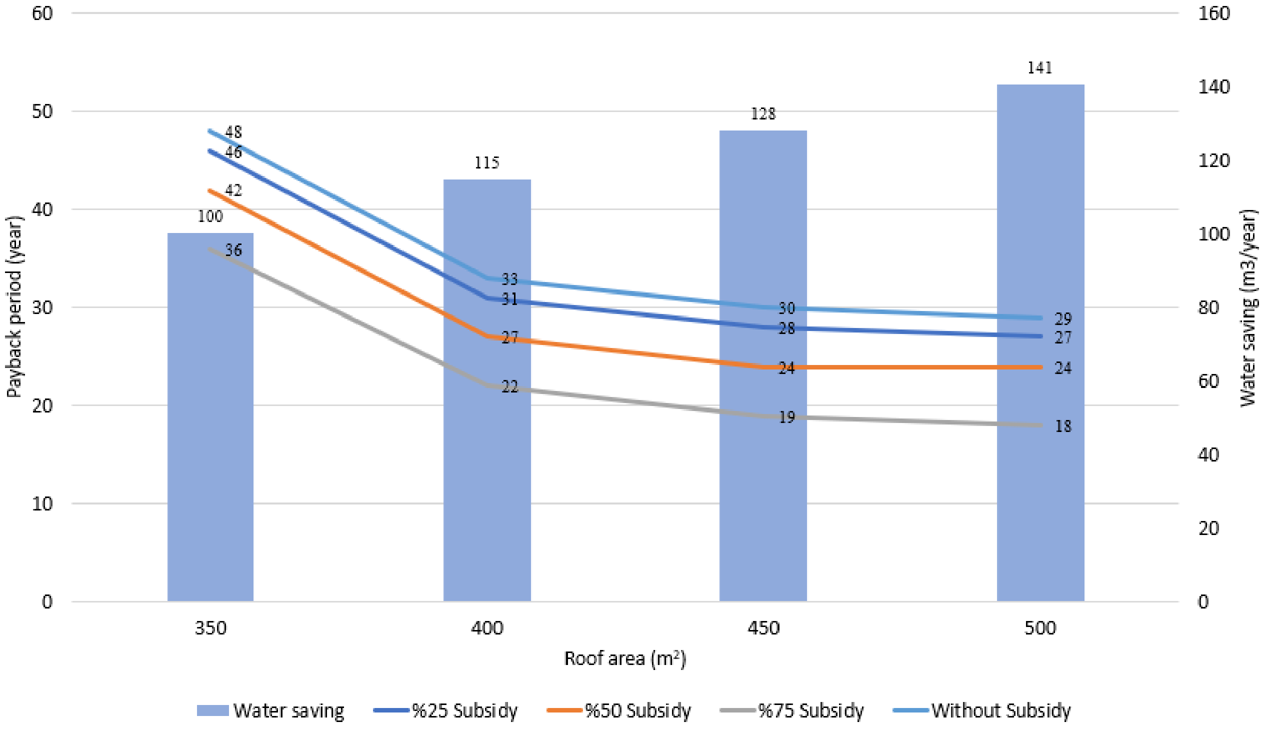

Figure 3. Impact of roof area and subsidy rates on payback period and water savings in RWH systems

The payback period is defined as the year in which the cumulative discounted cash flows exceed the ICC. In other words, even if the annual cash flow is positive from the first year, only after the NPV turns positive does the system generate a profit in total due to ICC. Payback periods decrease inversely proportional to the subsidy rates. While the payback period ranged between 48 and 29 years without subsidy, this period decreased to 36 and 18 years with 75% subsidy. These results reveal that subsidy mechanisms can significantly increase the economic feasibility of the system and strengthen the viability of RWH systems with shorter payback periods, especially in buildings with larger roof areas. Some studies in literature support subsidy to purchase storage tank and pump, which are the first investment cost items in the RWH system, should be offered to the user free of charge or at a discount by the local or municipal government [27-28]. In addition to the subsidy rates, the size of the roof area is among the main factors affecting the water saving and economic recycling performance of the system. Effect of increases in roof area on payback periods was not linear. In particular, while a significant decrease in the payback period is observed in the transition from 350 m² to 400 m², it is noticed that the rate of decrease decreases in the transition from 400 m² to 450 m² and 500 m². This indicates that the growth of the roof area initially provides a larger contribution to the economic performance of the system, but after a certain size, this effect marginally decreases. This trend indicates that system design and cost-effectiveness optimisation should be carefully considered in economic analyses. Based on these results, it can be concluded that a roof area of 400 m² can be considered as an optimum value, considering the rapid decrease in payback period and the significant improvement in terms of water saving. The decrease in the rate of decrease in payback period for larger roof areas indicates a decrease in the marginal benefit of economic performance. Therefore, 400 m² roof area stands out as a balancing point between cost and benefit.

The percentage of rainwater harvested from a 400 m² roof that meets the irrigation water needs of a 100 m² lawn area in each month of the year were demonstrate in Table 3. Especially in January-May and November, irrigation needs were met entirely by rainwater. However, due to low rainfall in June-August, dependency on the municipal water network increased and water savings dropped to 0% during this period.

Table 3. Monthly water balance analysis of RWH system and irrigation needs for 400 m² roof and 100 m² lawn area

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearly total	Yearly average
Rainfall (mm)	69.7	67.2	67.2	68.3	44.4	8.6	1.3	1	5.3	32.5	55.9	71.2	492,6	41
Rainwater yield (mm)	50.2	48.4	48.4	49.2	32.0	6.2	0.9	0.7	3.8	23.4	40.2	51.3	354,7	29,5
Seperated rainwater by first flush (mm/month)	12	11	12	11	9	3	1	1	1	6	8	11	86	7,1
Rainfall – first flush (mm)	38.2	37.4	36.4	38.2	23	3.2	0	0	2.8	17.4	32.2	40.3	269	22,4
Amount of rainwater collected from 400 m² roof (m³)	15.3	15	14.6	15.3	9.2	1.3	0	0	1.1	7	12.9	16.1	107.6	9
Water requirement for 100 m² lawn (m³)	15	15	15	15	15	15	15	15	15	15	15	15	180	15
Rainfall on 100 m² lawn (m³)	3.8	3.7	3.6	3.8	2.3	0.3	0	0	0.3	1.7	3.2	4	26,9	2,2
Irrigation water required for 100 m² lawn (m³)	11.2	11.3	11.4	11.2	12.7	14.7	15	15	14.7	13.3	11.8	11	153.1	12.8
Amount of water needed from municipal water distribution network (m³)	0	0	0	0	0	12.2	15	15	13.6	7.9	1.5	0	65.2	5.4
Monthly savings from municipal water distribution network (%)	100%	100%	100%	100%	100%	19%	0%	0%	9%	47%	90%	100%	-	64%

As a consequence of the reduction in precipitation levels and the concomitant increase in water usage from May onwards, the storage capacity of the tank is rapidly depleted. By June, July and August, the tank is almost entirely empty (Figure 4). Given the absence of precipitation during the summer months, the irrigation requirements will be fulfilled from municipal water distribution network, resulting in the rainwater tank remaining empty during this period. Following the increase in rainfall from September onwards, storage levels rise once more, enabling the system to become active once more in November. For a system with a 400 m² roof, the maximum volume of water that can be stored in the tank is 17 m³. The tank volume was selected to be 20 m³, in order to facilitate market availability and to allow for the inclusion of air space within the storage tank.

A similar study [36] indicates that the payback period of the system is reduced as the storage tank volume increases. Furthermore, the same study highlights that government subsidy contribute to a reduction in the payback period for such systems. In this study, if the ICC is fully subsidised by government incentives, the system generates a profit from the first year onwards.

The use of these RWH systems solely to meet irrigation needs results in a long payback period. In a feasibility study of a RWH in 5 different cities in Brazil, HRW was used for toilet flushing, cleaning and irrigation and the payback period was reported to be in the range of 1.5-10 years [37]. In a study carried out in Barcelona (Spain), HRW met more than 60% of lawn irrigation needs and the payback period was calculated to be 33-43 years for detached houses and 20-29 years for multi-storey buildings [38]. An economic feasibility study in Türkiye calculated that the average payback period for RWH systems is 36 years for residential buildings and 23 years for public buildings. Public buildings have shorter payback periods due to their larger roof areas and water demands [39]. In Türkiye, the water price for public buildings is higher than the water price for residential buildings [39]. From this point of view, it is expected that the payback period of the application of RWH in public buildings and the use of the collected water in irrigation water will be lower than that of residential buildings. Energy prices, storage tank costs, unit water price, annual inflation rate and annual interest rate affect the annual cash flow and NPV. It should be noted that the cost of these items varies from country to country. For this reason, payback periods are different from each other in the studies in the literature.

NPV of such systems is observed to increase in conjunction with an increase in the interest rate. This demonstrates that the RWH system is not financially viable in an economy characterized by a high interest rate. For the system to be profitable, the savings in water usage must exceed the O&M cost from the first year onwards. If the profit from water savings is higher than the annual O&M, the payback period of the system decreases with the increase in inflation. On the contrary, if the O&M is higher, the payback period increases. This situation emphasizes that water savings must be higher than O&M from the first year of the system. Yearly water savings and economic evaluation for 400 m² roof and 100 m² lawn area are given in Table 4. The increase in water price shortens the payback period in such systems. In countries where water is cheap, it is not economically attractive to install a RWH system. However, not only economic benefits but also environmental benefits are very important for RWH systems. To encourage RWH in water scarce countries, water bills can be increased and the initial investment equipment for the RWH system can be offered to the user free of charge.

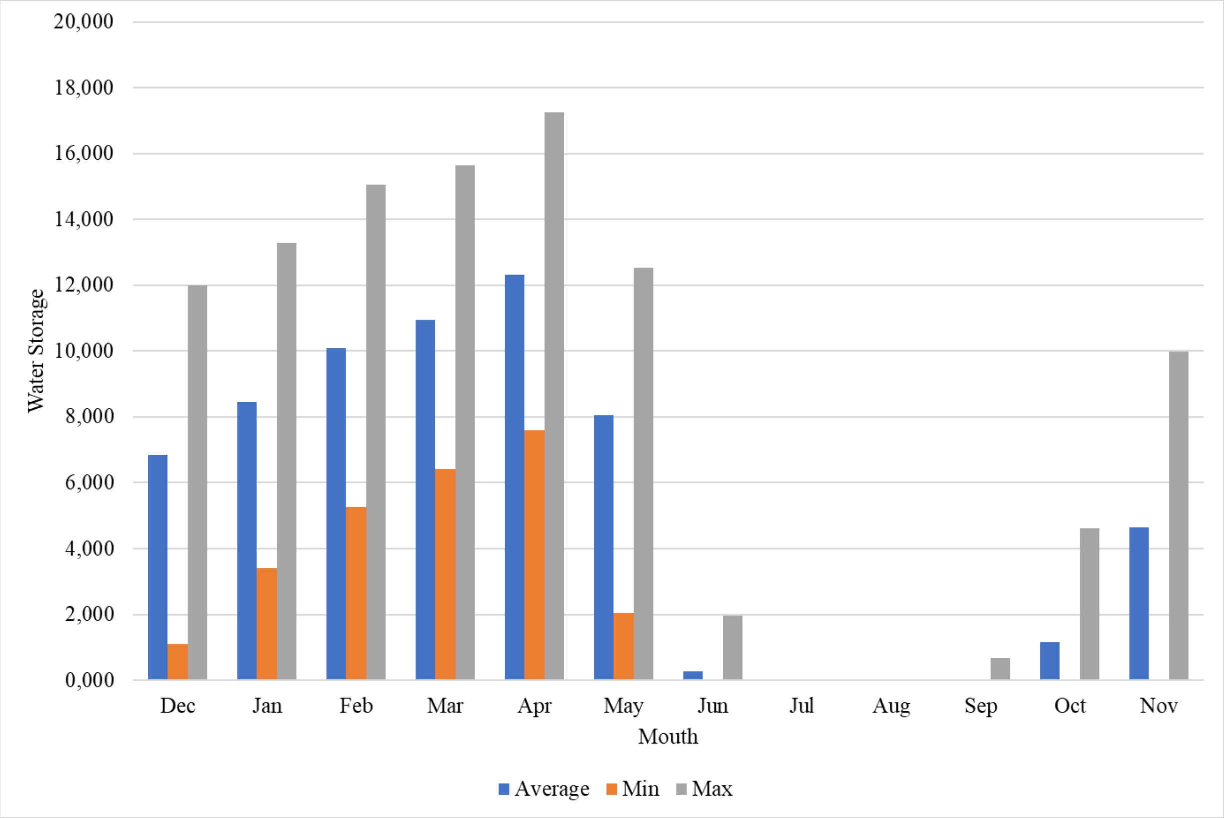

Figure 4. Monthly water storage variations: minimum, maximum, and average values for RWH system with 400m^2 roof

Table 4. Yearly Water Savings and Economic Evaluation for 400 m² roof and 100 m² lawn area

Year	Water Price (USD)	Annual water saving (USD)	O&M cost (USD)	Yearly cash flow (USD)	Sum of NPV-future value of ICC (USD)
1	0.8	91.8	79.1	12.7	-3737.6
2	0.9	107.2	92.3	14.8	-3798.3
3	1.1	125	107.8	17.3	-3858.6
4	1.3	145.9	125.8	20.2	-3918.0
5	1.5	170.3	146.8	23.5	-3976.3
10	3.2	368.6	317.7	50.9	-4236.3
20	15.0	1726.9	1488.4	238.5	-4274.9
30	70.5	8090.6	6973.0	1117.6	-1847.7
31	330.2	37904.2	32668.4	5235.7	-1275.0
32	385.4	44234.1	38124.0	6110.1	-603.2
33	449.7	51621.2	44490.8	7130.5	182.2

Conclusion

This study highlights the potential of RWH systems for enhancing water sustainability by demonstrating their ability to significantly reduce municipal water consumption for lawn irrigation purposes in Diyarbakır province. Results reveal that larger roof areas yield higher water savings, with a 400 m² roof achieving an optimal balance between cost-effectiveness and water conservation, saving 64% of annual irrigation water needs for a 100 m² lawn. The economic feasibility of RWH systems is strongly influenced by government subsidies, which notably shorten payback periods, and by contextual factors such as energy prices, inflation, and water costs. Seasonal variations underscore the necessity of designing RWH systems to complement municipal water supplies during dry periods. While economic incentives remain critical for widespread adoption, the environmental benefits of these systems provide a compelling case for their implementation, particularly in regions facing water scarcity. In addition, it is also emphasized the importance of using the first flush system to maintain appropriate water quality although it slightly reduces the amount of harvested rainwater. The implementation of RWH applications has the potential to alleviate the issue of water scarcity in arid regions. However, the economic viability of such initiatives remains contingent upon the provision of government incentives or subsidies.

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