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Using Harvested Rainwater from Urban Grass Surfaces for Landscapes Irrigation: Considering the Effect of Slope on Run-off Coefficient

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Abstract

Efficient water management is crucial in arid and semi-arid regions like Iran. In this study, the potential of rainwater harvesting (RWH) for irrigating urban parks and landscapes in Zanjan, Iran, was evaluated. For this purpose, the rainfall data from the Zanjan synoptic station during the period 2014-2022 was used. Using the ArcGIS software, the area and slope of parks and landscapes was determined. The volume of harvested rainwater from these surfaces was estimated using different run-off coefficients for different slopes. The results indicated that the total area of parks and landscapes in Zanjan is 537200 m², with slopes ranging from 0% to 18.47%. The irrigation requirements are only partially met by the harvested rainwater, except for March, when we had the most rain. In January and February, rainwater meets 7.68% and 12.60% of the needs, respectively. In March, all the water requirement is met, with extra water stored for April. This stored water fully meets the water requirement in April, with some left for May, covering 18.94% of its demand. In May, 26.88% of the needs are met. From June to December, rainwater meets between 0.54% and 10.92% of the needs. March, April and May have the highest potential for meeting irrigation needs through RWH. This emphasizes the importance of constructing RWH reservoirs, which helps save municipal water and prevents rainwater from being wasted.

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Introduction

Water scarcity stands as one of the most crucial challenges, highlighting the need to adopt innovative methods to meet the growing water demand, particularly in arid and semi-arid regions as well as developing countries. The limited rainfall in these regions has impacted natural resources and life, and the global climate change has intensified the challenges of water use (Yifru et al., 2021). Therefore, optimal use of water is always considered as a sustainable solution for the limited water resources (Wei et al., 2005; Kahinda et al., 2007; Helmreich & Horn, 2009).

Since rainfall occurs almost everywhere, harvesting, storing, and using rainwater as a supplementary technique for surface- and ground-water resources can supply part of the water required by various sectors and reduce urban floods. However, this supplementary resource is usually unavailable due to a lack of proper management (Opare, 2012; Rostami Khalaj et al., 2020; Beheshti et al., 2022; Chamani et al., 2022). The harvested and stored rainwater is less polluted than other water resources and can be used for drinking after disinfection (Vilane & Mwendera, 2011). According to the Pan American Health Organization (2017), even healthcare centers can use this water during times of crisis (PAHO, 2017). Accordingly, identifying the most suitable locations for rainwater harvesting (RWH) is a fundamental topic for global studies (Hatibu et al., 2006; Adham et al., 2016; Mahmoud et al., 2016).

Several studies have been conducted in the field of RWH for various uses. Gavit et al. (2018) used ArcGIS and remote sensing to investigate the sustainability of RWH structures in the Punad watershed, India, classifying the suitable locations into three categories based on the basin slope: high, medium, and low. Kanno et al (2021), using a 17-year dataset of rainfall, evaluated the potential of RWH in Dilla Town, Ethiopia, and stated that RWH can serve as an alternative resource for meeting domestic and industrial water requirements and even help supply water during the COVID-19 pandemic. Ahmed et al. (2022) studied RWH from rooftops at the Taxila University, Pakistan, and concluded that the monthly water which can be harvested from these surfaces equals 59% of available water resource for irrigation of trees and plants. Zhong et al. (2022) showed that RWH in Arizona can supply 32% of urban water requirements for eight months in a humid year, leading to an annual saving of $13.8 million. Jacque et al. (2023) investigated the hydrological feasibility of RWH for irrigation of landscapes and public gardens in the UK. They demonstrated that the gardens located in the more humid areas, with a low ratio of irrigation water demand to the amount water which can be harvested, have high potential for RWH. Halder and Bose (Halder & Bose, 2024) used remote sensing to identify and classify the suitable areas for RWH in Puralia, India. They compared the performance of Artificial Neural Network (ANN) and Random Forest (RF) in optimizing RWH strategies. Their findings revealed that rainfall, slope, run-off generation potential, soil, land cover, and drainage are the six key factors for selecting suitable locations for RWH. In Iran, Taran & Mahtabi (2016) assessed the potential of Bonab, Iran, for RWH. They concluded that by collecting run-off from all the urban surfaces in each month, 100% of the water demand of public, commercial and industrial centers can be supplied during the first two months of spring and from mid-fall to late-winter. Additionally, by collecting run-off from courtyards and rooftops in residential areas throughout the year, a portion of the domestic water demand could be met. Chamani et al. (2022) calculated the amount of water which can be harvested from annual rainfall in Aryan Shahr, Iran. They indicated that annually 141636 m^3 run-off can be harvested from the urban surfaces and utilized for various purposes, including irrigation of landscapes. Beheshti et al. (2022) investigated the use of retention ponds and rooftop rainwater collection in Birjand, Iran, and concluded that RWH can reduce run-off volume by 80% and contribute to landscape irrigation. Nevertheless, to our knowledge, the slope of urban surfaces from which rainwater is harvested and utilized for irrigation has not been taken into account so far in Iran. Slope is a key factor directly affecting the run-off coefficient and, consequently, the volume rainwater which can be harvested. In areas with steeper slopes, the volume of run-off increases due to reduced water infiltration into the soil (Park et al., 2014). The run-off coefficient is used to represent run-off generation on various regional scales and is defined as the ratio of the volume of surface water to the volume of rainfall over a specified period (Machado et al., 2022). Taking the factors affecting the run-off coefficient into consideration is particularly crucial in urban areas where there are many impervious surfaces and run-off is a serious threat (Shi et al., 2007). Despite the existence of standardized tables for run-off coefficients, recent studies have shown that these fixed values may not align with local realities and various environmental factors. For instance, Machado et al. (2022) indicated in their study in Sao Paulo, Brazil, that run-off coefficients calculated using hydrographs differed from the values found in standard tables and that the run-off coefficient had a strong correlation with land use. Similarly, Blume et al. (2007) emphasized that fixed run-off coefficients do not provide accurate information due to the influence of multiple environmental factors.

Among urban surfaces, according to the study by Mahtabi & Taran (2017), run-off generation on grass surfaces is more affected by slope than on other surfaces. In the present research, the potential for RWH from the grass surfaces in Zanjan, Iran, to supply irrigation water for the city's landscapes over the course of one year was examined. Irrigation of landscapes is important due to its numerous social benefits, including positive impacts on human physical and mental well-being (Maller et al., 2006; De Bell et al., 2020), contribution to tourism and labor economies (Croy et al., 2020), preservation of plant species diversity (Moyle & Weiler, 2017), and providing green infrastructure and ecosystem services (Cameron & Blanusa, 2016). For landscape irrigation, surface- and ground-water are often used, but these resources are especially limited during hot seasons and drought periods, requiring alternative resources. In this study, the total area of landscapes and grass surfaces in Zanjan, and their slopes in different parts of the city were determined. Then, the run-off coefficients for these surfaces in part were calculated. Finally, using monthly rainfall data, the run-off generated and, consequently, the potential amount of water which can be harvested from these surfaces were obtained. The innovative aspect of this study lies in its approach to incorporate the effect of slope on the run-off coefficient in RWH for urban grass surfaces in Iran. By highlighting the relation between slope variations and run-off generation, this study offers a more precise and localized method for estimating the potential of harvested rainwater. This focus addresses a critical gap in sustainable water management strategies, particularly in urban areas where impervious surfaces and water scarcity pose significant challenges.

Materials and Methods

Study Area

Zanjan city, the capital Zanjan province, is located at latitude 47° 47ˋ N and longitude 37° 08ˋE and an elevation of 1663 m above sea level in northwest Iran. In 2025, the city's area is 65 km^2. According to the latest population and housing census, the city's population is reported to be approximately 52000 people. The location of Zanjan is shown in Figure 1.

Fig 1. The location of Zanjan in Iran

Rainfall

In this study, using data from the synoptic station of Zanjan, the 9-year (2014-2022) average of total monthly rainfall was obtained (Table 1).

Table 1. Nine-year monthly average of rainfall (mm)

Month	Rainfall	Month	Rainfall
January	36.16	July	5.86
February	53.60	August	2.52
March	79.73	September	5.98
April	62.19	October	42.64
May	37.37	November	49.79
June	7.11	December	44.22

The volume of harvested rainwater

The volume of harvested rainwater from a surface (run-off discharge) is calculated using Eq.1 (Taran & Mahtabi, 2016):

$$V=CIA \quad (1)$$

where, V (L) is the volume of harvested rainwater or the run-off quantity, I (mm) is the rainfall height, and A (m^2) is the rainwater harvesting area. C is the run-off coefficient of the surface and represents the portion of rainfall that can be converted into run-off.

The water requirement of parks and landscapes

According to Publication No. 117.3 of Design Criteria for Urban and Rural Water Transmission and Distribution Systems (2023), concerning water consumption in Iran up to 2018, this study determined the water requirements of the domestic and public landscapes in Zanjan. Based on the climate classification in this publication, Zanjan is located in two climatic regions: semi-arid and cold, and semi-humid and cold. The average daily water consumption for landscapes in these regions is estimated to be 1.5 to 2 $L.m^{-2}.day^{-1}$, with an average of 1.75 $L.m^{-2}.day^{-1}$.

Results and discussion

The area and slope of parks and landscapes

The area of parks and landscapes within the urban boundaries of Zanjan, along with the slope of each region, was obtained using the ArcGIS software. Table 2 presents the area corresponding to each slope class. The total area of the parks and landscapes was determined to be 537200 m^2. The minimum and maximum slope classes for parks and landscapes within the urban boundaries were 0-1.45% and 13.47-18.47%, respectively, with all slopes categorized between these two classes. The largest and smallest area were 145400 m^2 and 16900 m^2, respectively, belonging to 0-1.45% and 8.18-8.91% slope classes; these slope classes account for 27.06% and 3.14% of the total area of parks and landscapes, respectively. Figure 2 depicts the distribution of parks and landscapes within the urban boundaries of Zanjan.

Table 2. The areas and slopes of the parks and landscapes in the urban area

Slope class (%)	Average Slope (%)	Area ($m^2 \times 10^4$)	Percentage of area
0-1.45	0.72	14.54	27.06
1.45-2.10	1.77	4.00	7.45
2.10-3.91	3.00	2.53	4.71
3.91-5.14	4.52	2.74	5.10
5.14-6.01	5.57	2.11	3.92
6.01-6.88	6.44	1.90	3.53
6.88-7.46	7.17	2.11	3.92
7.46-8.18	7.82	2.11	3.92
8.18-8.91	8.54	1.69	3.14
8.91-9.56	9.23	2.53	4.71
9.56-10.28	9.92	2.53	4.71
10.28-11.23	10.75	3.58	6.67
11.23-12.10	11.66	2.74	5.10
12.10-13.47	12.78	4.42	8.24
13.47-18.47	15.97	4.21	7.84
Total	-	53.72	100

Fig 2. The distribution of parks and landscapes with different slopes withing the urban area

The run-off coefficients of parks and landscapes

According to the values of run-off coefficient for grass surfaces with the slopes of 5%, 10%, and 15%, reported as 0.09, 0.19, and 0.24, respectively, by Mahtabi & Taran (2017), the run-off coefficient for different slopes in the present study (Table 2) can be estimated by interpolation and using the trendline of the graph in Figure 3. It is noted that the quadratic equation provided the best trendline with R^2=0.97. Table 3 gives the values of run-off coefficient for parks and landscapes with different slopes.

The volume of run-off which can be harvested from parks and landscapes

Considering the values of monthly rainfall presented in Table 1 and using Eq.1, the volume of run-off generated on the park and landscape surfaces or rainwater which can be harvested from these surfaces withing the urban area of Zanjan in different months was calculated for various slopes, as given in Table 4. Since the lowest rainfall has occurred in August (2.52 mm), the smallest volume of

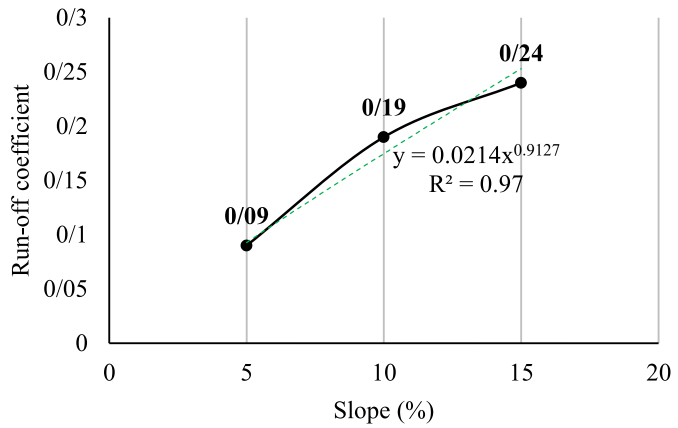

Fig 3. The trendline of the run-off coefficient of grass surfaces versus different slopes

Table 3. The estimated values of run-off coefficient for grass surfaces with different slopes

Average slope (%)	Run-off coefficient	Area ($m^2 \times 10^4$)
0.72	0.0159	14.54
1.77	0.0360	4.00
3.00	0.0583	2.53
4.52	0.0848	2.74
5.57	0.1026	2.11
6.44	0.1171	1.90
7.17	0.1292	2.11
7.82	0.1398	2.11
8.54	0.1515	1.69
9.23	0.1627	2.53
9.92	0.1738	2.53
10.75	0.1870	3.58
11.66	0.2014	2.74
12.78	0.2189	4.42
15.97	0.2683	4.21

rainwater which can be harvested belongs to this summer month (156058.97 L). in contrast, the largest volume of rainwater that can be harvested is 59019625.06 L which corresponds to the spring month of March with a rainfall of 79.73 mm.

Supplying the water required for the irrigation of parks and landscapes form the rainwater harvested from these surfaces

Since the water requirement of parks and landscapes in Zanjan is 1.75 $L.m^{-2}.day^{-1}$, and the total area of these surfaces is 537200 m^2, the water requirement was calculated in liters for each month (Table 5). It should be noted that the number of days in February, excluding leap years, was considered to be 28.

Figure 3 shows the volume of rainwater that can be harvested from parks and landscapes along with the water required for their irrigation in each month. The comparison between these two values reveals that in

Table 4. The volume of rainwater that can be harvested from parks and landscapes in different months

Run-off	V ($L\times10^3$)					
coefficient	January	February	March	April	May	June
0.0159	83.59	123.92	458.37	143.77	86.39	16.44
0.0360	52.06	77.18	1037.81	89.55	53.81	10.24
0.0583	53.33	79.06	1680.67	91.73	55.12	10.49
0.0848	84.01	124.54	2444.62	144.50	86.82	16.52
0.1026	78.27	116.04	2957.76	134.63	80.89	15.39
0.1171	80.44	119.25	3375.76	138.36	83.14	15.82
0.1292	98.56	146.12	3724.58	169.53	101.87	19.39
0.1398	106.65	158.11	4030.16	183.44	110.22	20.98
0.1515	92.57	137.23	4367.45	159.23	95.67	18.21
0.1627	148.83	220.63	4690.32	255.99	153.81	29.27
0.1738	158.98	235.69	5010.31	273.45	164.31	31.27
0.1870	242.05	358.83	5390.84	416.33	250.15	47.61
0.2014	199.52	295.78	5805.97	343.18	206.20	39.24
0.2189	349.82	518.60	6310.46	601.70	361.54	68.80
0.2683	408.39	605.44	7734.56	702.45	422.07	80.32
Total	2237.07	3316.42	59019.63	3847.85	2312.01	439.99
Run-off	**V ($L\times10^3$)**					
coefficient	**July**	**August**	**September**	**October**	**November**	**December**
0.0159	13.54	5.83	13.82	98.59	115.10	102.24
0.0360	8.43	3.63	8.61	61.41	71.70	63.68
0.0583	8.64	3.72	8.82	62.90	73.44	65.23
0.0848	13.61	5.86	13.89	99.09	115.69	102.75
0.1026	12.68	5.46	12.94	92.32	107.79	95.73
0.1171	13.03	5.61	13.30	94.88	110.78	98.39
0.1292	15.96	6.88	16.30	116.25	135.73	120.56
0.1398	17.27	7.44	17.63	125.79	146.87	130.45
0.1515	14.99	6.46	15.31	109.18	127.48	113.22
0.1627	24.10	10.38	24.61	175.54	204.95	182.03
0.1738	25.75	11.09	26.29	187.51	218.93	194.45
0.1870	39.20	16.89	40.02	285.49	333.32	296.05
0.2014	32.31	13.92	32.99	235.33	274.75	244.03
0.2189	56.65	24.40	57.84	412.60	481.73	427.87
0.2683	66.14	28.49	67.52	481.69	562.39	499.51
Total	362.30	156.06	369.87	2638.57	3080.62	2736.19

Table 5. The water requirements of parks and landscapes in different months ($L\times10^3$)

Month	Water requirement	Month	Water requirement
January	29143.10	July	29143.10
February	26323.80	August	29143.10
March	29143.10	September	28203
April	28203	October	29143.10
May	29143.10	November	28203
June	28203	December	29143.10

all months, expect for March which has the highest amount of rainfall throughout the year, the harvested rainwater can only supply a portion of the water required for irrigating parks and landscapes. In January and February, 7.68% and 12.60% of the water requirement, respectively, are met through rainwater RWH. In march, in addition to meeting 100% of the water requirement, 29876.53 kL of the harvested rainwater can be stored for the following month (April). Burszta-Adamiak & Przybylska (2024), in their research in Poland, stated that water stored in above-ground tanks could be used for watering plants, covering 62 to 82% of the need. They implied that underground reservoirs, having more capacity, could meet the water demand completely. Given that the water requirement in April is 28,203 kL, the stored water can fully cover this requirement. However, since the harvested rainwater in April itself amounts to 3847.85 kL, a surplus of 5521.38 kL from the stored water in March remains available for use in May. This amount can supply 18.94% of the water requirement in May. Considering the rainwater harvested in May, which is 2312.01 kL, a total of 26.88% of the water requirement in May will be met. Using the harvested rainwater from June to December, respectively 1.56%, 1.24%, 0.54%, 1.31%, 9.05%, 10.92%, and 10.92% of the water required for irrigating parks and landscapes in Zanjan can be supplied. Therefore, throughout the year, in the three months of March, April, and May the highest percentage of irrigation water can be met through RWH. Since these three months coincide with spring in Iran, when the highest number of tourists visit cities across the country (Mahtabi & Taran, 2018), ensuring sufficient water reaches urban grass surfaces enhances the beauty of parks and landscapes. In general, using harvested rainwater can reduce irrigation expenses, making it a cost-effective option for maintaining public gardens and parks (Cauteruccio & Lanza, 2022; Jacque et al., 2023). Chiu et al. (2020) have stated that RWH can provide a substantial amount of water for irrigation, especially in arid regions like Iran, where traditional water resources are under stress. Also, Saeedi & Goodarzi (2020) have reported that RWH contributes to sustainable landscape development, helping to mitigate the effects of urbanization and climate change on water resources. These highlight the importance of constructing RWH reservoirs/tanks for irrigation of these surfaces, which not only contributes to saving municipal water but also prevents rainwater wastage (Rostami Khalaj et al., 2020; Wesseling et al., 2021). The importance of collecting and storing rainwater for irrigation use has been reported in several studies. For instance, Taran & Mahtabi (2016) found out that utilizing spring rainfall in Bonab, Iran, can not only meet the water demand of the landscapes during spring months, but also fully compensate for the water shortage during the first two months of summer. Wurthmann (2019) stated that if sufficiently stored, rainwater can supply the water required for irrigation of landscapes in Florida, USA.

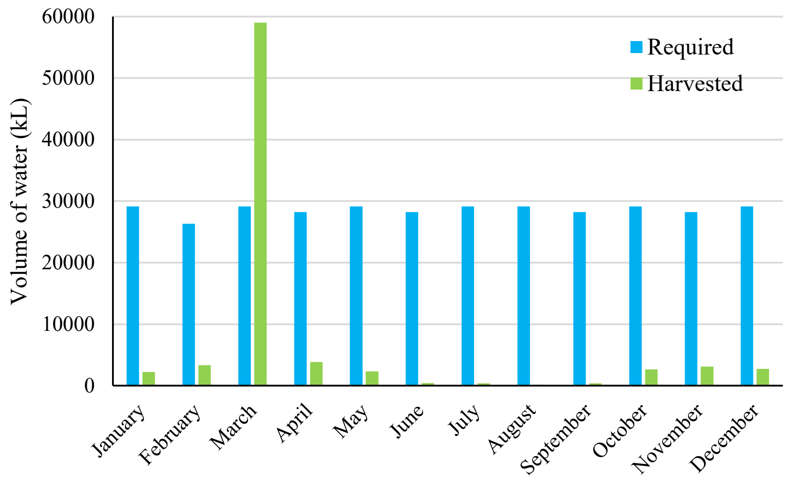

Fig 4. The volume of rainwater that can be harvested and the water required for irrigation

Conclusion

This research evaluated the potential of RWH for supplying irrigation water to parks and landscapes within the urban boundaries of Zanjan. The findings indicated that the total area of these surfaces is 537200 m², with varying slopes affecting run-off coefficients. Using rainfall data from a nine-year period (2014–2022), the volume of run-off generated in different months was calculated. The results showed that the highest volume of rainwater that can be harvested occurs in March, while the lowest occurs in August. The comparison between harvested rainwater and the monthly irrigation water requirement demonstrated that only March can fully meet the water requirement of parks and landscapes, with a surplus available for storage. The stored water from March can also fully meet the irrigation requirement in April and partially contribute to that of May. In contrast, during other months, RWH can only supply a fraction of the required irrigation water, ranging from 0.54% in September to 12.60% in February. Based on these findings, the construction of RWH reservoirs or storage tanks is recommended to save more water and minimize dependence on municipal water supplies. This is particularly important during spring, when tourism is at its highest, and keeping landscapes beautiful is essential for the city's appearance. Using RWH strategies can play a big role in sustainable water management by optimizing available water resources for irrigation purposes.

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