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Feasibility Study of Rainwater Harvesting from Large Rooftops (Case Study: Ahvaz City, Iran)

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Abstract
Humanity is currently facing one of its greatest challenges a shortage of renewable and accessible water resources. One of the best and most cost-effective solutions for sustainable water resource utilization is rainwater harvesting system (RWS). Rooftops of buildings can act as water micro-catchment surfaces and store rainwater before it turns into runoff losses. In order to investigate the potential of rainwater conservation and recycling, in this study, the feasibility of utilizing rainwater harvesting from rooftops of public and large buildings of Ahvaz city was evaluated. To achieve the goal, we utilized annual precipitation data, the Statistical Yearbook of the Ahvaz Metropolitan Area, and satellite imagery from Google Earth. Large buildings were categorized into 6 groups, and the total rooftop area suitable for implementing a rainwater harvesting system was estimated. It was calculated that approximately 222,708 m^3 of rainwater could be harvested annually from the rooftops of these buildings. The volume of harvestable water was distributed among different building categories, with industrial sites having the largest share, followed by governmental offices and educational centers. The results form the Sotnikova equations showed that by help of RWS could meet 11.42% of Ahvaz's industrial water demand, leading to a reduction in dependency on external water sources and economic savings. Recycled rainwater could supply up to 34.56% of the water demand for urban parks in Ahvaz.
Keywords: Ahvaz, Google Earth, Runoff, Water saving.

1. Intruduction

Water is the most fundamental need for human survival, and it can be sourced and utilized from surface water, groundwater, or rainwater (Gleick, 1996). According to the predictions of the International Water Association, the world will face a 40% water shortage by 2030. This challenge has prompted the presentation of innovative solutions to enhance sustainable water resource management practices (García-Montoya et al., 2015). In recent years, rainwater harvesting has garnered attention from researchers (e.g. Ebrahimi and Mohseni Saravi, 2021; Jahangiri and Assareh, 2019). They believe that this practice also has favorable effects on urban water infrastructure (Campisano et al., 2017). One of the best and most cost-effective solutions for sustainable water resource management is rainwater harvesting. On one hand, rooftops can serve as effective catchment surfaces, capturing rainwater and storing it before it is converted into runoff (Maddah and Ahmadi, 2020).

Due to the fact that rooftops are typically already waterproofed, a significant portion of the implementation costs is reduced. The conventional and simple household rainwater harvesting system (RWS), consists of four essential components: a catchment area (roofs, non-permeable paving surfaces, green roofs, etc.), a conveyance system (including pipes, fittings, and valves, etc.), a storage tank, and a pumping system (Campisano et al., 2017). The function of this system is described below.

Rainwater collected on the catchment surfaces is directed towards the storage tank via the conveyance system, where it is pumped towards the desired water demand using a pumping system. It is obvious that if the goal is to obtain drinking water, a filtration system will also be necessary. Figure 1, drawn using SolidWorks software, illustrates a simple rainwater harvesting system in a household.

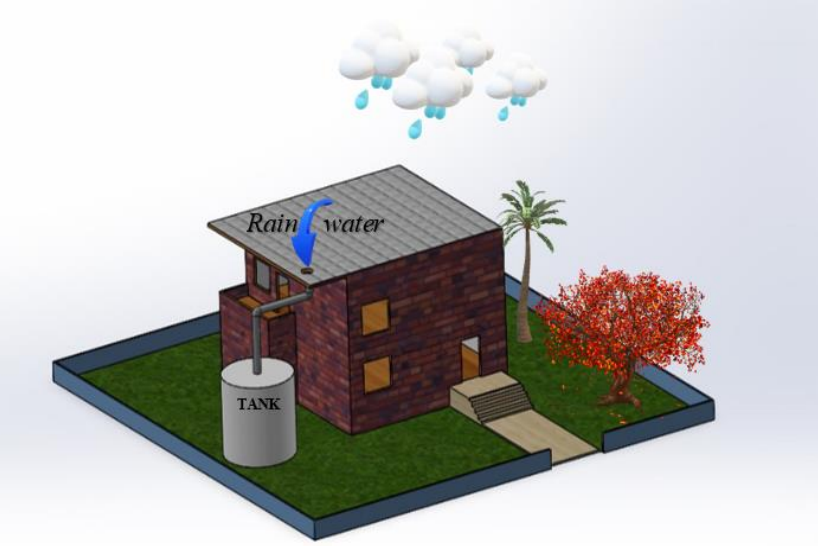

Fig. 1. A depiction of a rainwater harvesting system from rooftops aimed at storage (drawn by the authors).

Utilizing rainwater reduces reliance on primary urban water sources, contributes to environmental conservation, and promotes water conservation. Collecting rainwater from rooftops and similar surfaces helps preserve natural water resources, control flooding, and maintain groundwater quality. Reusing and recycling rainwater, in reducing sudden downpours and stabilizing water sources, are among the vital and significant benefits of this initiative. Extensive research has been conducted on this subject to date, yielding notable results.

Porhemmat et al. (2019) conducted a study on the building complexes of the Ministry of Energy and Tavanir to determine the amount of rainwater harvestable considering the precipitation received on the premises of these buildings. This area encompasses 12 hectares, with 3.7 hectares designated as green space. Their research indicated that by harvesting rainwater from the rooftops of the ministry buildings, it is possible to meet 80% of the annual water requirements for the green spaces (Porhemmat et al., 2019). In a study conducted by Adugna et al. (2018), rainwater harvesting from rooftops in the city of Addis Ababa, the capital of Ethiopia, was examined and evaluated. They investigated the role of rooftop rainwater harvesting by assessing eleven large public institutions in Addis Ababa. It was estimated that the city could replace up to 2.3% of its drinking water supply through rainwater harvesting from the rooftops of these large public institutions (Adugna et al., 2018). Abbas et al. (2021) conducted a study aimed at investigating the potential of rainwater harvesting from rooftops and its physio-economic impacts on the people in the Rawal Watershed Basin, Pakistan. The analysis of the questionnaires in this study showed that people believe rainwater harvesting from building rooftops can have a positive impact on their economic and health conditions. As a result, it was concluded that rainwater harvesting from building rooftops, as an alternative water source, has significant potential in the areas of the Rawal Watershed Basin (Abbas et al., 2021). In another exploration, the potential use of rainwater as a renewable water source in Tehran was precisely evaluated. Through detailed analysis of satellite images provided by Google Earth, the total area of rooftops suitable for rainwater harvesting in 22 different areas of Tehran was accurately measured. The results showed that in Tehran, residential rooftops constitute over 47% of the city's surface area and have the capacity to collect 25.6 million cubic meters of rainwater annually (Neshastegar and Taghavijeloudar, 2021). Jacque et al. (2023) investigated the feasibility of using Rainwater Harvesting Systems (RWS) to meet the water demand of landscapes and public gardens. Their findings indicated that harvested rainwater can serve as a valuable source for irrigation, significantly reducing the vulnerability of gardens and important tourist attractions in the country during dry years due to water absorption constraints (Jacque et al., 2023).

Kakoulas et al. (2022) stated that the school environment, which does not have water consumption in the summer season, has the ability to meet 60% of its own water needs through a rainwater collection system with a 24 cubic meter tank (Kakoulas et al., 2022). In this research, we intend to examine and evaluate the possibility of utilizing the rainwater harvesting method from the rooftops of large public centers in Ahvaz city. Ultimately, conducting a feasibility assessment of implementing this project in Ahvaz city will provide useful information to relevant managers to adopt appropriate patterns and strategies. In a study to interview 187 residents from six cities in six central provinces of Iran about their experiences, knowledge and views on the importance and benefits of rainwater harvesting, a comprehensive questionnaire was used. The results showed that more than 51 percent of participants believed that rainwater harvesting is very necessary for public and commercial buildings (Sheikh, 2021).

2. Materials and Methods

2.1. Study Area

Ahvaz is a city located in the southwestern part of Iran and serves as the capital of Khuzestan Province. Positioned at approximately 31 degrees and 30 minutes north latitude and 48 degrees and 65 minutes east longitude, the city lies in the Khuzestan plain at an elevation of 18 meters above sea level (Figure 2). The Karun River flows through the middle of Ahvaz. Originating from the Bakhtiari Mountains, the Karun River is the wettest and largest river in Iran, passing through the center of Ahvaz. With a length of 950 kilometers, it is the longest river entirely located within Iran and the only navigable river in the country. Moreover, the drinking water supply for the metropolitan area of Ahvaz is sourced from the Karun River. According to the 2016 census statistics, the population of Ahvaz is approximately 1.2 million people (Statistical Yearbook of Ahvaz Metropolitan Area, 2022). According to the Demarton classification, Ahvaz falls under the arid climate category (Seydi and Gondomkar, 2021)

In this type of climate, the annual precipitation is less than 250 mm, and the potential evapotranspiration exceeds the precipitation. Also, the annual precipitation is low and occurs as brief and scattered showers during the cold seasons.

2.2. Data used and research method

In this article, statistical data related to the rainfall in the city of Ahvaz is utilized to estimate the annual, monthly, and daily precipitation levels. The precipitation data used are obtained from the synoptic station in Ahvaz, provided by the Iranian Meteorological Organization. In the first step, some of the buildings and structures in Ahvaz are categorized based on characteristics such as roof area and geographical location, and are examined. Satellite images provided by Google Earth are employed to assess the potential for rainwater harvesting from accessible sources. These images enable the measurement of the capacity of existing rooftops and ceilings for implementing this water management method, using data from satellites such as Landsat and other satellite systems utilized in Google Earth web-service (Figure 3). With access to regional rainfall statistics and estimates of catchment areas, the potential volume of harvestable water is calculated.

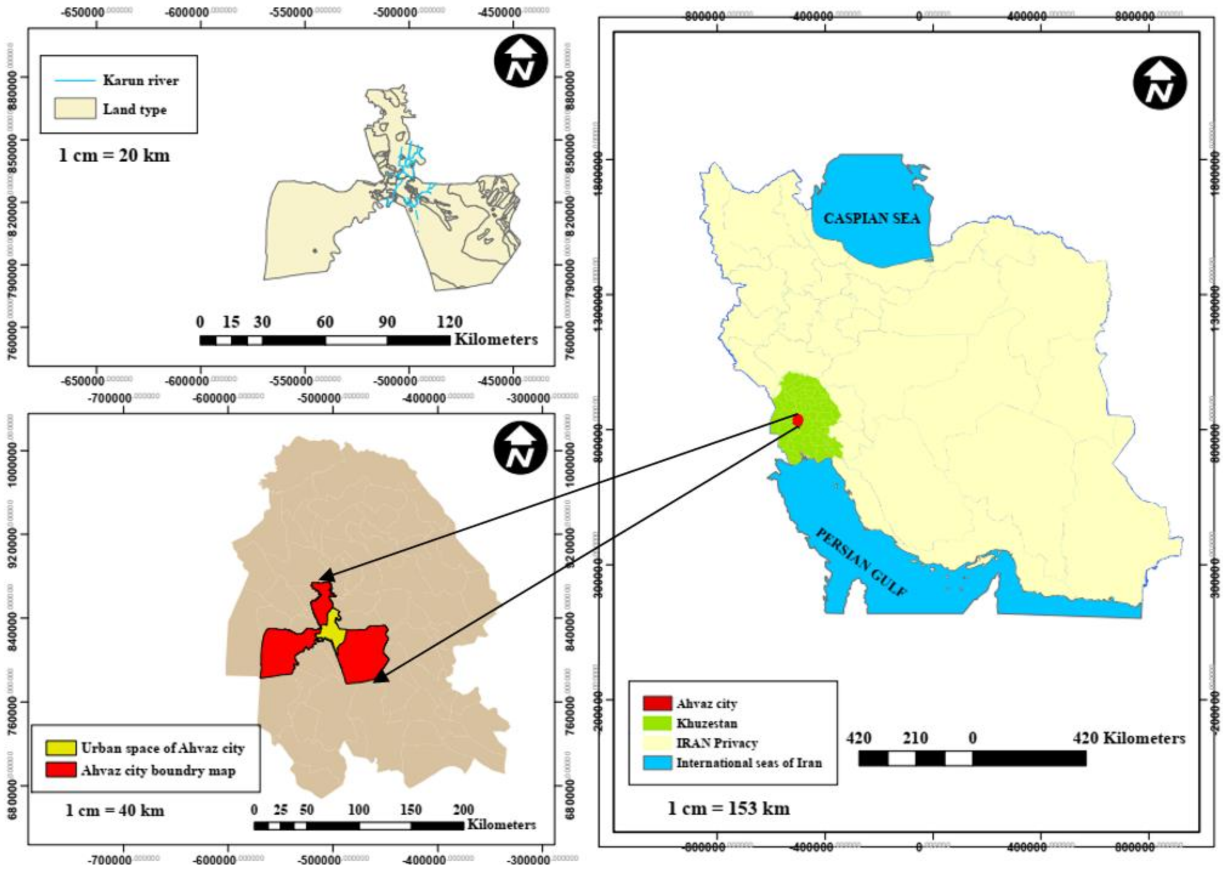

Fig. 2. Geographical map and location of Ahvaz city as the case study

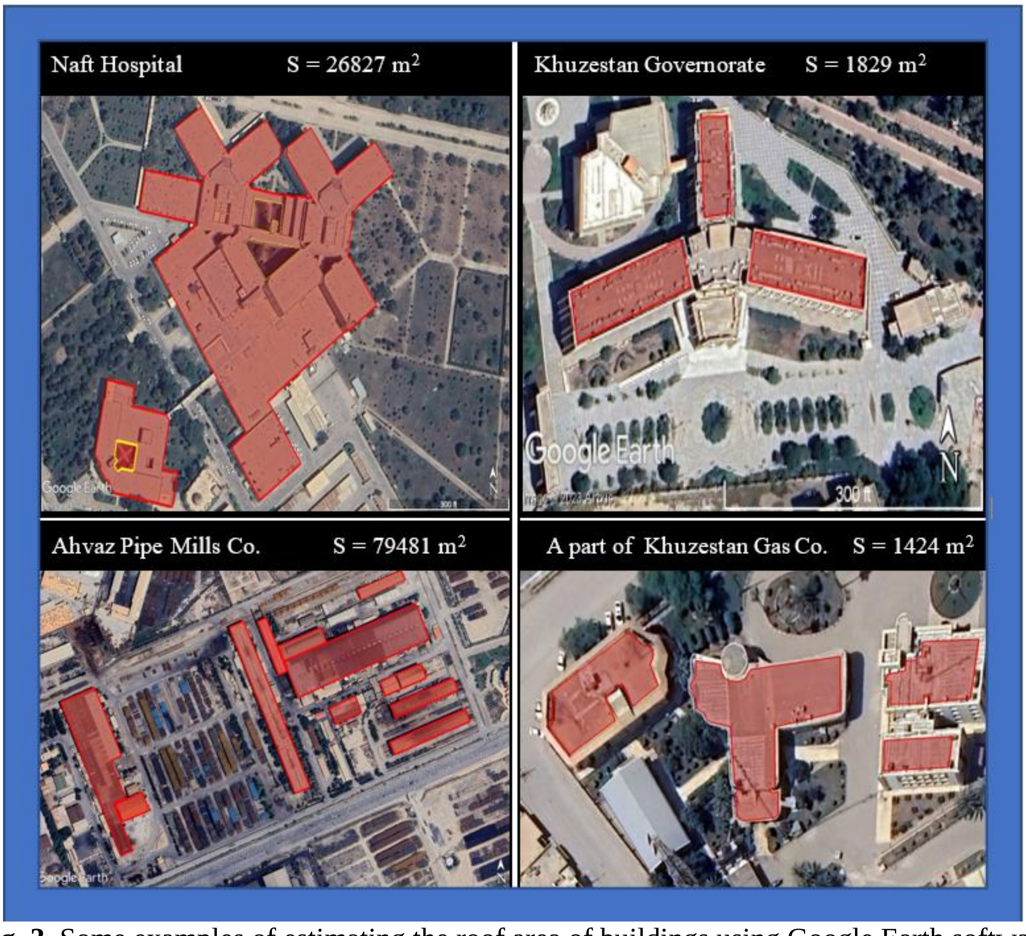

Fig. 3. Some examples of estimating the roof area of buildings using Google Earth software

Ultimately, after conducting computational studies and conceptual examinations, the feasibility of this method for harvesting rainwater resources in the city of Ahvaz was theoretically evaluated. Therefore, the following relationships were used in this article for this purpose.

$$P_a = S \times H_p \times C_d \qquad (1)$$

Eq. 1 calculates the potential rainwater harvesting from the roof of a building. In this equation: P_a represents the annual precipitation volume in cubic meters per *S*, *S* is the total surface area of the catchment in square meters, H_p denotes the annual precipitation in meters, and C_d is the runoff coefficient. Considering that the majority of roofs in Ahvaz city are flat with an Isogam coating, C_d is estimated to be 0.7 (Sotnikova et al., 2012).This estimate aligns with the findings of research conducted by Jahangiri and Assareh (2019) in Ahvaz. In their study, conducted over various seasons of the year, they determined the runoff coefficient for flow on rooftops. Ultimately, the average value of the coefficient determined in their research was found to be 0.713. Therefore, it can be concluded that the results of this study also indicate that the current estimate is consistent with previous empirical findings (Jahangiri & asareh, 2019).

Determining the precise volume required for rainwater collection reservoirs is a critical parameter in designing rainwater storage and utilization systems. Empirical relationships such as the Sotnikova equation (Eq. 2) have been extracted for them (Sotnikova et al., 2012).

$$V = 0.5 + 0.05 \times P_a \qquad (2)$$

3. Results and Discussion

Collecting statistics related to precipitation in each region is an essential preamble for assessing the potential of a rooftop rainwater harvesting system in that area. Accordingly, the annual precipitation in Ahvaz from 1995 to 2022 was investigated. The statistics are depicted in Figure 4, and the long-term average annual precipitation for the city of Ahvaz was estimated to be 202.475 millimeters based on it. Then, by substituting this value into Eq. 1 as the H_p parameter, subsequent calculations were performed.

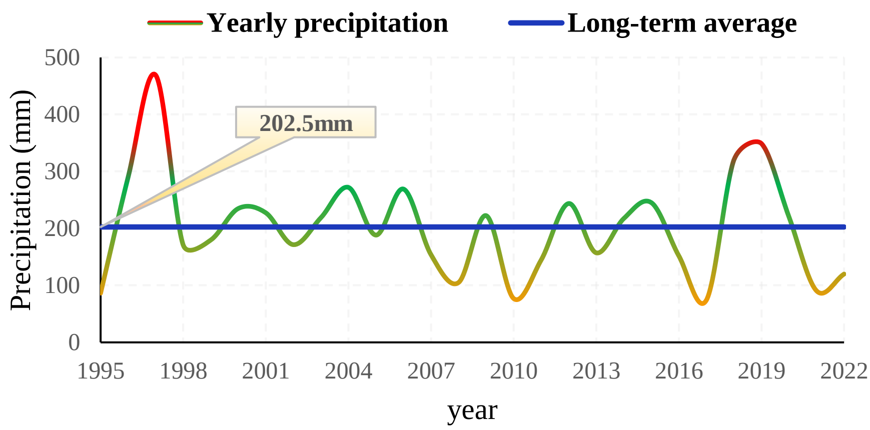

Fig. 4. Long-term annual precipitation of Ahvaz city

Through field surveys and observations in the city of Ahvaz, large buildings were categorized into six groups, and an estimate of the total rooftop area for implementing a rainwater harvesting system was made. In Table 1, by having the rooftop area and average precipitation and inserting them into Eq. 1, the potential for rainwater harvesting was calculated for each category. The total collectible water amounted to approximately two hundred and twenty-three thousand cubic meters. Additionally, using Eq. 2, the required reservoir volume for collection was calculated.

Table 1. Estimation of the catchment areas of selected roofs and the volume of water collectible from them.

Building type	S (m^2)	P_a (m^3)	V (m^3)
Administrative and governmental	189,190	26,814	1341
Hospitals	105,792	14,994	750
Shopping Centers	100,296	14,215	711
Religious sites	34,061	4,828	242
Educational Centers	180,680	25,608	1281
Industrial Sites	961,308	136,249	6813
Total	1,571,327	222,708	11138

In Figure 5, the volume of rainwater harvestable for each category is depicted as a percentage. Based on Eq. 1, The total annual harvestable water volume is estimated at 20,2708 cubic meters. Among these, industrial sites have significantly the largest share, followed by governmental offices and educational centers. This could be seen as an opportunity to harness the rainwater potential in prominent industries. Moreover, the importance of rainwater harvesting in governmental offices and educational centers is evident, which can be incorporated into proper planning for optimal rainwater utilization in these facilities. Although other venues have a smaller share, it is still considerable, and with proper planning, maximum utilization of this scheme can be achieved in Ahvaz city.

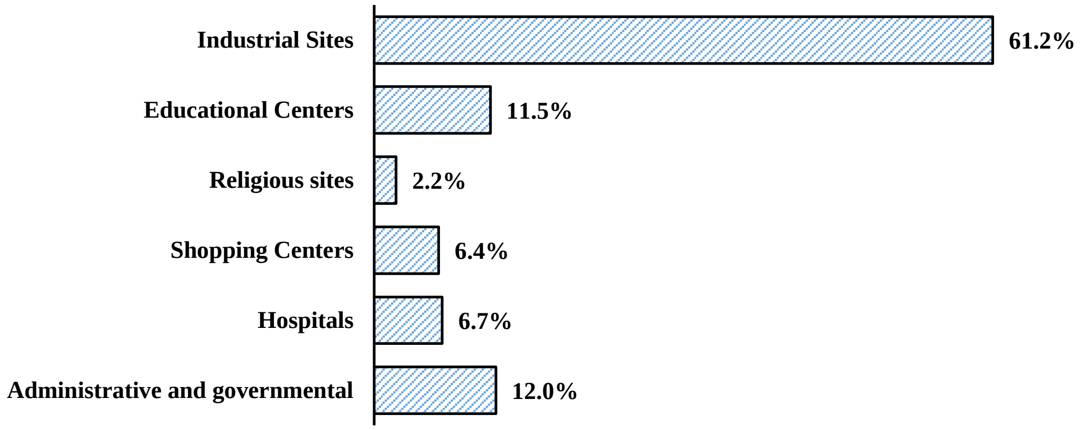

Fig. 5. The percentage distribution of the harvestable water volume for each designed category.

In this study, comparisons are made to investigate the potential for rainwater harvesting from large buildings in Ahvaz city using data obtained from the 2022 statistical yearbook of the Ahvaz Municipality (Statistical Yearbook of Ahvaz Metropolitan Area, 2022). It is important to note that the potential considered in this study is for non-residential buildings, and by considering this potential, a much higher utilization of rainwater will be possible. The reason for not focusing on residential structures in this article is the large number of them and the lack of precise data for conducting assessments and evaluating rainwater harvesting efficiency in them. Ahvaz, as one of Iran's major industrial centers, requires a high water demand for its industrial sector such as oil, steel manufacturing, power plants. With the amount of water extracted through this method, 11.42% of Ahvaz industrial sector's annual water demand can be met. This approach provides the opportunity to reduce dependence on external water sources and is justified for industrial facilities due to their water-receiving surfaces. Not only does this initiative help reduce industrial costs for purchasing water, but it also contributes to environmental conservation and strengthens industrial sustainability. Improving water management through this method will enhance water efficiency and regional water resource independence.

If only the potential for rainwater harvesting for industrial facilities is considered, 7.32% of their annual water demand can be met. By employing appropriate runoff coefficient values, this figure can increase to 10%. Furthermore, reducing the need for water transportation from distant sources will lead to a reduction in air pollution and energy consumption associated with transportation. Paying attention to these factors can help promote and implement these policies, ultimately leading to improvements in the economic and environmental conditions of Ahvaz city.

One of the key issues in urban planning is providing the necessary water for irrigating green spaces within the city. According to the statistics provided by Ahvaz Municipality, the average water consumption per square meter of green space is estimated to be around 2.2 liters per day (Statistical Yearbook of Ahvaz Metropolitan Area, 2022). Therefore, by multiplying the area of each green space by its water consumption, we can determine the water demand. In Figure 6, the water demand for the green spaces in each of the eight districts of Ahvaz city is illustrated. Additionally, the amount of recycled water in this study is shown as a percentage relative to the water demand for green spaces in each area. It should be noted that the amount of recycled water examined in this article only covers a small portion of the total water consumption for green spaces in Ahvaz city. Nevertheless, directing and managing this amount of water towards areas that may potentially face water shortages would be beneficial and rational.

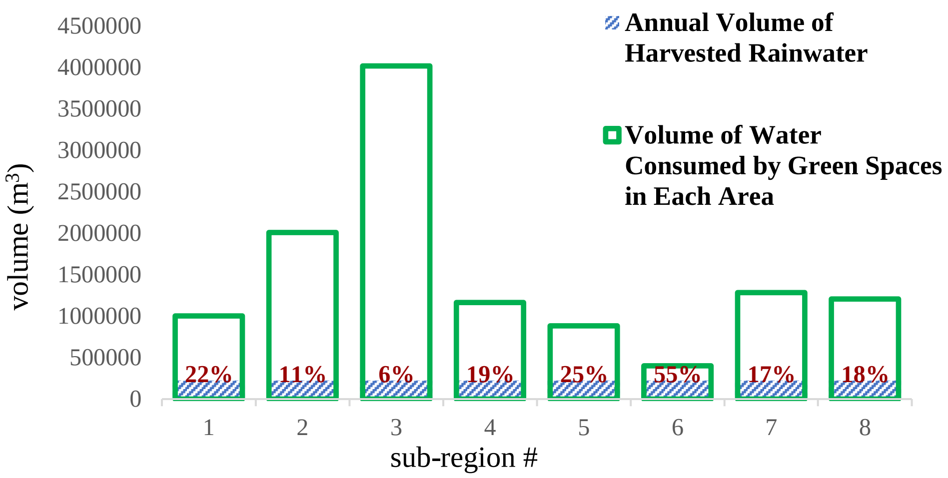

Fig. 6. Annual water use (m^3) of green spaces vs collected rainwater and provision percentage, in Ahvaz defined sub-regiens.

Given that harvesting and utilizing rainwater from rooftops can serve as a suitable source to meet part of water demand. Employing aforementioned method can contribute to reducing the consumption of network water.

The city of Ahvaz has 79 urban parks with a total area of 730,362 square meters. According to calculations, the use of harvested rainwater from large rooftops can supply 34.56% of the water needed for irrigating these green areas, which is of significant importance. In addition, utilizing the method of harvesting rainwater from rooftops is one of the effective solutions in urban stormwater management. Implementing this approach can prevent excessive water infiltration into the city's drainage system channels. This process acts as an efficient rainwater harvesting system and can help reduce the risks of flooding and runoff congestion in cities. A study has shown that the impact of flood reduction was estimated to be about 1% when 10% of the total urban area was used as rainwater collection surface (Kim and Yoo, 2009).

Similar studies (Jacque et al., 2023; Kakoulas et al., 2022; and Adugna et al., 2018) have been conducted in other parts of the world with posetive similar results. For instance, research conducted in Addis Ababa (Adugna et al., 2018) and Tehran (Neshastegar and Taghavijeloudar, 2021) have shown that rainwater harvesting from large rooftops can contribute to meeting urban water demands such as green space irrigation.

Considering the critical role of water resources and the climate changes that have posed serious challenges to sustainable water supply, optimal utilization of existing water sources is inevitable. In this regard, rainwater harvesting emerges as a sustainable and cost-effective method for collecting and efficiently utilizing surface water, which can help alleviate pressure on groundwater resources and municipal water supply. Therefore, the formulation and implementation of laws that encourage the installation and operation of rainwater harvesting systems on building rooftops appear to be essential. To achieve this goal, laws should be designed in a way that, on one hand, provides sufficient incentives for homeowners and commercial building owners to implement these systems and, on the other hand, ensures that these systems comply with environmental and technical standards. This could include tax exemptions, subsidies for equipment installation, or even construction requirements for renovations and new projects. Some municipalities in Spain have enacted laws to promote the utilization of water resources such as rainwater, greywater, and groundwater. One notable example is the municipality of Sant Cugat del Vallès near Barcelona. In 2002, this municipality passed a law requiring the installation of rainwater harvesting systems for buildings with over 300 square meters of green space. Families installing such systems themselves receive a subsidy of up to 1200 euros. Eight years later, another 40 municipalities in the Catalonia region adopted similar laws for new buildings (Domènech and Saurí, 2011). In Brazil, the government supports a program aimed at installing one million rainwater tanks in semi-arid regions of the country. Research focusing on rainwater harvesting methods indicates that many countries, such as Japan, Australia, Jordan, and others, have been pioneers in legislating for the implementation and adoption of this system. The study delves into the analysis of the details of laws and regulations in these countries, elucidating how the government and local municipalities support the optimal use of rainwater (Ghahremani and Omidvar, 2020). Based on a comprehensive study conducted to assess the economic feasibility of this scheme in the city of Taleqan, Iran, it is recommended that the government cover at least 50% of the costs for implementing a rainwater harvesting system. This financial support can be facilitated through the provision of low-interest loans for rainwater extraction. Research findings also indicate that the cost of constructing a rainwater harvesting system is dependent on the associated storage reservoir. Therefore, governmental financial support in this regard is deemed necessary for the success of this initiative (Ebrahimi and Mohseni Saravi, 2021).

Based on the results obtained from this study, it can be said that the utilization of rainwater harvesting systems through the rooftops of Ahvaz city represents a suitable and sustainable solution for reducing dependency on external water sources and meeting a portion of the city's water needs. Developing models to promote and implement these systems more extensively by city officials can lead to more optimal management of urban water and runoff.

4. Conclusion

Given the statistics on precipitation in Ahvaz from 1995 to 2022, the average annual rainfall in this city has been estimated at 202.475 millimeters. Based on field surveys and classification of large buildings in Ahvaz, the potential for rainwater harvesting from these buildings is estimated at approximately 222,000 cubic meters per year.

The majority of extractable water volume is related to industrial buildings, followed by government and educational centers. This can be seen as an opportunity to utilize rainwater potential in prominent industries. Moreover, the importance of rainwater harvesting in governmental and educational centers is evident, which can be included in appropriate planning for optimal use of rainwater in these facilities.

With this method, 11.42% of the water demand of Ahvaz's industries can be met, reducing dependency on external water sources and providing economic savings. Recycled rainwater can supply up to 34.56% of the water needed for urban parks in Ahvaz, leading to flood risk reduction and better urban runoff management.

As a result, it is necessary to formulate new laws aimed at encouraging and mandating the installation of rainwater harvesting systems. This step can be effective and vital in improving water resource management, reducing dependency on external sources, and implementing environmental protection measures in Ahvaz.

According to the authors of this article, the present study is important from several aspects:

- Research on rainwater harvesting from rooftops in Ahvaz can be considered as a public investment project and lead to optimal utilization of water resources in the city.
- Storing rainwater reduces the burden on the city's sewage system, contributing to environmental improvement.
- Rainwater harvesting from rooftops can help conserve groundwater and surface water resources in Ahvaz, where there is scarcity, and facilitate better water consumption management.
- Conducting research on rainwater harvesting from rooftops in Ahvaz can contribute to community education and awareness about the benefits and proper methods of using this method.

5. Disclosure statement

No potential conflict of interest was reported by the authors.

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