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Rooftop Rainwater Harvesting for Mosul City as Water Resources Using GIS

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ABSTRACT

The collection of rainwater from rooftops is a sustainable and widely practiced technique in many countries. This approach is designed to capture rainwater from building roofs, enabling its storage and efficient use to address water scarcity in urban areas. In this study, Mosul is chosen as a case study for rooftop rainwater harvesting. An analysis of the city's climate over 30 years (1984–2014) shows that the average annual precipitation was 352.1 mm. Using advanced software, the total rooftop area in the city is determined to be 63.292 Km^2, providing an accurate measure of the potential collection area during the rainy season. To estimate the rainwater harvesting potential, the Gould and Nissen formula was applied. The calculation reveals that rooftops in the study area could collect approximately 21.170×10^9 liters of water annually. This corresponds to an estimated 39.42 liters per capita per day, which meets international standards. According to these standards, a daily per capita allocation of 20 liters is considered adequate to meet basic human water needs.

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تقييم إمكانية حصاد مياه الأمطار من أسطح المنازل في مدينة الموصل باستخدام تطبيقات نظم المعلومات الجغرافية

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الملخص

يُعَدُّ جمع مياه الأمطار من أسطح المباني تقنية مستدامة تُطبَّق على نطاق واسع في العديد من دول العالم، إذ تهدف هذه الطريقة إلى استغلال مياه الأمطار المتساقطة على الأسطح من خلال تخزينها واستخدامها بكفاءة لمعالجة مشكلات شح المياه في المناطق الحضرية. في هذه الدراسة، تم اختيار مدينة الموصل كحالة تطبيقية لنظام حصاد مياه الأمطار من الأسطح. أظهر تحليل المناخ في المدينة خلال فترة ثلاثين عامًا (1984–2014) أن متوسط الهطول السنوي بلغ 352.1 ملم. وبالاعتماد على برامج تحليل متقدمة، تم حساب المساحة الإجمالية لأسطح المباني بدقة لتبلغ 63.292 كم²، وهو ما يمثل المساحة الممكن الاستفادة منها خلال موسم الأمطار. ولتقدير إمكانات حصاد المياه، تم استخدام طريقة Gould and Nissen. وقد بينت النتائج أن أسطح المباني في منطقة الدراسة يمكن أن تجمع نحو 21.170 × 10^9 لتر من المياه سنويًا، أي ما يعادل 39.42 لترًا للفرد يوميًا، وهو معدل يتماشى مع المعايير الدولية التي تعتبر أن توفير 20 لترًا يوميًا للفرد كافٍ لتغطية الاحتياجات الأساسية من المياه.

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Introduction

The world's population is growing, cities are growing, and more water is needed to meet their demands. especially cities that lack groundwater or surface water. Rainwater harvesting is a method for gathering, storing, and utilizing rainwater for irrigation, groundwater recharge, household water supply, and other uses (Singh and Devi, 2017). The harvesting process for rainwater and surface runoff is one of the most important aspects of investment that can correspond to the climatic conditions and the nature of the studied area (Al-Kubaisi and Al-Kubaisi, 2023).

The relationship between precipitation intensity and surface temperature has emerged in response to the growing worry over human-induced global warming (Al-Sekar and Al-Dabbas, 2022). Freshwater reserves worldwide are drying out, especially in developing countries, due to population growth, urbanization, changes in land use, and climate change (Khatri et al., 2008).

The Tigris River, dividing Mosul City into two halves, relies to a significant extent on water originating from northern Iraq. This water primarily comes from rainfall and melting snow, which are essential for recharging groundwater. Consequently, rainfall in Mosul serves as a secondary water source. Therefore, future strategies must focus on maximizing the utilization of rainwater that falls within the city's boundaries by capturing and storing it instead of allowing it to evaporate from solid surfaces. This captured rainwater can act as a supplementary resource to the city's primary water supply.

To achieve this, it is crucial to study and evaluate the rainfall on urban rooftops using specific methodologies aligned with practical and effective water management strategies. Water availability has been significantly affected, particularly in arid and semi-arid regions, due to the overexploitation of various water resources, which has, in turn, heightened the demand for sustainable water solutions (Jones et al., 2009).

Rainwater harvesting, an ancient practice rooted in the traditions of early civilizations, aims to make optimal use of rainfall by capturing it where it falls and preventing it from draining away. Given the favorable properties and intrinsic quality of rainwater, this traditional method has gained renewed importance in modern times (Dwivedi and Bhadauria, 2006).

The collection of rainwater from rooftops aims to meet the growing demand for water due to population increases and to calculate the potential volume of water that can be harvested annually. This approach helps alleviate the strain on drainage systems during periods of heavy rainfall, thereby minimizing urban flooding. Furthermore, it offers the possibility of directing collected rainwater towards replenishing groundwater reserves. An additional benefit includes the purification of rainwater from contaminants, making it suitable for agricultural and industrial applications.

Study area

Mosul City is the center of the Nineveh Governorate and a significant city in northern Iraq. After the capital Baghdad, the city is regarded as the second-largest in terms of population.

The study area is located between longitudes 43°14′57.573″ E and 43°02′43.102″ E and latitudes 36°24′57.109″ N and 36°16′42.038″ N. The area of Nineveh Governorate is estimated at 37,303 Km². In comparison, the area of the city of Mosul is estimated at 743.6 Km² according to the Ministry of Planning report in 2021 (Spatial Development Gaps Report, Nineveh Governorate, 2021) (Fig. 1).

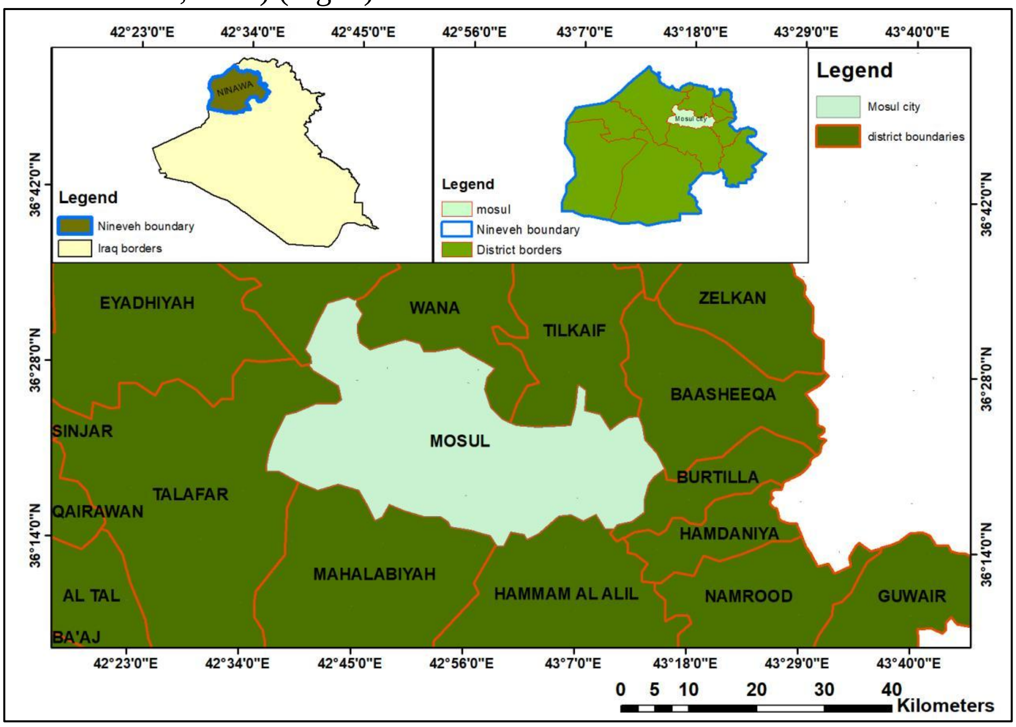

Fig. 1. Location of the study area.

Based on the research, the percentages of land use in the city of Mosul show that the rate of residential land use reaches about 34.5%, which amounts to approximately 93.4 km² according to the Urban Planning Directorate of Nineveh Governorate and the basic design for the city of Mosul for the year 2021 (Al-Qaba, 2022).

Materials and Methods

Data Collection

Climatic data are one of the important and main factors on which research is based in achieving its results, and the Mosul station is used for this purpose. The climatic factors and their effects on the study area between 1984 and 2014 are investigated. It is important to note that the recording of the climate data in the study area has problems because of battles that happened from 2014 to 2017, which caused a pause in the collection of climate data.

Summers in Mosul are hot and dry, and winters there are cold with rare frost, according to meteorological data that covered the years 1984-2014, the total annual precipitation was 352.1 mm, the relative humidity was 51.4%, the monthly average temperature was 20.47 °C, the evaporation was 173.6 mm, the wind speed was 1.1 m/s, and the sunlight duration was 8.3 hours per day (Fig. 2).

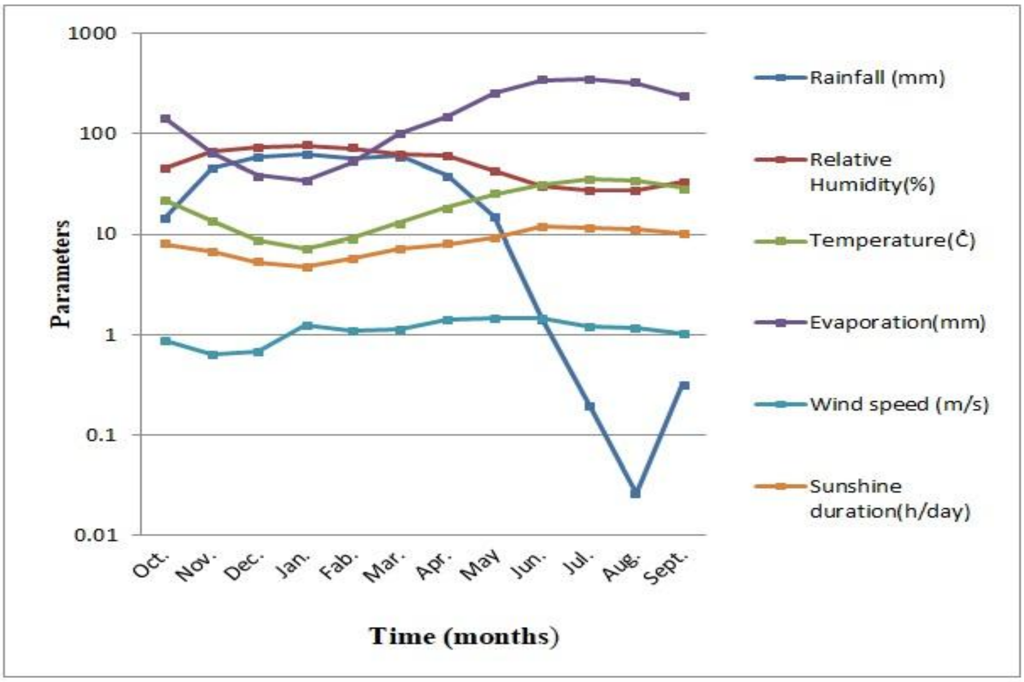

Fig. 2. Relations between various climate elements in the study area for a period of 1984-2014.

The process of collecting data in a large and wide city such as Mosul City is considered a very difficult process, especially since there are no accurate statistics for the roof areas of buildings and unbuilt areas. Therefore, in the process of data collection, it is required to draw the boundaries of all buildings within the city by using satellite visuals of the city and drawing on them. The analysis is conducted using ArcGIS 10.4 software. (Fig. 3).

After drawing the boundaries of the roofs of the buildings, it is found through some software operations that the area of all these roofs is 63.292 Km². This area is the total of the roofs that can be considered areas for collecting water from rain in the rainy season (Figs. 4, 5).

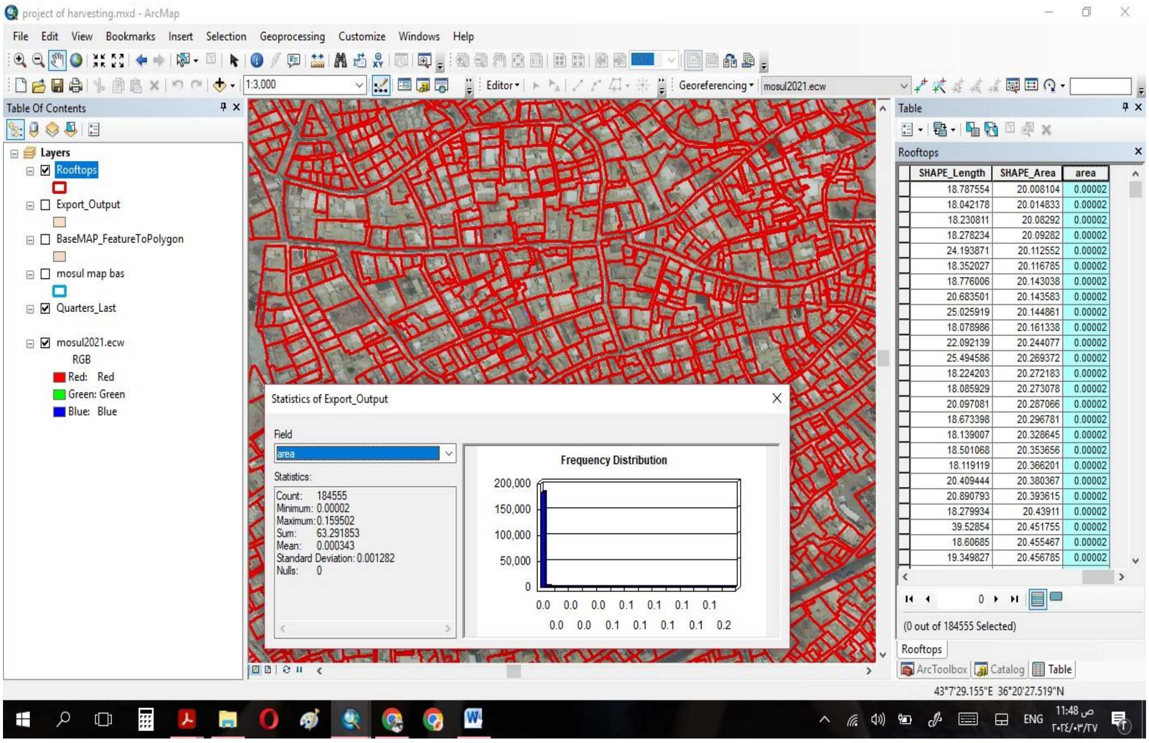

Fig. 3. Shapefiles of Mosul City in ArcGIS.

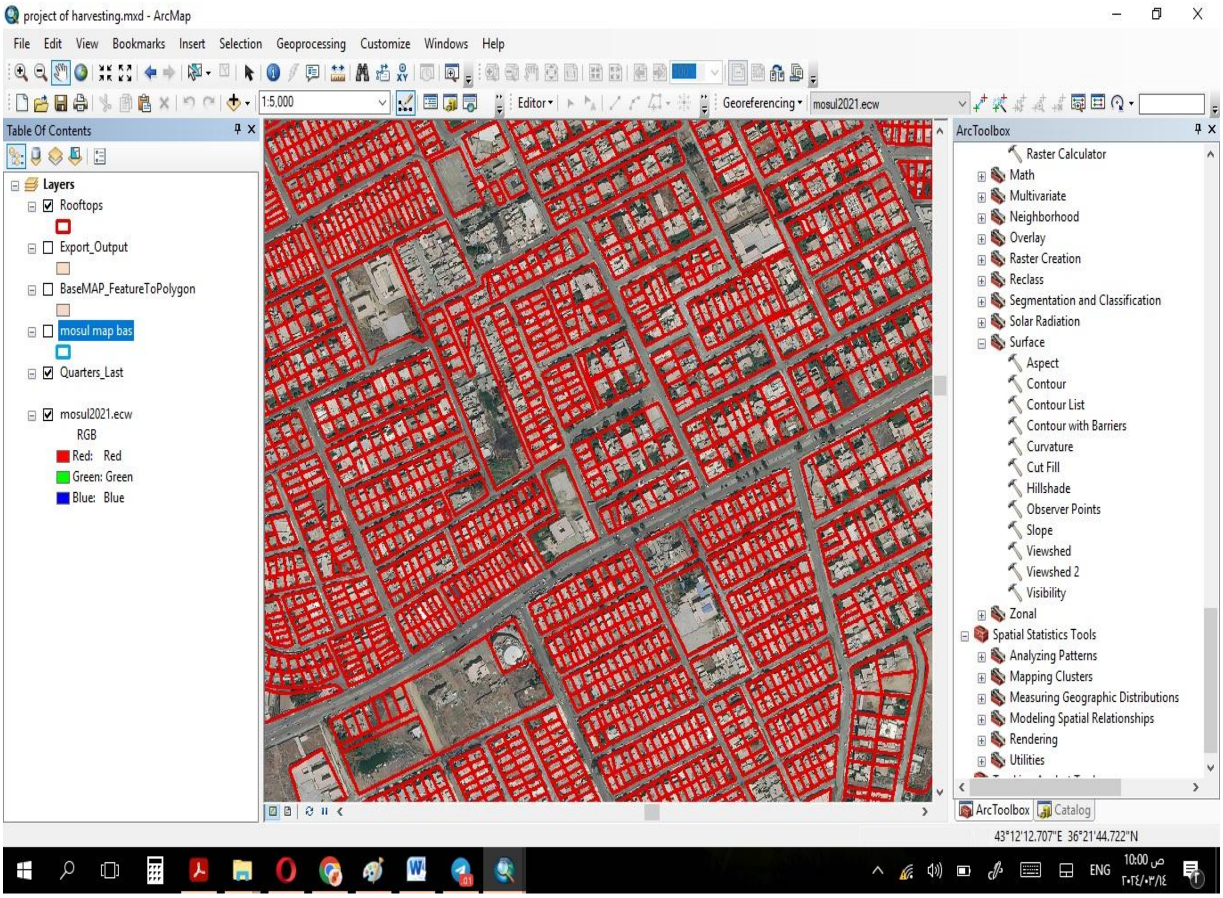

Fig. 4. Digitizing the rooftop of the building to calculate the area in GIS.

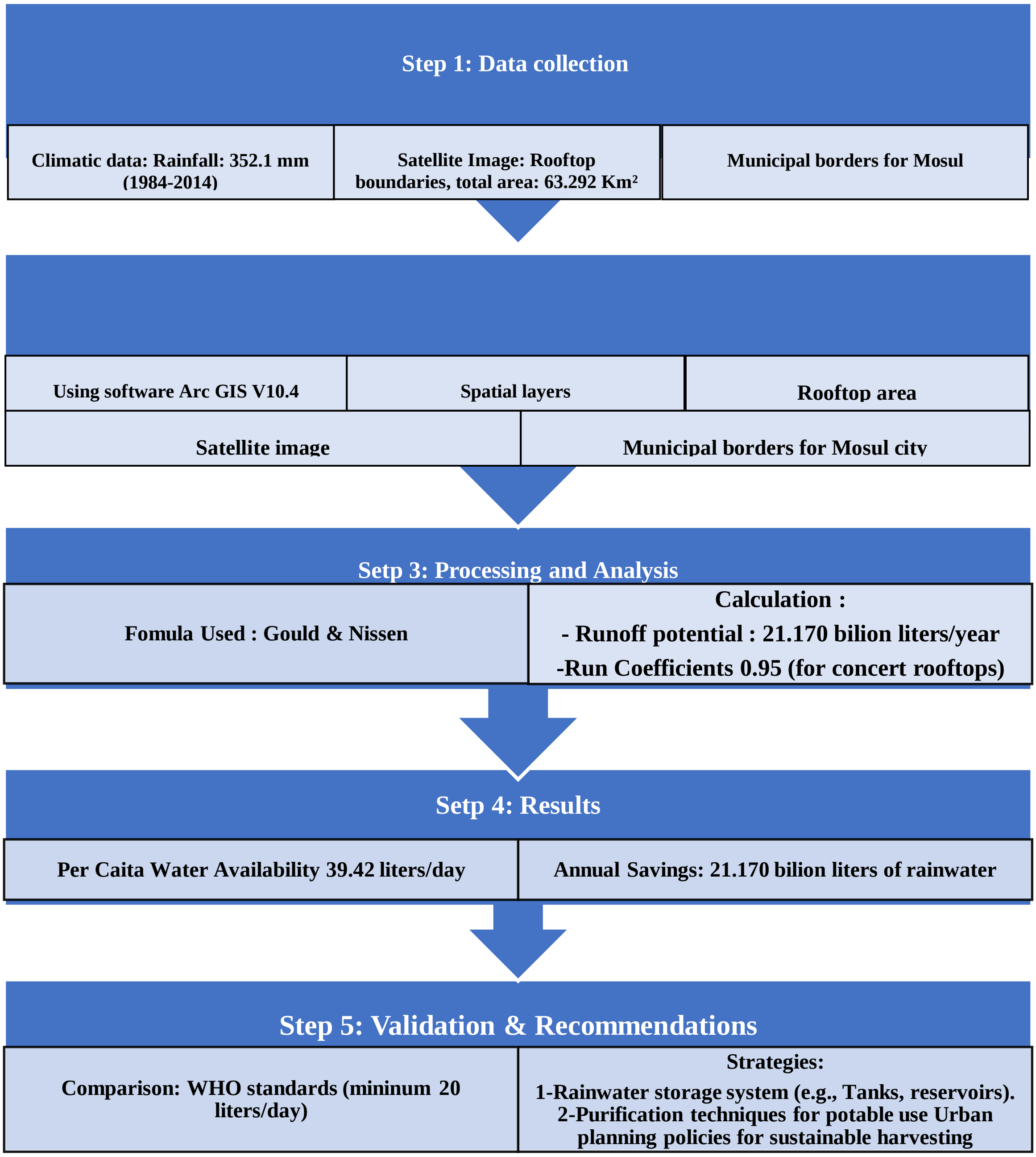

Fig. 5. Flowchart for the steps of rooftop rainwater harvesting for Mosul City.

Results

Evaluation of the potential of harvesting rainwater

The Gould and Nissen Formula (1999) is used to determine the potential of the study area's rooftops for rainwater harvesting :

$$S = R*A*Cr \qquad \text{(Hari, 2019) ……. (1)}$$

Where:

S = Potential of roof rainwater harvesting (In cu. m); R = Average annual rainfall in m. A = Roof area in Sq. m. Cr = Coefficient of Runoff

Coefficient of runoff (Cr)

The proportion of water that runs off to the total amount of rain that falls on the rooftop is known as the Coefficient of Rooftop (Cr) for any catchment. The potential for collecting rainwater from rooftops is determined by different sorts of runoff coefficients, which depend on the surface type (Table 1) (Hari et al., 2018).

Table 1: Potential rooftop rainwater harvesting in Mosul City.

Type of Roof	Area (m^2)	Runoff Coefficients	Annual Rainfall in (mm)	(S=R*A*Cr) Runoff (cu. m)	(S=R*A*Cr) Runoff (liters)
Concrete Roof	63,292	0.95	352.1	21,170,857.54	21,170,857,540

Quantity of water requirement

The process of determining the amount of water required for human consumption in any city is determined by many criteria. Therefore, some researchers suggested, based on these criteria, that the amount of water required per person per day be 15 liters, if this amount is considered a major indicator of meeting the minimum standards of disaster relief (Howard et al., 2003)

The Department of International Development (United Kingdom) also prepared a guideline in which Well (1998) mentioned that the minimum needed amount of water per person is 20 liters per day.

From the aforementioned, it can be concluded that the least amount of water a person can need in the city of Mosul is 20 liters per day in harsh conditions to cover drinking and household activities. According to a report issued by the Nineveh Governorate's Statistics Directorate, the population of Mosul District was 1,471,353 in 2021 (Al-Qaba, 2022).

Water per capita

According to the data obtained from the foregoing, the per capita share of water per day collected from rooftop Rainwater harvesting is:

$$Per - Capita\ demand = \frac{Value\ of\ roof\ rainwater\ harvesting}{number\ of\ population\ of\ Mosul\ city} \ldots\ldots\ldots (2)$$

$\mathrm{Per - Capita\ demand} = 14388.7$ Liters annually for every person

$\mathrm{Per - Capita\ demand} = 14388.7 \div 365 = 39.42$ Liters per day per person

Discussion

Domestic Water Requirements and the Potential of Rooftop Rainwater Harvesting

This section examines the domestic water requirements in the study area and evaluates the potential for water savings and storage through the implementation of rooftop rainwater harvesting (RRWH). Additionally, it analyzes the disparity between per capita water availability in the study area and the World Health Organization's (WHO) recommended minimum water requirement.

Rainwater collected from rooftops in Kathmandu’s urban districts is primarily used for non-potable purposes, such as cleaning, laundry, and toilet flushing. According to survey findings (Mishra and Dev, 2021), none of the respondents reported using harvested rainwater for drinking due to a lack of awareness regarding filtration and purification methods. This presents a significant opportunity to enhance the usability of RRWH through the integration of accessible and cost-effective water treatment systems.

Domestic Water Availability and Requirements

The study determined that per capita domestic water availability from RRWH reached 39.42 liters per day, which is 19.42 liters higher than the WHO's recommended minimum of 20 liters per day for survival. This substantial difference indicates that even if harvested rainwater availability were reduced by half, it would still meet the WHO's survival threshold.

Given that the average urban domestic water demand ranges between 50 and 100 liters per person per day, these findings suggest that RRWH can serve as a valuable supplementary source to conventional water supplies, thereby reducing dependence on surface and groundwater resources. Furthermore, with the incorporation of appropriate filtration systems, harvested rainwater could be safely utilized for potable purposes, further bridging the gap between demand and availability.

Water Savings and Storage Potential

The study's findings highlight the potential for water savings and long-term storage through RRWH:

• Daily Water Collection per Household: With an average of 39.42 liters per person, a household of five could collect approximately 197 liters per day.

• Annual Storage Potential: Assuming a rainy season of four months, the total harvested rainwater per household could reach approximately 23,640 liters, which could be stored for use during the dry season.

Although comprehensive climate data from 2014 to 2023 is unavailable, anecdotal evidence suggests that these years experienced drier conditions compared to previous decades. This further underscores the importance of rainwater harvesting as a supplementary water resource. Implementing effective storage solutions, such as rooftop tanks or underground reservoirs, can enable surplus water collection during the rainy season, enhancing water security in drier months.

Future Considerations and Policy Implications

The study emphasizes the critical role of RRWH in addressing domestic water scarcity, particularly in urban regions with limited access to conventional water sources, such as Kathmandu and similar arid regions, including Iraq. To maximize the effectiveness of RRWH, the following measures should be prioritized:

•Public Awareness and Education: Conducting community-based awareness programs to educate residents about water filtration, purification, and safe reuse of harvested rainwater.

•Investment in Storage Infrastructure: Expanding access to high-capacity storage tanks and underground reservoirs to preserve harvested rainwater for dry seasons.

•Policy Integration and Urban Water Management: Incorporating RRWH into national and municipal water management strategies as a sustainable, cost-effective, and reliable alternative water source.

By implementing these recommendations, RRWH can play a pivotal role in enhancing urban water resilience, reducing over-reliance on groundwater and municipal supplies, and mitigating the impacts of climate variability on water availability.

Although climate data from 2014 to 2023 is unavailable, anecdotal evidence suggests these years were drier than previous periods. This further emphasizes the importance of rainwater harvesting as a supplementary water source. By adopting effective storage solutions, such as rooftop tanks or underground reservoirs, surplus water collected during the rainy season can be preserved for future use, enhancing water security during drier months.

Future Considerations

The study underscores the crucial role of rooftop rainwater harvesting in meeting domestic water needs, particularly in water-scarce regions like Kathmandu and similar areas, including Iraq. To maximize the benefits of this system, the following measures should be considered:

- *Public Awareness Campaigns*: Educating communities about rainwater filtration methods and safe reuse.
- *Investment in Storage Infrastructure*: Prioritizing the construction of tanks and reservoirs.
- *Policy Integration*: Incorporating rainwater harvesting into urban water management strategies as a sustainable and reliable resource.

Conclusions

1. The results of the study indicate that rooftop rainwater harvesting in Mosul City is a sustainable and effective solution for meeting the basic water needs of the population, as the collected water exceeds the minimum amount recommended by the World Health Organization.
2. Rainwater harvesting serves as a supplementary water source, helping to reduce pressure on traditional water resources, especially during periods of rainfall scarcity.
3. Proper storage systems for rainwater harvesting enhance the city's water security, particularly during dry periods, ensuring a reliable water supply when natural water sources are low.
4. It is essential to increase public awareness about the importance of rainwater harvesting systems and to develop technological solutions to ensure water treatment and make it suitable for various household purposes.
5. Rainwater harvesting should be integrated into future urban water management strategies, with improved infrastructure for water storage and appropriate policies to ensure the long-term sustainability of the system.

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