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WATER HARVESTING TO ADDRESS THE CLIMATE CHANGE IN JORDAN USING REMOTE SENSING AND CLIMATE DATA

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Abstract

Climate change, especially in the eastern Mediterranean basin, has received intense attention because it inevitably affects natural resources. A decrease in rainfall has already been observed in Jordan and neighboring countries. Jordan has a Mediterranean climate, characterized by hot summers and mild, humid winters. The decrease and fluctuation of rainfall from year to year has led to pressure on water resources and a decrease in the availability of water for drinking and various uses, even in the northern region, which has more rainfall than others. Therefore, this study analyzes the trend of rainfall in northern Jordan, specifically the city of Irbid the second largest city in the country with 650000 inhabitent. Statistical methods such as regression, moving averages, and cumulative differences were used to examin the trend of rainfall in the city. Meanwhile satellite images were used to calculate the rooftop area of buildings in the city and then estimate the amount of possible harvested rainwater that can be collected through water harvesting techniques for daily use. The study found that the long-term average annual rainfall in Irbid reaches 466 mm with concentration in winter in (December, January, February), at a rate of 65% of the annual precipitation, while 23% falls in the spring in (March, April, May), in addition to the fact that the rainfall rate reaches 12% in (September, October, November). The results showed that the total area of buildings' rooftops in Irbid is about 6.93 square kilometers, and the total amount of estimated harvested water is about 26 million cubic metres. . This amount of water, if invested, will improve the per capita share of water in the city of Irbid to become 39.7 cubic metres comparing to the current amount of 60 cubic metres.

Keywords: precipitation tren, rooftops, water resourcesm Jordan weather

Introduction

Rainwater harvesting is a traditional practice back hundreds of years. Archeological evidence attests to the capture of rainwater as far as 4000 years ago (Che-Ani A.I., 2009), Sustainable access to water for potable and non-potable uses continues to pose a huge challenge in developing countries (Isaac. I., et al., 2016), Rainwater harvesting has been consedered as one of the options to improve water supply especially in rural and peri-urban areas of low-income countries (Cruddas. P., et al., 2013; Opare, 2012), Water resources are very scarce in the Middle East and North Africa reagion (Al-Ansari, N.A. 2013: Biswas, A.K, 1994). Jordan is one of the countries in the MENA region. It covers an area of 89,300 square kilometers populated by 11 million inhabitants. Recently, it is suffering from water shortage problems. Rainwater harvesting (RWH) was suggested as one of the solutions for the water shortage problems (Al-Ansari, N.A. 2013: Zakaria, S., 2012). Due to climate change, the precipitation

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patterns will be modified leading to extreme events which will affect the availability of water resources particularly in tropical and Mediterranean areas and this will significantly affect sectors like agriculture, industry and urban development.

Water harvesting techniques are means of collecting rainfall or groundwater and storing it for use in irrigation, drinking, and industrial production. Water harvesting is considered one of the important practices that contribute to improving the sustainability of water resources in the world, as most surface and groundwater are unbalanced throughout the world. In addition, climate change, population growth, and economic development bring additional challenges to providing clean and sustainable water. Hence, the role of water harvesting comes in enhancing the availability of water resources and improving their distribution and effective use. Water harvesting can rely on various techniques, such as collecting rainwater from building roofs and collecting it in tanks, using irrigation systems based on point and drip irrigation, and collecting groundwater from wells and underground wells. Water harvesting also involves managing surface water resources effectively and developing smart irrigation systems to make the most of available resources. By adopting water harvesting practices, water sufficiency can be enhanced and water use balanced in correct and sustainable ways.

Remote Sensing techneques are used to monitor water distribution and changes, estimate water needs for crops, analyze drought, and manage water resources to make better decisions regarding to water management in various sectors, thus improving water use efficiency and achieving better water harvest. Also google earth angine can be used for the same purpose (Hazaymeh, K. M. & Zeitoun, M. 2024). Using climate data in studying water harvesting is essentaial issue, it plays an important role in understanding changes in the pattern of precipitation, and the seasons in which it is available or absent. Climatic data are used to estimate the water needs of crops and determine how to effectively distribute water resources during growing periods, in addition it is also used to predict rainy seasons, droughts, and other climate changes that can affect water harvesting, contributing to better water harvesting and environmental conservation.

Jordan is considered one of the countries that suffer from a severe shortage of water resources, as it relies heavily on groundwater and on the water of major rivers such as the Jordan River and the Yarmouk River. Due to increasing demand for water, deteriorating water quality, and environmental and economic challenges, Jordan faces major challenges in managing its water resources. In fact, water harvesting in Jordan reflects a strong commitment to improving water resource management, enhancing water availability for agriculture, drinking, industry, and preserving the environment in light of the significant water-related challenges in the region. Most of the rainfall in Jordan is associated with the Mediterranean cyclones, which move along northern to northeasterly paths (Zeitoun et al., 2022).

The average rainfall in Jordan is about 8.1 Billion m³, and about 90% of it is lost through evaporation, and the water sector in Jordan faces a major challenge to meet the demand for water from available sources due to population growth and the frequent influx of refugees from neighboring countries, in addition to the expansion of economic and agricultural development. The total water from all sources is 1,093 million m³ of renewable fresh water, of which the per capita share in 2021 is about 61 m³ for all uses. This makes Jordan one of the poorest countries in the world in terms of renewable water resources from traditional sources.

The per capita share is less than the global absolute scarcity rate 500 m³ per capita. It is expected that the per capita share of annual renewable water resources in 2040 will reach about 35 cubic meters, if the available quantities remain at their current levels. This means that Jordan needs to provide quantities of water amounting to approximately 50 billion per year to reach the level of absolute water scarcity, that is, eight times the current traditional renewable water resources, or five times the water resources used from all sources (Figure1).

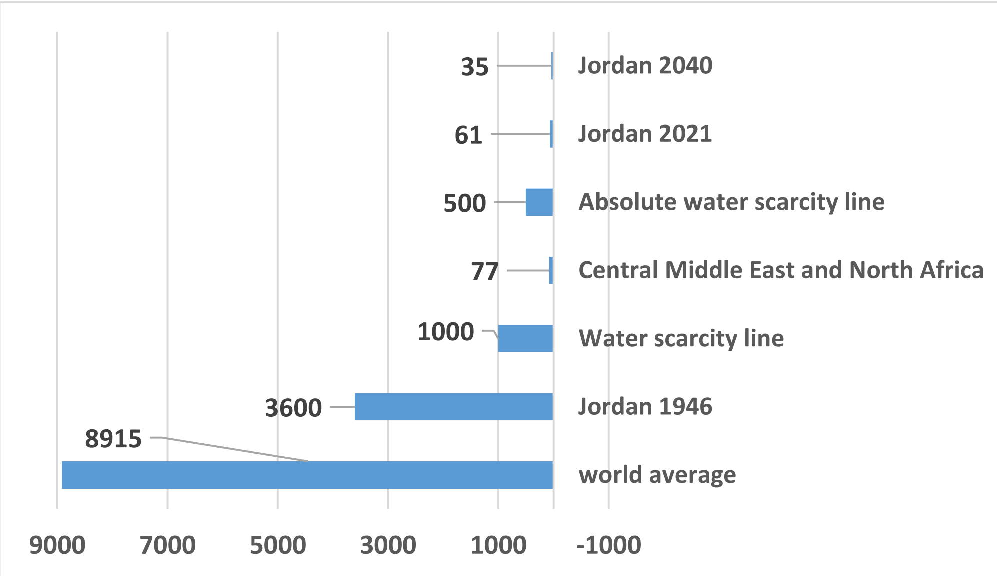


Figure1: The per capita of water in Jordan in cubic meters from 1946 to 2024 https://irbid.gov.jo

This study comes to analyze the trend of precipitation in northern Jordan, specifically in Irbid city, using statistical methods such as regression, moving averages, and cumulative differences, as well as using satellite images to calculate the roofs area of buildings in the city and then estimate the expected amount of rainwater that can be collected through water harvesting techniques to be used during the long arid period.

Materials and Methods

Study Area

The city of Irbid is in northwestern part in Jordan, between longitudes 35° 48' 20" and 35° 53' 20" East, and latitudes 32 31 40 and 32 35 00 North (Fig.1). The total are is 410 km², Irbid. It is dominated by plains with deep red Mediterranean soil - terrarosa, in addition to the rendeziana soil on its eastern parts. Its average elevation is about 620 meters above sea level. Irbid is the third largest city in Jordan with a total population of ~ 650000 in 2022. The city has witnessed a high population growth rate (4.2% per year between 1979 and 1994) and 1.9% between 1994 and 2004). The area of the population center has expanded at a rate of more than 5% annually since 1990, and all its suburbs have been urbanized thanks to intense migration from the countryside.The Mediterranean climate prevails in Irbid, which is characterized by hot, dry summer and cold, rainy winter.

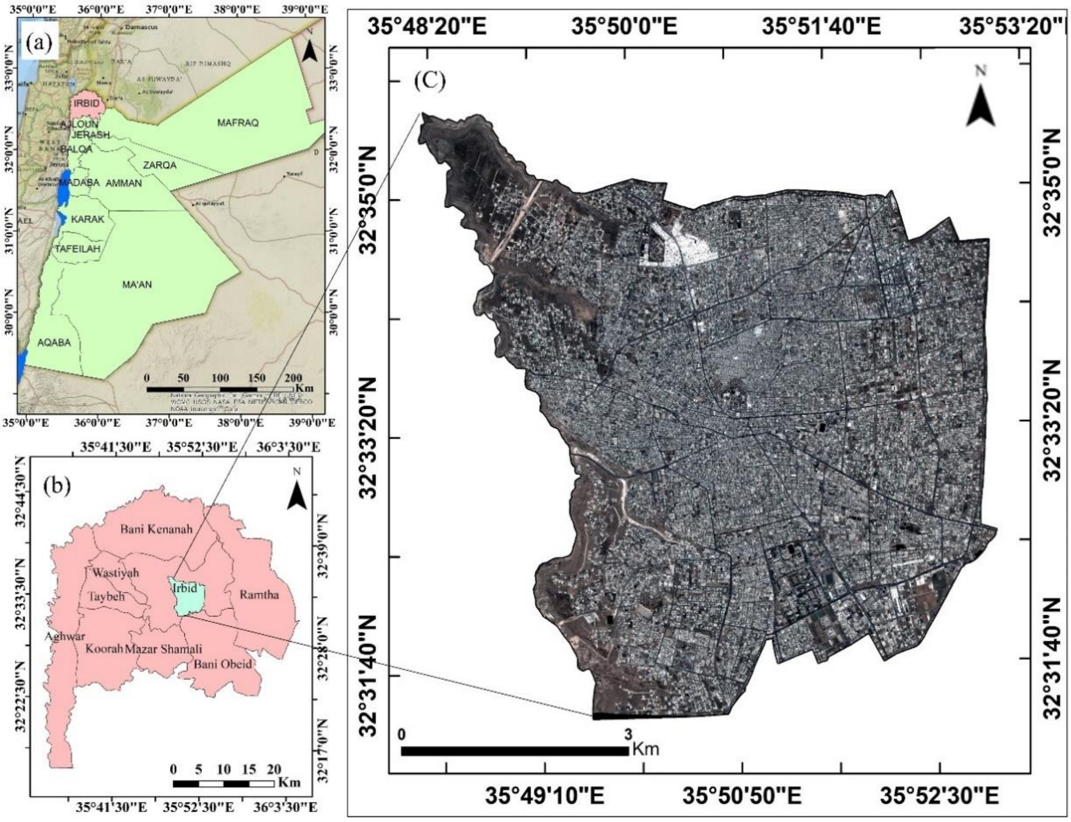


Figure 2. (a) Jordan map at the governorates level, (b) Irbid governorate at the district level, and (c) a true color composite image of red, green, and blue spectral bands of Pleiades-B1 satellite image for Irbid city (the Study area).

Precipitation data and its processing

Monthly precipitation data for the period 1970–2020 were obtained from the Jordan meterological department. The annual-mean and 3-year moving averages were used to smooth out short-term fluctuations in a time series with the base period while still preserving the slowly varying trend (Carpenter et al., 2013 ; Hansen et al. 2010).

$$\text{Ad}=\frac{\sum_{i=1}^{n} M(d-i)+1}{n} \quad n \leq$$

Where, n = Number of data, d = moving average, Years M = Data calculate the simple moving average when time period is 3.

Long-term annual average of precipitation (Pm) was calculated from the monthly values as follows (Kawale. et al., 2011):

$$Mean\ (fi)\ = \frac{fi + \cdots + fi - 1 + fi + 1 + \cdots + fn}{n-1}$$

In addition, the Variance was calculated in this paper, It is calculated by the sum of the squares of the deviations from the arithmetic mean to measure the dispersion in the precipitation of the years, as follows (Kawale et al., 2011):

$$Variance = \frac{1}{n}\sum_{i}(fi - Mean\ (fi))^2$$

$$= \frac{1}{n}\sum_{i}(fi - \frac{n}{n-1} * Mean + \frac{1}{n-1} * fi)^2$$

$$= \frac{1}{n}\sum_{i}\frac{n^2}{(n-1)^2} * fi - Mean)^2$$

$$= \left(\frac{n}{n-1}\right)^2 * Variance(f1, \ldots, fn)$$

In addition, the Coefficient of Variance is calculated, as follows (Shehadeh,2002):

$$\text{CV}=\mu/\ \sigma$$

where,σ=standard deviation, μ=mean

Also stander deviation was calculated as folloeing (Musa, 2006):

$$SDV= \sqrt{\frac{\sum(x_i - \mu)^2}{N}}$$

where

N= the size of the population, x_i =each value from the population, μ the population mean.

Estimating the amount of harvested rainwater from building's rooftops in Irbid city

To estimate the potential amount of harvested water from rooftops in Irbid city, a systematic methodology is proposed. The first step involves gathering data on the rooftop areas of buildings within the city. Precise measurements can be obtained from various sources such as satellite imagery, building plans, or municipal records. The total roof area is then calculated by summing the individual areas of all rooftops, ensuring that the measurements are in square meters for consistency. Simultaneously, reliable and up-to-date precipitation data for Irbid city is acquired from sources the local meteorological agency and weather stations. The precipitation values should be recorded in millimeters. Subsequently, the estimation equation is implemented as following (Ghisi et al., 2007; Kisakye et al., 2018):

$$TWHm=P * A * Q$$

where TWHm is total monthly harvestable runoff volume (m²) in month t, P is the monthly rainfall (mm), A is the roof area (m²) and Q is the dimensionless runoff coefficient which was considered as 0.8. The runoff coefficient indicates that 20% of the rainwater used to clean roofs and lost through evaporation. (Ghisi et al.,2007), To Calculate catchment capacity we can say, every 1 millimetre of rain over 1 square metre of roof equals 1 litre of water.This equation is applied using the obtained values for roof area and precipitation to calculate the potential amount of harvested water in liters for each rooftop. The results are then reported in a clear and interpretable figures at monthly, seasonally, and annual scales, highlighting the estimated amounts of harvested water for rooftops in Irbid city.

Extracting the building's rooftops in Irbid city

The process of generating a map of buildings' rooftops involves the utilization of different data sources and the application of diverse methodologies. This map was generated in previous study of Hazaymeh et al. (2023). The method included two main steps such as: i) extracting buildings' rooftops using multispectral (MS) pansharpened Pleiades-B1 image, and ii) extracting the buildings' rooftops map using NDVI and elevation data

In the case of the pansharpened Pleiades-B1 image, a classification method incorporating a support vector machine (SVM) model was employed. The initial step involved image segmentation, wherein the pansharpened image with its four spectral bands served as the base image. An edge-based segmentation method was implemented to group pixel-units with similar spectral and morphological characteristics, with 50% identified as the optimal scale level for identifying buildings' rooftops and minimizing segmentation errors. Subsequently, the integration of small segments into larger parts was carried out to enhance the delineation of buildings. An 80% integration level was chosen after experimentation across different levels. The process of selecting training samples followed, defining two main land cover categories: buildings and others such as (streets, bare lands, and vegetation). These samples were strategically chosen to achieve a representative spatial distribution, considering differences in size, shape, and color of the land cover types. The supervised classification process using the SVM method was then executed to generate a binary land use map, distinguishing between buildings and non-buildings. SVM, known for its effectiveness in cases with distinguishable margins between classes, played a crucial role in this phase.

In the extraction of buildings' rooftops using NDVI and elevation data, the NDVI was employed to map the spatial distribution of vegetation cover. NDVI values determined the presence of vegetated areas, urban spaces, and water bodies. Additionally, the normalized Digital Surface Model (nDSM) was calculated using Digital Terrain Model (DTM) and Digital Surface Model (DSM) data, considering pixels with a height less than 2 meters as non-building features.

In the final step, a decision-level data fusion model was performed, combining building attributes from SVM, nDSM, and NDVI. The output maps from these sources were combined to generate the ultimate buildings' rooftops map. Post-classification refinements, including Lee spatial filtering and the use of the regularize building footprint spatial tool in ArcGIS Pro, were applied to address any remaining classification errors. These refinements aimed to enhance the accuracy of the generated map in light of the inherent challenges in automatic classification processes for remote sensing images.

Results

The climate data

The long-term of annual average precipitation in Irbid reaches to 466 mm.Figures 3and 4 show a clear fluctuation in annual precipitation amount, which are distributed over three seasons. Rainfall fluctuations are observed during the rainy months of the year, as well as its interruption during the summer months (June, July, August), which are characterized by heat waves and dust storms.

When dividing the data into two time periods, each of which was 25 years long, the average for the first period was 487 mm, while the average for the second period was 443 mm. It is noted that the average for the second period decreased by about 44 mm from the first, and was less than the long-term average by about 23 mm.

Table1: Long-term average precipitation, and average for two periods

Period	Years	Average	long-term average
1970-1994	25	487.7	466
1995-2019	25	443.5	

The coefficient of variation for annual precipitation in Irbid reached 25% for the period 1937-1976 (Shehadeh, 1990), while the coefficient of variation was 33% for the period 1970-2019. Although the northwestern regions, including the city of Irbid, has less fluctuation in precipitation than other areas in Jordan, there is an increasing in its fluctuation, which is explained by the decrease in annual averages.

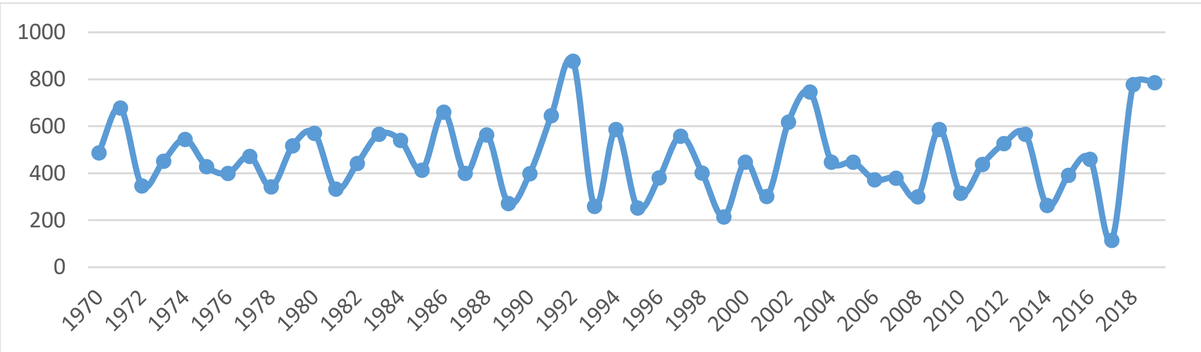


Figure3: 3-year moving average of precipitation in IrbidIrbid for the period 1970-2019

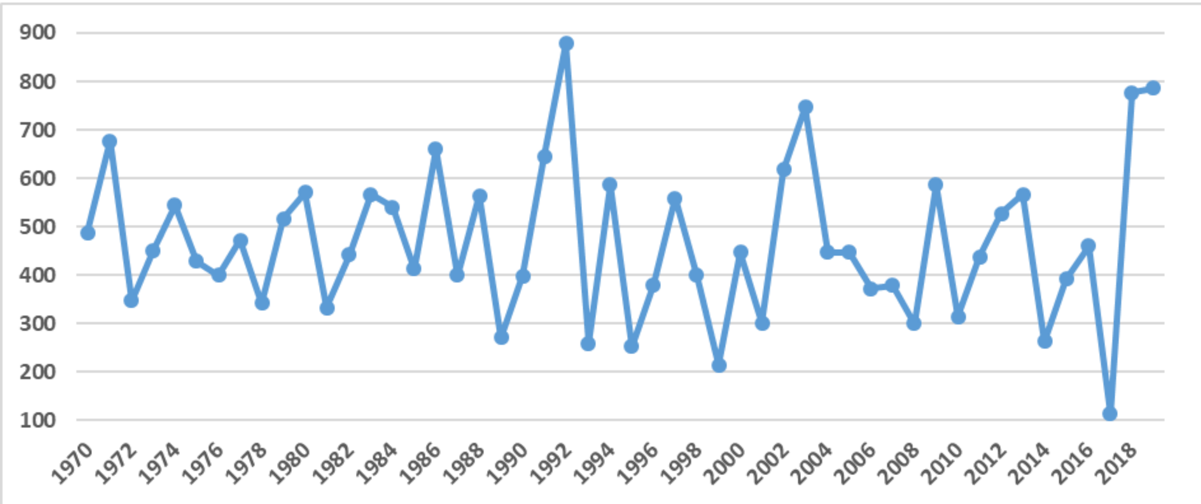


Figure 4: Annual total precipitation values in IrbidIrbid for the period 1970-2019

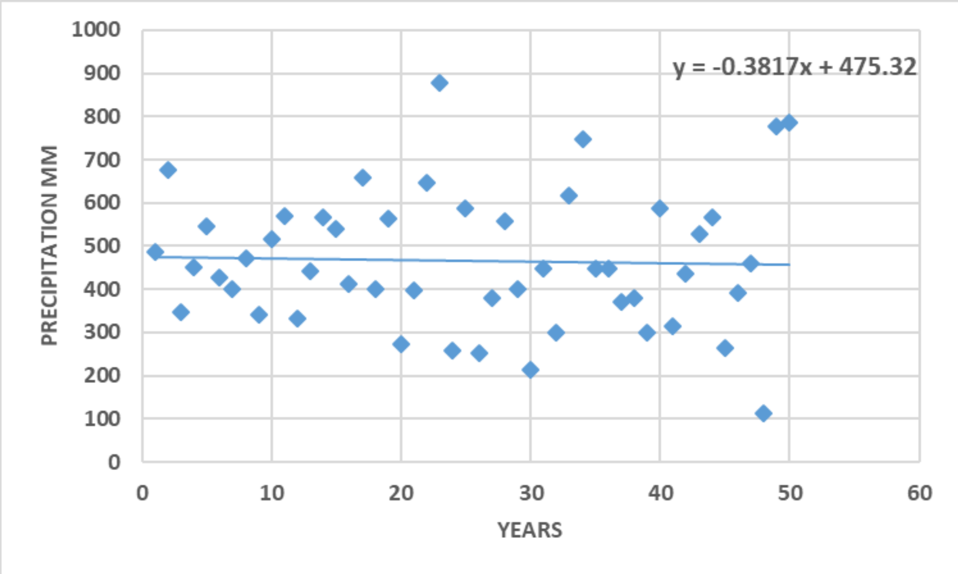


Figure 4:Lenier regression line and R- squered value of annual precipitation in Irbid for the period 1970-2019

Most precipitation (i.e., 65%) falls in the winter season in (December, January, February), while 23% falls in the spring season in (March, April, May), in addition the percentage of autumn precipitation reaches to 12% in (September, October, November) (Figure 5).

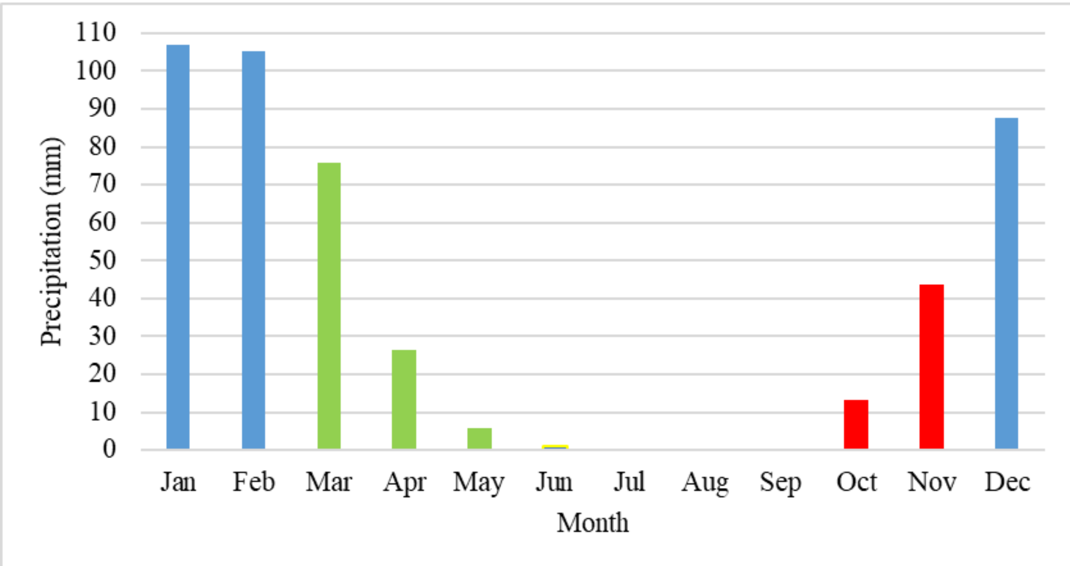


Figure 5: Monthly averages of precepitation in Irbid for the period 1970 – 2019

Results of buildings' rooftops extraction in Irbid city

Figure 6 displays the ultimate map depicting the rooftops of buildings within Irbid city. The findings revealed that the aggregate area of these building rooftops measured approximately 6.93 km². Comparatively, the registered building area in the municipality of Irbid was recorded at 6.34 km² in

2021. The precision, recall, and F-score metrics used for detection accuracy assessment yielded values of 0.956, 0.854, and 0.902, respectively. The outcomes underscore the viability of utilizing high spatial resolution remote sensing and elevation data for mapping building rooftops in the diverse urban landscape of the study area. It is important to note that discrepancies in the measured area may be attributed to potential misclassification issues or the presence of unregistered buildings within the city, aspects that warrant further investigation by municipal authorities.

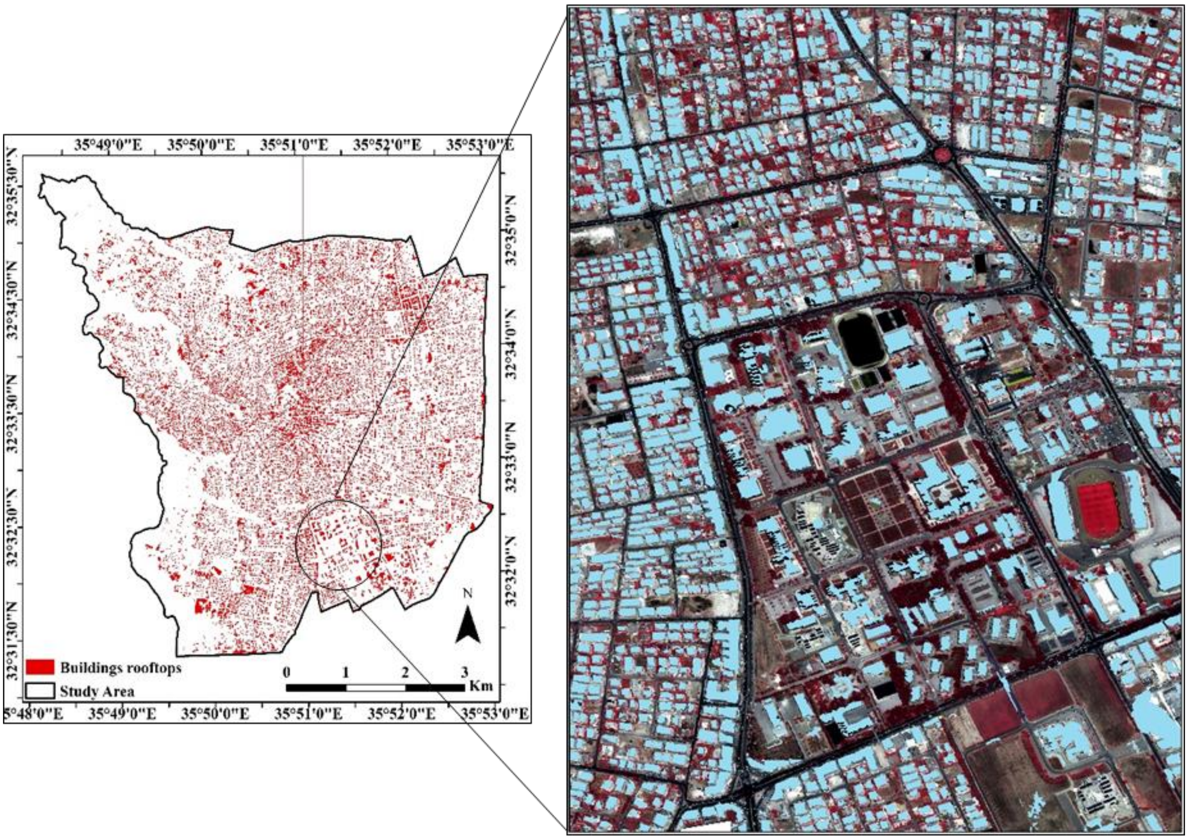


Figure 6. The map illustrating the rooftops of buildings in Irbid city as derived from a fusion of data sources, including the high spatial resolution Pleiades-B1 image, NDVI (Normalized Difference Vegetation Index), and nDSM (normalized Digital Surface Model) data.

The estimated amount of harvested water

Figures 7 and 8 show the potential estimated amount of harvested water after calculating the total area of the rooftops in the city and applying the equation of calculating the amount of harvested water from the rooftops. The figures showed variations in the monthly estimated amount of water in relation to the total precipitation. Meanwhile, the total amount of harvested water was estimated as 25858324.8 m^3. This amount of water if invested would improve the water per-capita in Irbid city to reach to 39.7 m^3 in addition to the current status. If precipitation is utilized in the winter month, the per capita share will increase about 25 m^3, but if precipitation is utilized in the spring and winter seasons, the per capita share will increase about 35 m^3.

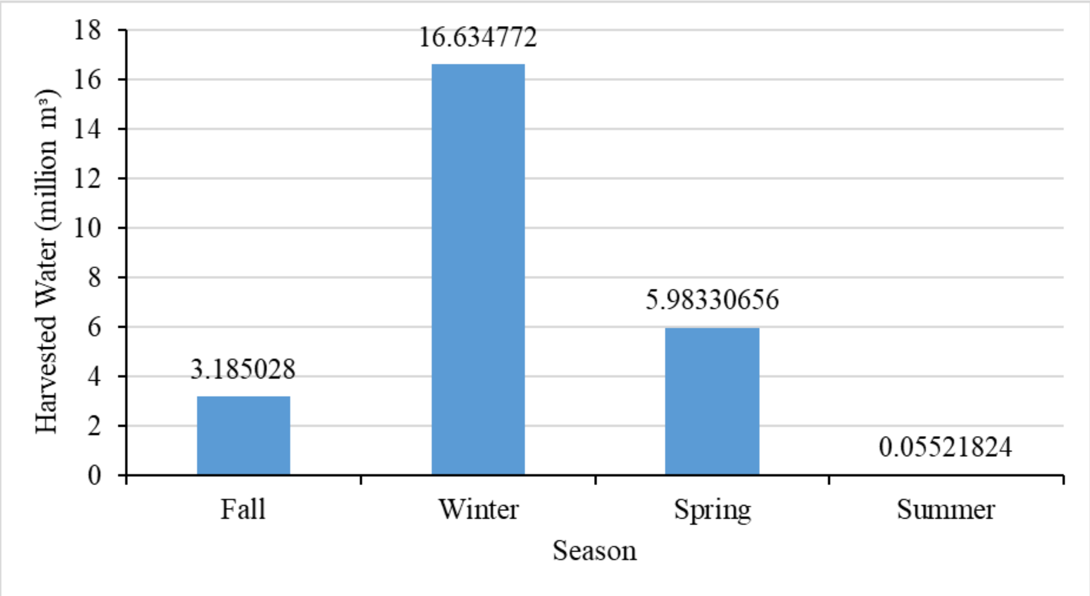
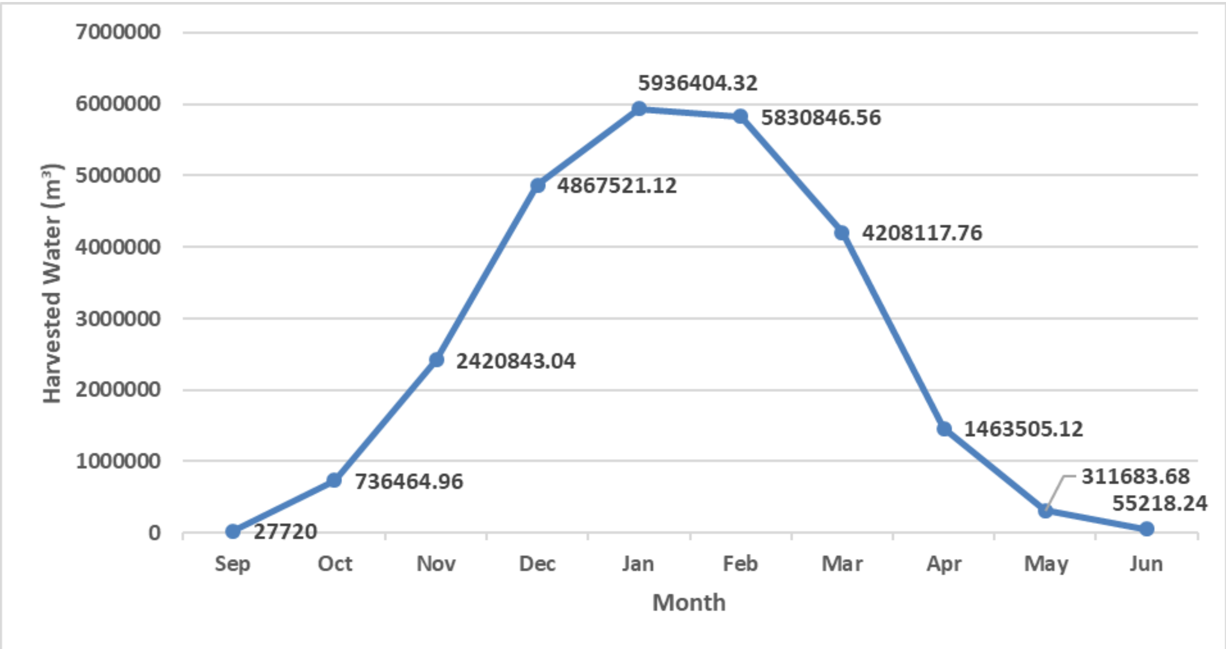


Figure 7. The potential estimated amount of harvested water in seasons after calculating the total area of the rooftops in the Irbid city



Figures 8. The potential estimated amount of harvested water in months after calculating the total area of the rooftops Irbid city.

Discussion

Though the calculation of the potential amount of harvested water would be straitforward, however, consideration should be given to the spatial variation in precipitation across different areas of Irbid city, and if available, spatially distributed precipitation data is incorporated to refine the estimation for specific regions within the city. Validation and calibration exercises could be conducted to enhance the accuracy of the model. The estimated amounts could be compared to actual collected data, if available, or adjustments are made based on observed discrepancies. Additionally, sensitivity analysis would be performed to assess the impact of variations in roof area and precipitation on the estimated harvested water amounts. This analysis helps understand the reliability of the estimation under different scenarios. Also, to ensure ongoing accuracy, a framework for continuous monitoring and updates should be established, considering changes in the built environment, rooftop configurations, and precipitation patterns over time. In this situation, regular updates to data inputs and reassessment of the estimation are recommended.

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