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Determining the Best Rainwater Harvesting System in Al-Muthanna Governorate, Iraq

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Abstract

Rainwater harvesting is one of the available solutions to overcome water scarcity in arid and semi-arid regions with highly variable rainfall and unexpected periods of drought or floods. This study aims to identify the best rainwater harvesting system in Al-Muthanna governorate using Remote Sensing (RS) and Geographic Information System (GIS) techniques. Landsat 8 images were used to produce the land use map which shows five different classes: water (0.2%), bare soil (82.11%), built-up (15.71%), forest (0.27%), and farmland and grass (1.71%). The results revealed that the rainwater harvesting system can be applied only in the north and north-eastern parts of the study area which consists of residential and agricultural areas and has a maximum monthly mean rainfall range of (85.32-157.21) mm. Rooftops, semi-circular bunds, and ponds are the most suitable systems for rainwater harvesting in Al-Muthanna. The rooftops system can provide 7000-13,500 litres of water for domestic purposes. Furthermore, if the water quality was low, it could be also used in agriculture practices or to irrigate home gardens.

Keywords: Rainwater harvesting, Rooftops, Land use, GIS, Al-Muthanna.

تحديد أفضل نظام لتجميع مياه الأمطار في محافظة المثنى، العراق

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الخلاصة

يعد تجميع مياه الأمطار أحد الحلول المتاحة للتغلب على شحة المياه في المناطق الجافة وشبه الجافة والتي تتميز بأمطار متذبذبه وفترات غير متوقعة من الجفاف أو الفيضانات. لذلك، فإن هذه الدراسة تهدف الى تحديد أفضل نظام لتجميع مياه الأمطار في محافظة المثنى باستخدام تقنيات التحسس النائي ونظم المعلومات الجغرافية. تم استخدام صور القمر الصناعي لاندسات 8 للحصول على خارطة استخدامات الأراضي والتي أظهرت خمسة تصنيفات مختلفة: المياه (0.2%)، التربة الجرداء (82.11%)، المناطق السكنية (15.71%)،

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الأشجار الكثيفة (%0.27), والأراضي الزراعية والعشب (%1.71). أظهرت النتائج بأن نظام تجميع مياه الأمطار يمكن تطبيقه فقط في الأجزاء الشمالية والشمالية الشرقية من المحافظة والتي تتألف من مناطق سكنية وزراعية ويتراوح أقصى معدل شهري للأمطار فيها بين (157.21−85.32) ملم. تعد سطوح المباني، السدود نصف الدائرية، والبرك من أفضل الأنظمة لتجميع مياه الأمطار في المثنى حيث إن نظام سطوح المباني يمكن ان يوفر (13500−7000) لترمن الماء للأغراض المنزلية. من ناحية اخرى، إذا كانت جودة المياه منخفضة، فيمكن استخدامها للأغراض الزراعية او لسقي الحدائق المنزلية.

1. Introduction

Many countries are facing a severe pressure of water shortage around the world. The demographic patterns changes, socio-economic development, technological innovation, and environmental degradation, particularly climate change, are responsible for creating an acute water scarcity for human life [1].

In Iraq, despite the existence of the Tigris and Euphrates rivers, the country faces a complex water crisis that is expected to persist and might have implications at the humanitarian, economic, security, and social levels, including population movements. In July 2019, the International Organization for Migration (IOM) reported that 21,314 internationally displaced persons from the central and southern governorates were displaced because of water scarcity, high salinity levels, and outbreak of waterborne diseases [2]. Therefore, rainwater harvesting systems were suggested as one of the solutions to overcome the water shortage problems in Iraq.

Rainwater rainwater harvesting is the oldest-most recent technique that collects water from natural catchment areas to enhance available water for specific areas. Humans used a rainwater harvesting for thousands of years as a conventional technique for providing drinking water for people, livestock, and agriculture [3]. The practices as rainwater harvesting, storage, and reuse are sustainable methods to increase water supply[4]. In other words, the technique of rainwater harvesting provides dirt-free water that can be used for drinking and direct consumption. It is necessary to supplement groundwater supplies during dry seasons through simple infiltration devices, reduce contamination, and avoid flooding from roads [5].

Many previous researchers studied rainwater harvesting around the world such as Dadhich and Mathur (2016) assessed the rooftops rainwater harvesting in three different cities of Rajasthan, India. Google Earth and Quantum (QGIS) techniques were used to consider the intersected measurements of the area for placing containers that collect rainwater. The average rainfall with the tank capacity of the overall rooftops was estimated. The results showed that one of the three cities was highly suited for the rainwater harvesting methods implementation [6]. Khan et al. (2021) examined the rainwater harvesting system viability in Australia in terms of water savings, reliability, and financial viability. They found that the rainwater harvesting system reliability for the case of ‘toilet flushing and laundry’ water usage is considerably high (80-100) %, while for the combination of toilet flushing, laundry, and irrigation water usage reliability drops below 50% for most of the continent. Also, the results showed that the rainwater harvesting system benefit-cost ratio can be achieved under certain conditions [7]. Dao et al. (2021) assessed the use of rainwater and the effect of operation and maintenance activities of the rainwater system on drinking water quality in rural areas in Ha Nam province of Vietnam. Their study showed that 100% of surveyed households used a rainwater for drinking and 98% for cooking [8]. Al-Qawasmi (2021) investigated the feasibility of rainwater harvesting from residential rooftops in all the eighty-nine Jordanian districts. The building growth rate was used to calculate the forecast number of buildings from 2016 to 2025. To assess the potential of rainwater harvesting, two scenarios were used: numerical and tabulated by plumbing code. She found that the potential water harvesting was different between the two scenarios [9].

In Iraq, several researchers studied rainwater harvesting, specifically the rainwater harvesting site selection, without identifying the system that is used for harvesting rainwater. For example, Al-Khuzaie et al. (2020) selected the optimized sites for water harvesting in Al-Qadisiyah governorate by using GIS and RS techniques. The Soil Conservation Service Curve Number (SCS-CN) model was used to calculate the potential runoff as an intermediate input. The Multi-Criteria Evaluation (MCE) techniques were adopted to identify the relative importance and suitability levels of the input parameters set to manage a water supply. They identified the rainwater harvesting suitable sites and divided them into four classes (very low, low, moderate, and high) in terms of their suitability for water harvesting [10]. Similarly, Ahmed et al. (2020) predicted the best rainwater harvesting sites in Horan valley by using the Analytical Hierarchy Process (AHP) and the pairwise comparison method [11].

Al-Muthanna governorate is located in an arid area, has limited water supplies, and experiencing drought and water scarcity in 22 locations as described by the IOM [2]. This work aims to identify the most suitable rainwater harvesting system in the governorate of Al-Muthanna and benefit from rainfall before it turns to surface runoff.

1.1 Categorization of Rainwater Harvesting Systems

There are many different systems of rainwater harvesting which have been developed over time. Rainwater harvesting technology with identical systems might be indicated by different names in different districts, while others might be indicated by similar names even though they are completely different in reality [12]. Generally, the rainwater harvesting system consists of three main components: a catchment area, where the rainfall is collected, a storage facility, where the water is stored to be used when needed, and a target system, which specifies how the water will be used and what target it will serve. In general, the main aim of their usage is to provide water for human consumption and other water-related activities, as well as, to reduce runoff lag during rainy seasons [13]. Accordingly, this richness of rainwater harvesting technologies and components makes their classification vary in the literature, depending on the focus given by the researchers. For example, rainwater harvesting systems for agricultural purposes are classified into three major categories, based on the catchment area size and the runoff transfer distance: micro catchment rainwater harvesting (such as contour bunds, contour ridges, semi-circular bunds), macro catchment rainwater harvesting (like trapezoidal bunds and contour stone bunds), and floodwater harvesting (such as permeable rock dams and water spreading bunds). Moreover, a sub-categorization of the micro catchment rainwater harvesting systems has been made, which include catchment surfaces, including rooftop systems, courtyards, and other impermeable structures [14]. This type of collection is mainly used for domestic purposes, although if the quality of water is low, it could be used in agriculture practices or to irrigate home gardens [15]. While, based on the source of water (catchment area), rainwater harvesting systems are classified into in-situ (such as terracing and living barriers) and ex-situ technologies (such as pavement collection and ponds), and manmade/impermeable surfaces, as shown in Figure 1 [16].

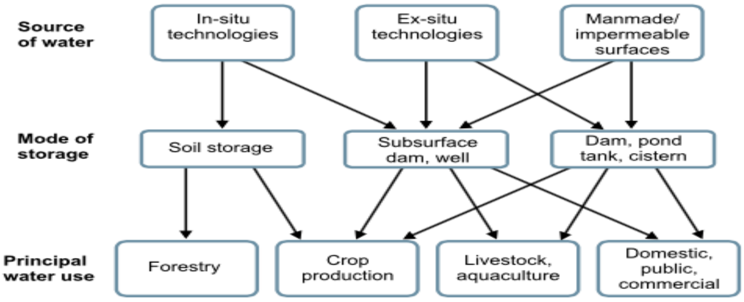

Figure 1- Rainwater harvesting technologies scheme according to the source of water, storage mode, and principal water use [16].

1.2 Rainwater harvesting Design Systems

Among the various rainwater harvesting systems, two design systems will be illustrated: 1) keylines system, which is used for agricultural purposes, and 2) rooftop catchments, as an example for domestic water supply.

1.2.1 Keylines Rainwater Harvesting Systems

Keylines are a generalized approach for rainwater harvesting systems used in agriculture. Their main aim is to improve soil fertility by raising the content of total organic matter within the soil. This system is based on the natural topography, contours, and slopes of the land [17]. It offers one of the most powerful tools which are the swales or ditches construction with a small gradient away from gullies, thus bringing overflow runoff in the erosion gullies into the shoulders. Although this system has received little scientific support, it is common with farmers, who regard it useful to enhance the soil organic matter properties[18]. The keylines system has several advantages, some of which can be seen immediately, while others have long-term results. These can be some examples: reduced soil erosion, restoration of subsurface hydrological flows and aquifers, reduction of floods and droughts, and reduction of sediments carried by rivers [19].

1.2.2 Rooftops Rainwater Harvesting Design System

Rooftops rainwater harvesting is the technique through which rainwater is captured from different roof catchments and stored in reservoirs [6]. It is the most common technique, out of the various methods used currently, that collects rainwater for domestic purposes [14]. The harvested rainwater can be stored in a sub-surface groundwater reservoir by adopting artificial recharge techniques to supply household needs through storage in tanks. Moreover, rainwater is allowed to get collected in built-up tanks [6]. In other words, there are two storage tanks for a roof harvesting system, which are aboveground storage (Figure 2a) and underground storage (Figure 2b) [20].

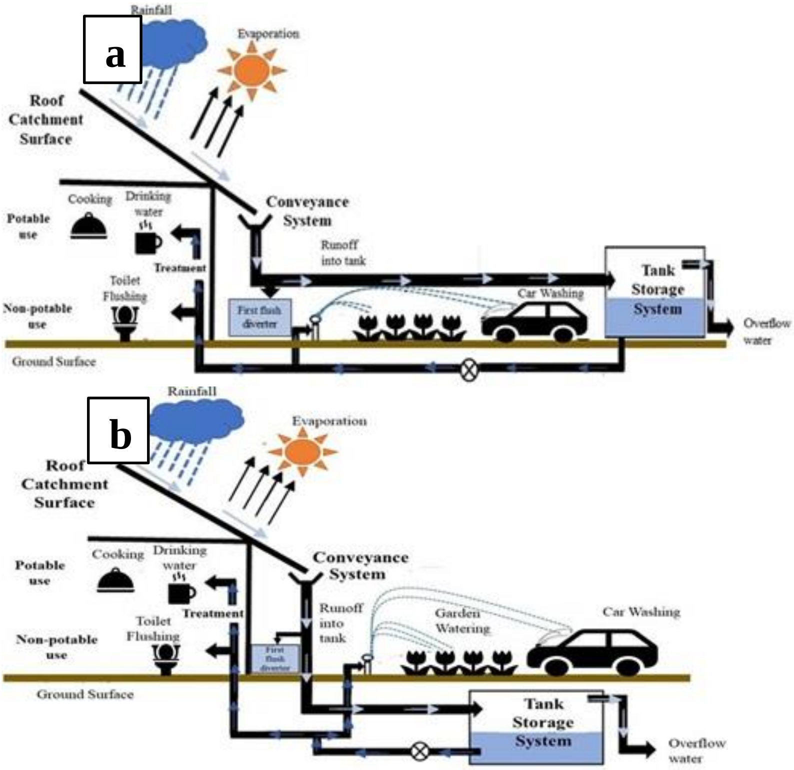

Figure 2- (a-b) Design of rooftops rainwater harvesting storage system [20].

The harvested rainwater amount can be calculated applying equation (1) [6]:

$$\mathrm{W\ (liters)} = \mathrm{T} \times \mathrm{A} \times \mathrm{R} \qquad (1)$$

Where, W= the available water from the roof; T= the total rooftop area (m^2); A= the monthly mean rainfall (mm); and R= the rooftop runoff coefficient.

The runoff coefficient for any catchment is defined as the ratio between volumes of water that runs of and that of the total volume of rain that falls on the rooftop. The runoff coefficient value depends on the rooftop type ,as presented in Table 1 [6]:

Table 1- Runoff coefficients for different rooftops [6].

Type of Roof	Rooftop Coefficient
Galvanized sheets	0.90
Asbestos	0.80
Tiled	0.75
Concrete	0.70

2. Material and Methods

2.1 Study Area

Al-Muthanna Governorate is located southwest of Iraq between the two latitudes (31° 43′ 43″ - 29° 03′ 45″) N and longitudes (46° 41′ 15″ - 43° 48′ 45″) E borders Saudi-Arabia. The total area is 51,740 km^2 (11.9% of Iraq), which makes it the second-largest governorate in Iraq [21, 22], and holds the second-fewest population in the country (835,797 in 2019, 3% of the total) [23]. Al-Muthanna climate is a desert climate; in summer temperatures easily exceeding 40°C, while rainfall is very limited and restricted to the winter months [24]. Desert plains dominate the landscape except in the north near Al-Samawa station where a thin ribbon of irrigated farmland along the Euphrates River [21, 25], as illustrated in Figure 3.

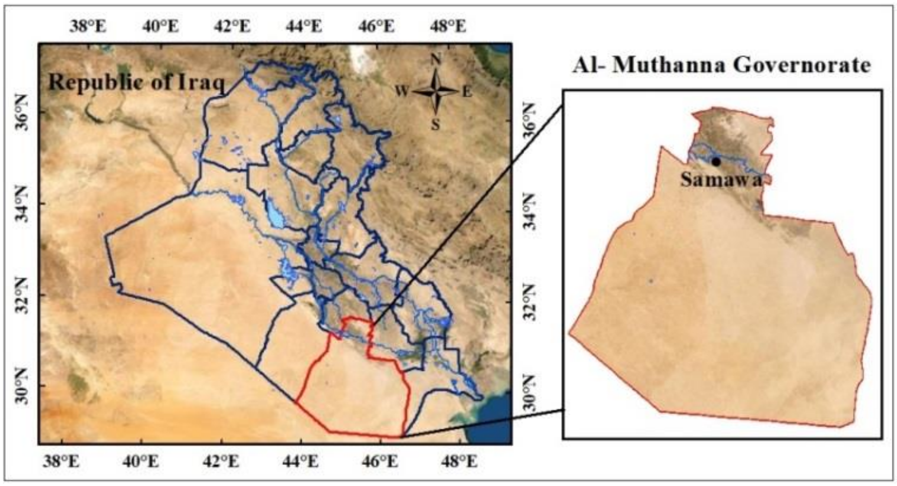

Figure 3- Study area location (Al-Muthanna governorate)

2.2 Data Collection

To study the rainfall behavior, the maximum monthly mean rainfall data from the Iraqi meteorological organization and seismology were analyzed for the years 1988-2018, as shown in Figure 4.

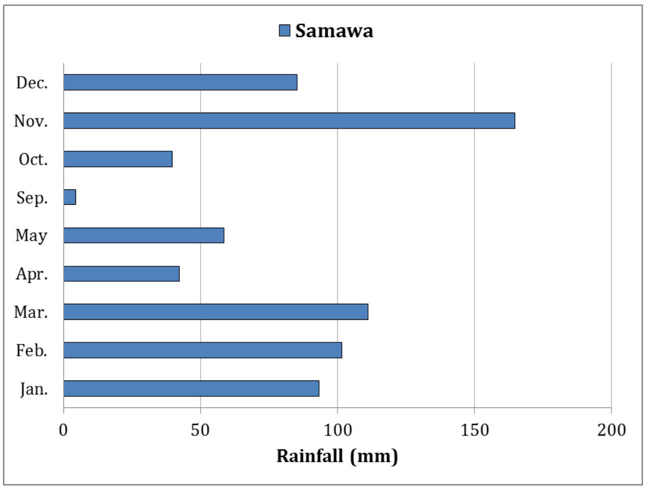

Figure 4- The maximum monthly mean rainfall of Al-Muthanna (1988-2018) (Samawa station

RS rainfall data estimation from the Global Precipitation Measurements (GPM) Mission (https://giovanni.gsfc.nasa.gov/giovanni/) is considered as a potential alternative to supply the rain gauge data with a good spatial distribution [26]. Therefore, from the period of study and based on Figure 4, monthly mean rainfall data of the rainiest month (November 2018) were used to estimate the rainfall values distribution, as clarified in Figure 5.

In addition, Landsat 8 images obtained from the United States Geological Survey (USGS) [27] are used to generate the land use map for the study area, see Figure 6. These two datasets are geographically corrected to the Universal Transverse Mercator (UTM) coordinate system utilizing the World Geodetic System (WGS) 1984 datum, Zone 38, processed, analyzed, and interpreted by using ArcGIS 10.4.1 software.

3. Results and Discussion

Rainfall data and Landsat 8 images are used to determine the best rainwater harvesting system for Al-Muthanna governorate. Rainfall data for November 2018, based on GPM, was downloaded in Geotiff form and processed with a spatial distribution of 0.1 degree to estimate the rainfall values distribution of the study area. Figure 5 shows the map-accumulated monthly rainfall.

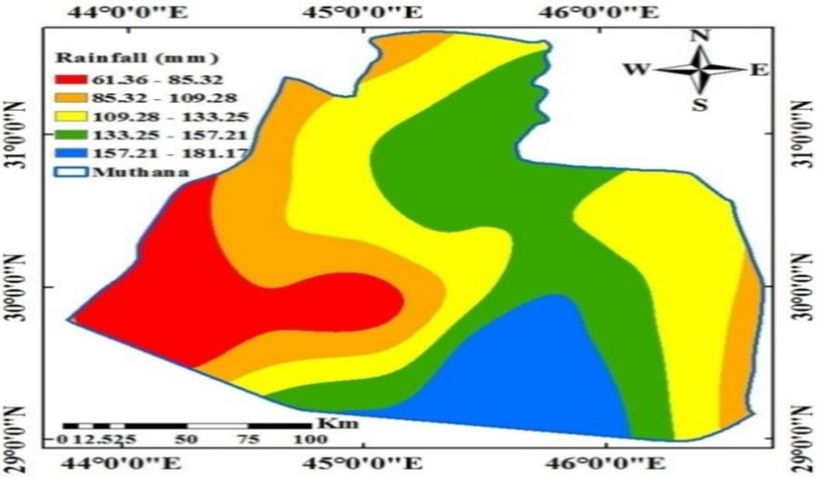

Figure 5- The map-accumulated monthly rainfall based on GPM data (mm/month).

Landsat 8 images obtained from the USGS with a spatial resolution of 30m were processed and classified to obtain the land use map. Seven Landsat 8 images for April 2018 were combined to create a mosaic raster of the considered area. The supervised maximumlikelihood classification was used to produce the land use map, for which training samples were collected using field surveys to create a spectral signature file. Five land use classes were identified: water, built-up, forest, farmland and grass, and bare soil, as illustrated in Figure 6. The water encompasses 0.2%, bare soil 82.11%, built-up 15.71%, forest 0.27%, and farmland and grass 1.71%.

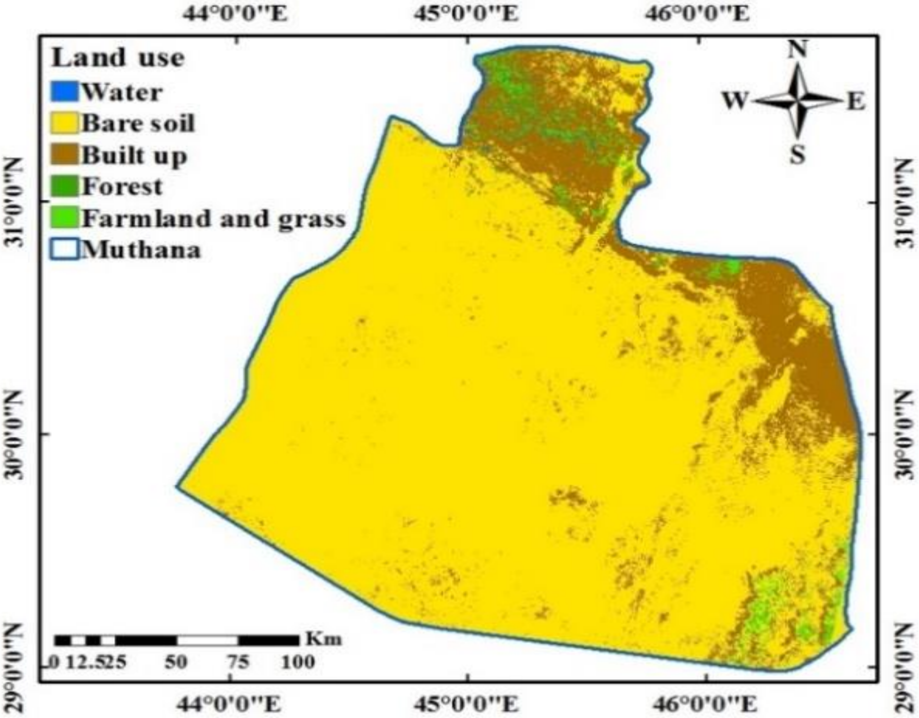

Figure 6- Land use map of Al-Muthanna.

Depending on these results, it is clear that the built-up and farmland and grass classes have a low proportion and are restricted on the northern and northeastern parts of the studied area, as well by comparing them with the rainfall map (Figure 5) which shows that the rainfall values range is (85.32-157.21) mm, the northern and northeastern parts were chosen to identify the best rainwater harvesting system for Al-Muthanna. To achieve that, these parts were analyzed to determine their classes more clearly using the ArcGIS Online basemap. The land use map (Figure 6) and the basemap (Figure 7) reveale that the majority of these parts are consist of residential and agricultural areas, which constitute ≈18% of the governorate.

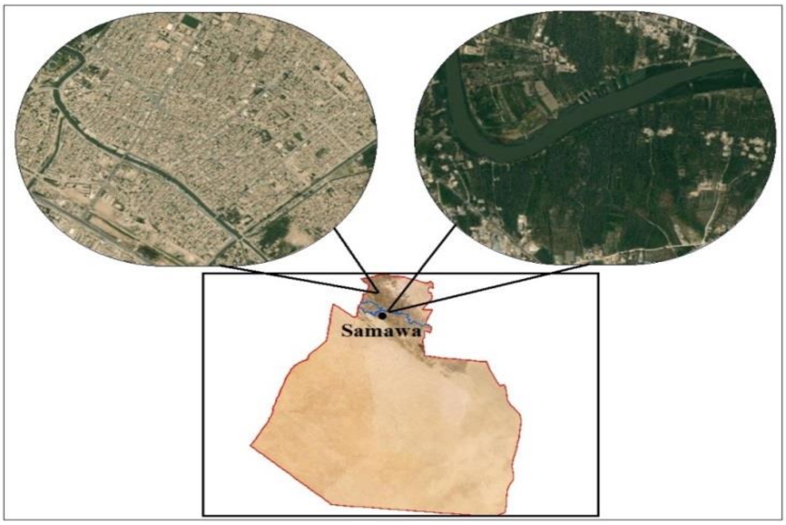

Figure 7- Al-Muthanna ArcGIS Online basemap.

Accordingly, the most suitable rainwater harvesting technique for the residential areas is the rooftops system, whereas the semi-circular bunds and ponds systems are appropriate to the agricultural lands. Table 2 shows the harvested rainwater amounts from different roofs which were calculated applying equation (1) and assuming that T= 100 m^2, A= 100 mm, 150 mm.

Table 2- The harvested rainwater amounts from different roofs.

Type of Roof	Monthly mean rainfall (mm)	Harvested rainwater amount (liters)
Galvanized sheets	100	9,000
	150	13,500
Asbestos	100	8,000
	150	12,000
Tiled	100	7,500
	150	11,250
Concrete	100	7,000
	150	10,500

4. Conclusions

In this research, RS and GIS techniques were used to select the best rainwater harvesting technique for Al-Muthanna Governorate. Results indicated that the rainwater harvesting system can be identified depending on the rainfall values distribution pattern and the land use map of the considered area. In other words, it is possible to determine the best system by identifying the class of the study area (residential, agricultural, etc.) and the rainfall amount. Also, it was concluded that the rainwater harvesting system can be applied only in the north and northeastern parts of the studied area since most of the other parts are bare soil. Rooftops and semi-circular bunds and ponds are the most suitable systems for rainwater harvesting in Al-Muthanna. Rooftops system can provide 7000-13,500 liters of water for domestic purposes. Furthermore, if the water quality was low, it could be also used in agriculture practices or to support home gardens. Thus, we suggest that the rooftops should be covered with galvanized sheets in winter to get the most benefit from rainfall, which should be tilted and moveable roofs to avoid the heat effect in summer.

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