Al-Mustansiriyah Journal of Science
ISSN: 1814-635X (print), ISSN:2521-3520 (online) Volume 32, Issue 2, 2021 DOI: http://doi.org/10.23851/mjs.v32i2.990

Research Article Open Access

Rainwater Harvesting Using GIS Technique: A Case Study of Diyala Governorate, Iraq

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Article Info

Received
31/03/2021

Accepted
25/04/2021

Published
13/05/2021

ABSTRACT

To improve the management of water resources in Iraq, there are several methods, including the use of rainwater harvesting techniques. In this study, the Digital Elevation Model (DEM) and Landsat satellite imagery were used under the GIS environment to identify the suitable zones for rainwater harvesting. The accomplishment of rainwater harvesting systems strongly depends on their technical designing and identifying the suitable sites. Six criteria have been used to identify the rainwater harvesting sites in Diyala governorate. The procedure of identifying the suitable sites for rainwater harvesting was applied twice for Diyala governorate. Firstly, it was applied by using the criteria of rainfall, slope, stream order, distance to roads, and land use, and secondly rainfall, slope, stream order, distance to roads, and Normalized Difference Vegetation Index (NDVI) criteria was used for this purpose. As a result, the study area was divided into three suitability zones: low, moderate, and high according to the specific criteria that were used to identify the rainwater harvesting suitable sites. It was found that in the application of land use criterion the low suitability zone represents 26%, 58% represents the moderate, and 16% for the high suitability zone, while in the method of NDVI it was found that 29% represents the zone that has low suitability, 57% represents the moderate, and 14% represents the high suitability zone. The compared results led to conclude that the land use is the most influential criterion for identifying the rainwater harvesting suitability sites and found that most of the Eastern parts of Diyala governorate is a promising area for rainwater harvesting and ArcGIS is a very useful, time-saving, and cost-effective tool for identifying the rainwater harvesting suitable sites.

KEYWORDS: Rainwater harvesting, Digital Elevation Model (DEM), Suitability map, Normalized Difference Vegetation Index (NDVI), land use, GIS, Diyala.

INTRODUCTION

The climate of Iraq is a continental, subtropical, and semi-arid except the mountainous region in the North and North East of the country which has a Mediterranean climate. Rain is very seasonal and unpredictable, lasting from December to February, except in the North and Northeastern parts of the country, where the rainy season occurs from November to April. The monthly mean rainfall was estimated to be 216 mm, but varies from 1200 mm in the North East to less than 100 mm in the South [1].

Until the 1970s, Iraq was generally considered to have rich water resources from Tigris and Euphrates rivers. The construction of dams on these rivers and their branches beyond Iraqi borders, along with the effects of climate change and mismanagement of water resources has limited the supply of water to Iraq. The growing need for water in Turkey and Syria could lead to the drying of these rivers by 2040 [2]. Therefore, rainwater harvesting systems were suggested as one of the solutions to overcome the water shortage problems in Iraq [3].

Rainwater harvesting is the oldest-most recent technique that collects water from natural catchment areas to enhance available water for specific areas. Around 9000 years ago, humans used rainwater harvesting as a conventional technique for providing drinking water for people, livestock, and agriculture, since there was a limited amount of obtainable water [4]. The achievement of rainwater harvesting systems strongly depends on the technical design and the identifying of suitable sites. The proper designing, constructing and operating of the harvesting systems will improve the rainwater availability for domestic use and agricultural production [5, 6]. In the recent decades many researchers in different parts of the world have focused on rainwater harvesting. For example, Buraihi & Shariff, (2015) [7] evaluated the parameters that have a significant contribution to the selection of rainwater harvesting sites in Kirkuk city by applying the Multi-Criteria Decision Analysis (MCDA) method. These parameters and their features were integrated into GIS to produce the potential map of rainwater harvesting. Suitable sites for different rainwater harvesting structures, such as farm ponds and check dams, were also identified. As a result, the study area was classified into three rainwater harvesting suitable zones: low, moderate, and high suitability zone, where it was found that about 4% of the area is appropriate for check dams and 3.7% is appropriate for farm ponds. Ali, (2018) [8] generated a suitability map in Badrah-Wasit by integrating the Multi-Criteria Analysis (MCA) and the weighted overlay method into GIS. The water harvesting potential sites were determined according to the five criteria: rainfall, NDVI, slope, stream order, and distance to roads. Consequently, the study area was divided into three zones: low (35%), moderate (27%), and high (2%) suitability zone. Ibrahim et al., (2019) [9] identified the appropriate sites for dam's construction in Dohuk governorate and evaluated the rate of runoff that could be stored in them by integrating Remote Sensing (RS) and Geographic Information System (GIS) based on the Analytical Hierarchy Process (AHP) analysis, and using five layers which are runoff potential, stream order, slope, land use/cover, and soil quality. The rainwater harvesting suitability sites were determined by applying the Multi-Criteria Evaluation (MCE). Results illustrate that 15% of the area represents the excellent suitable sites, 21% represents the moderate suitable sites, and 51% have poor suitability or unsuitable for harvesting rainwater. In this study, Diyala Governorate was selected because it is one of the semi-arid regions that suffering from water scarcity and has appropriate quantities of rain that are required for rainwater harvesting.

The main goal of this study was to generate a suitability map for rainwater harvesting sites to handle water scarcity in Diyala, improve water resource management, and this will allow benefiting in terms of cities design and agriculture purposes according to the specific criteria that used in this research. This study is different from the other previous studies because we did not found a rainwater harvesting research for Diyala and with the criteria that used in this study with a comparison of the land use and NDVI criteria.

MATERIAL AND METHODS

1. Study Area

Diyala governorate is located in the North-Eastern side of Iraq among the two latitudes (33° and 35°) N and the two longitudes (45° and 46°) E, and covers an area of about 17.685 km^2 as shown in Figure 1. The area is characterized by topography; the highest elevation reaches 1826 m above mean sea level in the Northeast of the area, while the lowest elevation is about 17 m above mean sea level in the Southern parts (DEM value).

2. Data Acquisition

Landsat satellite imagery, Digital Elevation Model (DEM), and rainfall data were adopted to be used for rainwater harvesting. The Landsat images were taken with a spatial resolution of 30 m, on 13 January 2018 which obtained from the website of the United States Geological Survey (USGS) and geographically corrected to the Universal Transverse Mercator (UTM) coordinate system utilizing the World Geodetic System (WGS) 1984 datum, Zone 38 by using ArcGIS 10.4.1 software. Landsat images were used to detect the land use and NDVI. The drainage network was generated using DEM (SRTM) data which obtained from the USGS. The monthly mean rainfall data were delivered by the Iraqi Meteorological Organization and Seismology from 1988 to 2018 as measured by the two meteorological stations in the study area, Al-Khalis and Khanaqeen.

ISSN: 1814-635X (print), ISSN:2521-3520 (online) Volume 32, Issue 2, 2021 DOI: http://doi.org/10.23851/mjs.v32i2.990

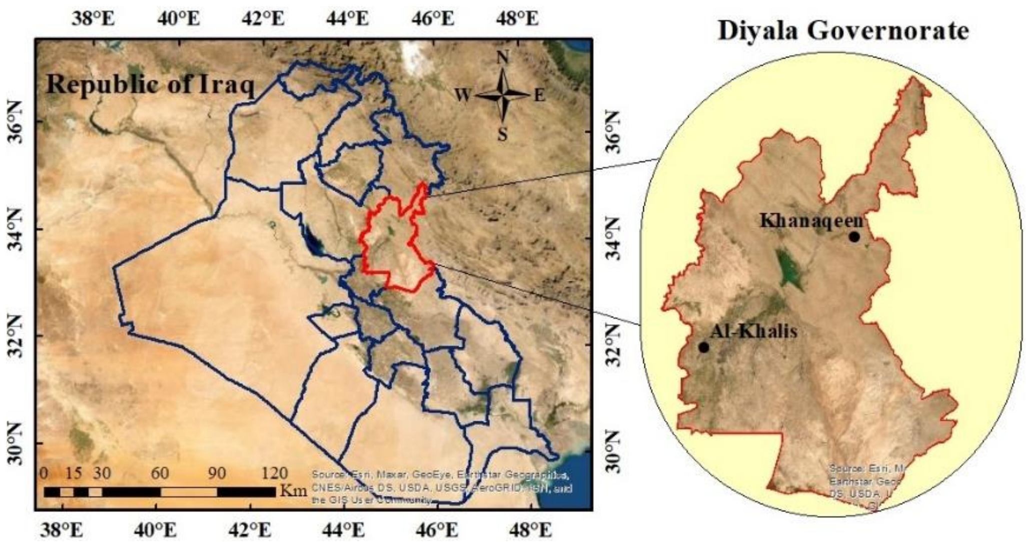

Figure 1. Study area location (Diyala).

RESULTS AND DISCUSSION

1. Criteria Selection

Food and Agriculture Organization of the United Nations (FAO) listed six key factors to identify the suitable sites for rainwater harvesting: climate, hydrology, agronomy, topography, soils, and socioeconomics [10]. In this study, six criteria were used for rainwater harvesting site selection based on the available data. We followed the recommendations of the FAO and used rainfall as a parameter for climate, stream order for hydrology, slope for topography, land use and NDVI as parameters for agronomy, and the distance to roads as a parameter for the socioeconomics factor. ArcGIS 10.4.1 software was used to integrate and analyze the data as a part of the process for identifying the rainwater harvesting suitable sites.

1.1. Rainfall

This analysis was based on the monthly mean rainfall for the period (1988-2018). Figure 2 shows the rainfall behavior of Diyala stations where the maximum value (~51 mm) was recorded in January by Khanaqeen station while the minimum value was recorded by Al-Khalis station in May (~4 mm).

Interpolation (spline) was used to interpolate the rainfall data for the study area from the rainfall values obtained from Al-Khalis and Khanaqeen stations. Spline is one of the interpolation methods which is used to estimate values at unmeasured locations. ArcGIS10.4.1 spatial analyst toolbar was used to interpolate the rainfall data set. Rainfall is the main criterion for identifying the rainwater harvesting suitable sites. The majority of the areas with high suitability had rainfall values varied between 45 and 58 mm. The interpolated rainfall map is illustrated in Figure 3.

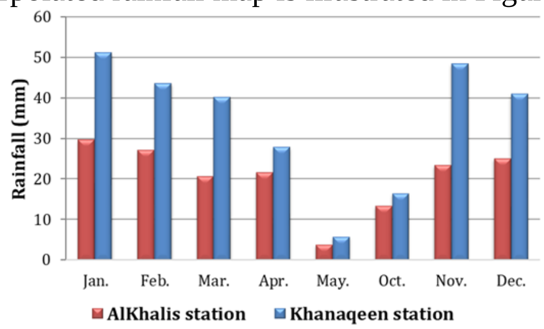

Figure 2. The monthly mean rainfall of Diyala stations.

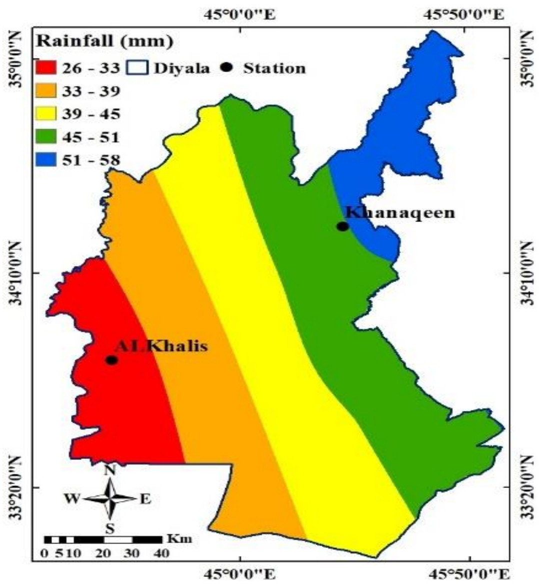

Figure 3. The spatial distribution of monthly mean rainfall of Diyala.

1.2. Slope

Slope is created from a terrain ratio, which indicates the ratio of the difference in elevation between two points divided by the straight horizontal distance between them [11]. The slope is derived from the DEM and classified into 5 classes according to the FAO slope classification. The slopes of ≥ 5 % are considered unsuitable for water harvesting because of their vulnerability to high rates of erosion [12]. The slope map of the study area is presented in Figure 4.

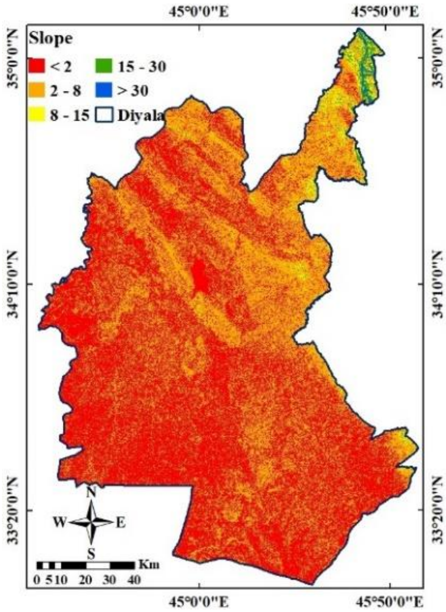

Figure 4. The slope map of Diyala.

1.3. Stream Order

The hydrological parameters were derived from the spatial analysis tools to produce the stream order map based on the DEM data. The orders of the stream are based on the linking of tributaries. Stream order represents the hierarchical relation between the flow parts and allows for labeling the drainage basins based on their size. Besides, the order analysis is important for mapping rainwater conservation streams, because of higher stream orders having lower permeability and infiltration. It was found that the study area has 8 stream orders as shown in Figure 5.

1.4. Land Use

Land use is one of the main criteria used for selecting the rainwater harvesting suitable sites. The hydrological response of the river basins is affected by the land use change and rainfall. Land use was obtained from satellite imagery registered on 13 January 2018 with a spatial resolution of 30 m. The maximum-likelihood supervised classification was used to classify land use using the means, variance, and covariance from the signature file. Five types of land use were identified: water, built up, forest, farmland and grass, and bare soil as shown in Figure 6.

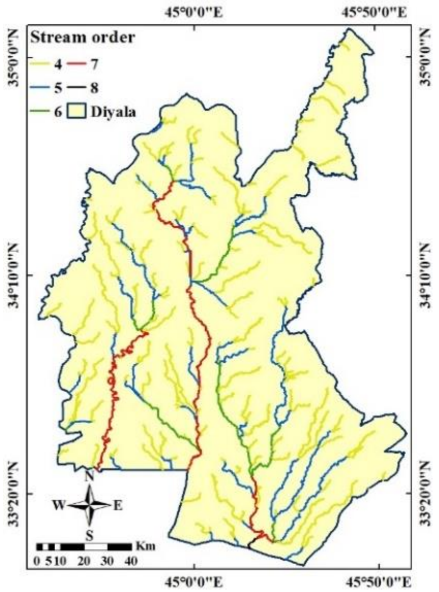

Figure 5. Stream orders map of Diyala.

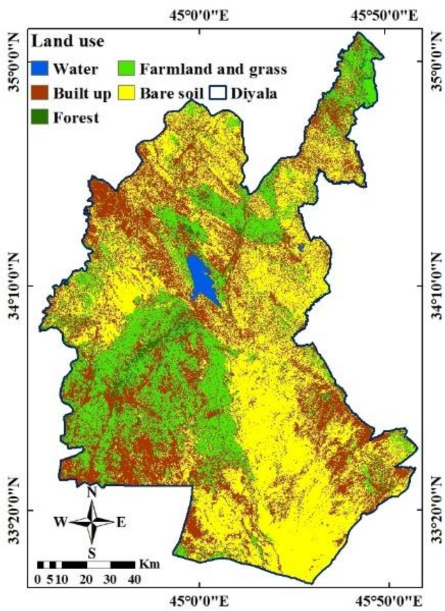

Figure 6. Land use map of Diyala.

1.5. Normalized Difference Vegetation Index

Figure 7 shows the NDVI map of Diyala. The data was obtained from the analysis of the Landsat 8 image registered on 13 January 2018 with a spatial resolution of 30m. The NDVI was calculated by using the Red band (RED) and Near-Infrared band (NIR) using the raster calculator in ArcGIS by applying Equation (1).

$$\text{NDVI} = \frac{(NIR - RED)}{(NIR + RED)} \tag{1}$$

The NDVI value is ranging between -1 and 1, where high positive values refer to high green

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vegetation and negative values refer to non-vegetated surface features such as water, ice, snow, or clouds [13].

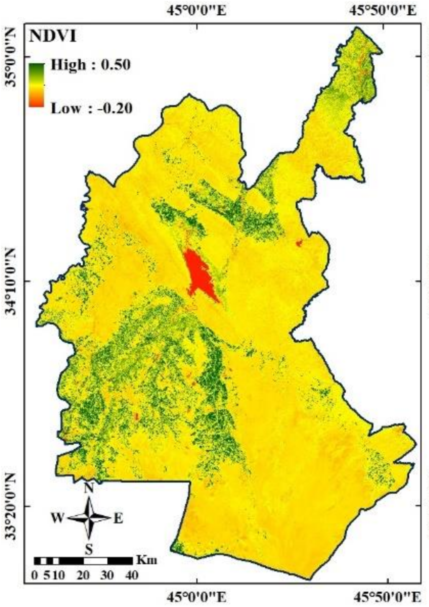

Figure 7. NDVI map of Diyala.

1.6. Distance to Roads

The road layer was input as a polyline feature then changed to a distance layer by applying the Euclidean distance function in ArcGIS as shown in Figure 8. The Euclidean distance formula was utilized to measure the distance between two points in the plane with coordinates (x, y).

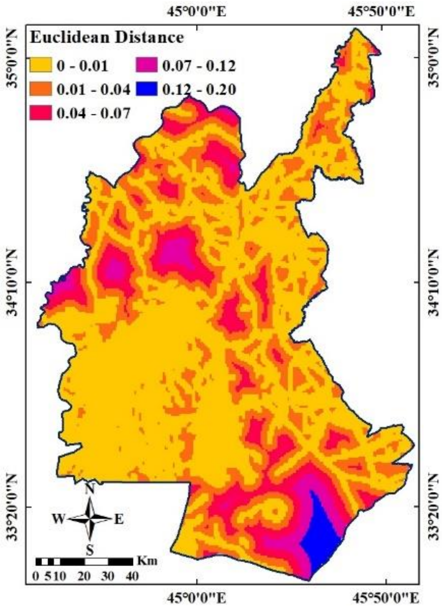

Figure 8. Distance to roads of Diyala.

2. Suitability Classification for Each Criterion

Because of the variety of measurements and scales for the various criteria, each criterion was reclassified. The previously mentioned criteria were used to classify pixel values from 0 to 10. The least suitable zones were classified as 0, while the most suitable were classified as 10, as illustrated in Table 1.

3. GIS Analysis and Suitability Map Generation

The GIS database required for determining rainwater harvesting potential sites was developed using ArcGIS with both vector and raster databases. Suitable sites for rainwater harvesting were identified by reclassifying the criteria layers and combining them applying the raster calculator tool in the spatial analyst module of ArcGIS 10.4.1. Each criterion was clipped to the area of study, reclassified to a numerical value, and assigned rankings of suitability for rainwater harvesting.

4. Rainwater Harvesting Suitable Sites

The first step is to prepare all data for the criteria used for rainwater harvesting. Rainfall data was interpolated to produce the rainfall layer. DEM with a resolution of 30 m was clipped and extracted to obtain the slopes and stream orders of the study area, while Landsat images is used to obtain the Land use and NDVI. The five key layers were combined, but each pixel was scored differently.

Both generated suitability maps (obtained with the land use and NDVI) were classified into three classes of rainwater harvesting suitability: low suitability, moderate suitability, and high suitability as presented in Figures 9a and 9b.

The results of both applying criteria indicated that most of the Eastern parts of Diyala were proper for rainwater harvesting.

5. Comparison between Land Use and NDVI

Landsat images registered on 13 January 2018 with a resolution of 30 meters were used to produce the land use and NDVI maps for the study area. The main objective of this comparison was to distinguish which one of the two criteria (land use or NDVI) has the larger influence on the rainwater harvesting suitability sites. Therefore, the procedure of identifying the suitable sites for rainwater harvesting was applied twice for Diyala governorate. Firstly, it was applied by using the criteria of rainfall, slope, stream order, distance to roads, and land use, and secondly rainfall, slope, stream order, distance to roads, and Normalized Difference Vegetation Index (NDVI) criteria was used for this purpose (see Figure 9).

Table 1. Criteria, classification, suitability levels, scores, and weights for each criterion for identifying the rainwater harvesting suitable sites in Diyala.

Criterion	Class	Value	Score	Weight
Rainfall (mm)	Very low suitability	26 - 33	3	60 %
	Low suitability	33 - 39	5	
	Moderate suitability	39 - 45	6	
	High suitability	45 - 51	8	
	Very high suitability	51 - 58	9	
Land use	Water	Restricted	Restricted	30 %
	Built up	Low	4	
	Forest	High	7	
	Farmland and grass	Very high	9	
	Bare soil	Moderate	5	
NDVI	Restricted	-0.20 - -0.02	Restricted	30 %
	Very low suitability	-0.02 - 0.08	1	
	Low suitability	0.08 - 0.14	4	
	Moderate suitability	0.14 - 0.23	5	
	High suitability	0.23 - 0.50	8	
Roads	Moderate suitability	0 - 0.01	5	9 %
	High suitability	0.01 - 0.04	7	
	Very high suitability	0.04 - 0.07	9	
	Low suitability	0.07 - 0.12	3	
	Very low suitability	0.12 - 0.20	1	
Stream order	Very high suitability	> 7	9	0.5 %
	High suitability	7	8	
	Moderate suitability	6	3	
	Low suitability	5	2	
	Very low suitability	< 4	1	
Slope (degree)	Flat	< 2	8	0.5 %
	Undulating	2 - 8	9	
	Rolling	8 - 15	3	
	Hilly	15 - 30	2	
	Mountainous	> 30	1	

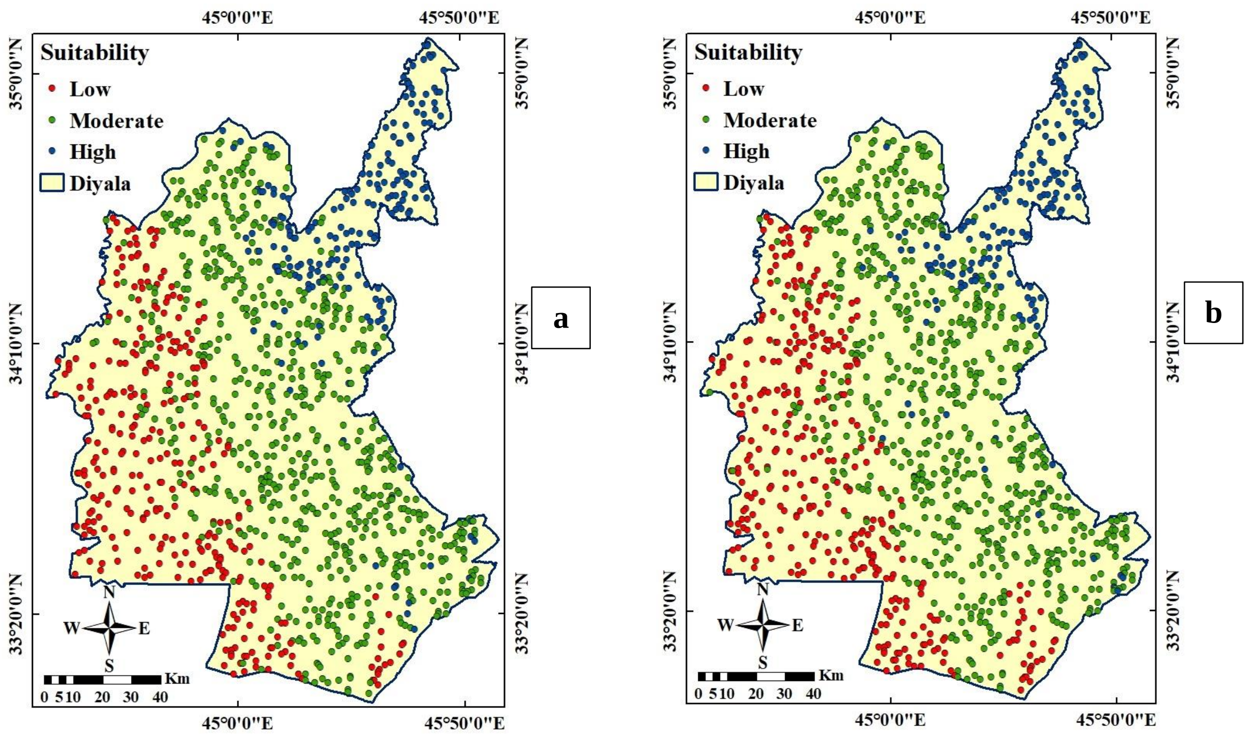

Figure 9. The suitability map of Diyala: a) with applying land use criterion; b) with applying NDVI criterion.

The results obtained with the land use shows that the suitability was ranging from 3.49 to 8.78 while 2.6 to 7.88 for results obtained with the NDVI, as shown in Tables 2 and 3.

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Table 2. Land use suitability ranging and coverage percent.

Suitability ranging	Classes	Percentage %
3.49 – 5.26	Low	26
5.26 – 7.02	Moderate	58
7.02 – 8.78	High	16

Table 3. The NDVI suitability ranging and coverage percent.

Suitability ranging	Classes	Percentage %
2.6 – 4.36	Low	29
4.36 – 6.12	Moderate	57
6.12 – 7.88	High	14

Results in Tables 2 and 3 indicated that the land use was the most influential criterion for identifying the rainwater harvesting suitable sites with a minor difference when compared with that of the NDVI.

CONCLUSIONS

This study found that most of the Eastern parts of Diyala governorate is a promising region for rainwater harvesting for both applying land use and NDVI criteria. The produced maps have been divided into three suitability zones: low, moderate, and high suitability. The most suitable sites are dominated in the Northeastern parts of the study area with 26% coverage in case of land use and 29% when applying the NDVI criterion. The moderate suitability class is the largest class between the three suitability classes and comprised of the center parts of Diyala and covering a percentage of 58% in the case of land use and 57% in the case of NDVI. The zone with the low suitability prevalent in the Western parts of the region with 16% is when applying land use and 14% in the case of NDVI.

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