Assessment of Surface Runoff and Suitability for Rain Water Harvesting in the Greater Zab Basin Using the NRCS-CN and AHP Methods

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***Abstract*— The Greater Zab River basin is a vital source of water for agriculture, industry, and domestic use in the Turkey and Kurdistan region of Iraq. The aim of this research is to determine the amount of water that flows on the surface in the Greater Zab basin using Geographical Information System (GIS), Remote Sensing (RS) techniques and analyse suitability of the study area for rainwater harvesting. This study used the Soil Conservation Service Curve Number method to estimate surface runoff in the basin. The study employed the Analytic Hierarchy Process (AHP) technique to determine the weight of each criterion. The research revealed that in the Greater Zab basin, the yearly depth of surface runoff has been around 60.1 mm during the last four decades. Additionally, the typical amount of rainfall recorded was 634.5 ± 117 mm, indicating a significant potential for water harvesting in the region. According to the findings, 4.3% of the study area was deemed highly suitable or suitable for water harvesting, while 48% had moderate suitability. The study's findings have important implications for sustainable water resource management in the Greater Zab basin. The study's findings on appropriate locations for collecting rainwater can provide valuable insight for future water resource management initiatives in the area. Overall, the study underscores the importance of proactive water resource management strategies to ensure the long-term sustainability of the Greater Zab River basin**

Keywords: Antecedent moisture condition; Curve number method; Geographical Information System; Hydrologic soil groups; Runoff estimation; Water resource management..

I. INTRODUCTION

Arid and semi-arid countries are facing a significant challenge of water scarcity, which can be attributed to population growth and increased agricultural production aimed at achieving better agricultural sustainability, as explained by (Mohamed et al., 2019). The excess water that occurs due to rainfall or flood irrigation when the soil becomes saturated and unable to absorb any more water is called runoff, as Mohamed et al. further elucidate in their study. Runoff from the land surface is a significant component of the regional and global hydrological cycle and a key water resource for agriculture, industry, and urban water use (Jaiswal et al., 2020; Jayawardena, 2020; Li et al., 2015).

It is essential to comprehend the intricate connections between rainfall and runoff procedures and make precise assessments of surface runoff to effectively design, plan, and manage catchments. Hydrological modelling is a useful tool in achieving this, as it allows for the estimation of continuous surface runoff and enhances understanding of catchment behaviors. Additionally, it enables modelling of the impacts of climate and land use changes on surface water balance, as demonstrated by research conducted by (Zhao et al., 2012) (Li et al., 2015). Advanced methods such as remote sensing and geographic information systems can aid in the collection, storage, and analysis of data on spatial and temporal distributions.

The Soil Conservation Service Curve Number (SCS-CN) method is one of the earliest and most basic ways to model runoff, and there are various mechanisms available to do so (Khzr et al., 2021). Developed by the USDA-Soil Conservation Service in 1972, the SCS-CN method is commonly used to estimate direct runoff for a particular rainfall event from small agricultural watersheds (Shi et al., 2009). The CN factor value relies on several environmental factors, such as soil, land use, land cover, and climate conditions. The SCS-CN method is preferred by engineers because it is straightforward, has well-documented environmental inputs, and incorporates various factors that impact runoff generation into a single CN parameter

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(Al-Quraishi & Negm, 2020). When coupled with land use data, models like the SCS-CN can estimate how changes in land use can alter runoff (Hu et al., 2020).

The SCS-CN model provides a fast method to approximate changes in water runoff resulting from modifications in land usage. This method is a simple, predictable, and conceptual method for estimating direct runoff depth based on storm rainfall depth (Hong & Adler, 2008; Khzr et al., 2021; Rawat & Singh, 2017; Santhi & Campus, 2017; Walega et al., 2020). It depends on real-time data, and fewer assumptions are involved. The SCS-CN model is a commonly employed technique to calculate the amount of surface water runoff in a given area during a specific rain event. It relies on easy-to-use tables and graphs that are practical and accessible. The curve values indicate the level of runoff and infiltration, with a high number indicating more runoff and less infiltration, and a low number suggesting the opposite. (Kumar et al., 2021).

The aim of this study is to identify the hydrological characteristics of the study area, evaluate the amount of surface runoff, and determine the potential for rainwater harvesting. To achieve this goal, the researchers plan to utilize the NRCS-CN method in combination with the Analytical Hierarchy Process and Weighted Overlay techniques. The NRCS-CN approach is useful for estimating changes in runoff due to alterations in land use, making it a valuable tool for catchment planning, design, and management.

1. Methods and Data Collection

2.1 The Study Area

The Greater Zab River basin is a significant tributary of the Greater Zab River, covering an area of 26,323 square kilometers. The basin lies between longitudes 43°- 45°E and latitudes 36° - 38°N, originating from the Ararat Mountain in Turkey and passing through the Kurdistan Regional Iraqi (KRI) before joining the Tigris River in south Mosul (Abbas et al., 2017). However, the topography of the basin varies, with the highest area reaching around 4,000 meters in the north and the lowest area around 180 meters above sea level in the south (Figure 1). Also the Greater Zab River is the third most important river in Iraq, contributing a significant share of water to the Tigris River. About 65% of the basin is within the Iraqi Kurdistan region, while the remaining 35% is in Turkey. Normally the Rainfall begins in October in the autumn until May, moreover average annual precipitation in the basin ranges from 379.8 mm to 1,094 mm, with an average of 534.5 mm, and the average annual temperature is 14.3°C (Abbas et al., 2018). As well the precipitation usually starts around October and ends in May (Hakan Oguz, Tarq Hassan, 2020).Finally the EskiKelek discharge station is located at the lowest section of the basin at the watershed outlet, at coordinates 36° N and 43.35° E (Abbas et al., 2016).

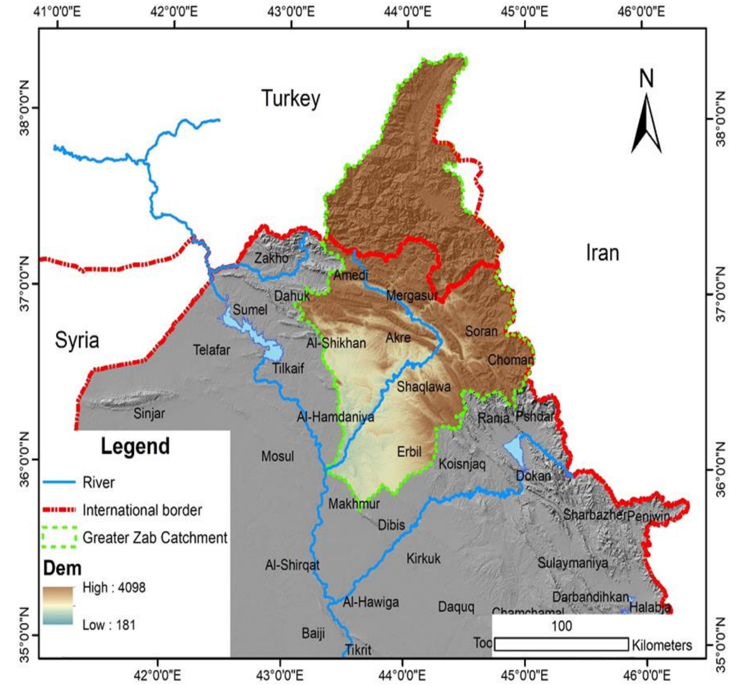


Figure 1: The Study Area (Greater Zab Basin)

2.2 Data preparation and general methods

To estimate rainfall-runoff using the NRCS-CN method, the LULC map of 2021 (Figure 3) was used from Sentinel satellite imagery (Brown et al., 2022). Soil map (Figure 4) were procured from the Global Hydrological Soil Groups (Ross et al., 2018) and rainfall data (Figure 5) for the period of 1981 to 2021 was collected from the CHIRPS satellite (Funk et al., 2015). We also used Digital Elevation Model (DEM) data at 30m resolution (Farr et al., 2007) to create maps of elevation, river streams, drainage density, and slope (Figures 6-9). The DEM, CHIRPS and LULC of study area (Table 1) were downloaded from Google Earth Engine (GEE). ArcGIS 10.8 was used for mapping and analysis purposes, and the methodology analysis is shown in Figure 2.

The researchers used hydrologic group maps and overlaid them onto the land use and land cover (LULC) map. Each pixel was then assigned a CN value based on the NRCS-CN, as shown in Figure 2. Determining accurate CN values is essential for the SCS and Curve Number methods to estimate rainfall-runoff, as these methods rely heavily on CN values. This approach has been employed in various studies such as those by (Al-Quraishi & Negm, 2020; Jaiswal et al., 2020; Matomela et al., 2020)The CN value is determined by considering factors such as Hydrological Soil Group, Land Use, and Antecedent Soil Moisture Conditions. To estimate rainfall-runoff for different combinations of LULC, soil groups, and antecedent moisture conditions, the SCS-CN method is commonly used (Gabriels et al., 2021; Karunanidhi et al., 2020; Kumar et al., 2021; Meshram et al., 2017).

Table 1 shows the sources of the data used in the study.

Data	References
Precipitation	https://chc.ucsb.edu/data/chirps
Soil Data	https://daac.ornl.gov/SOILS/guides/Global_Hydrologic_Soil_Group.html
Digital Elevation Model	https://cmr.earthdata.nasa.gov/search/concepts/C1000000240-LPDAAC_ECS.html
Land Use Land Cover	GOOGLE/DYNAMICWORLD/V1

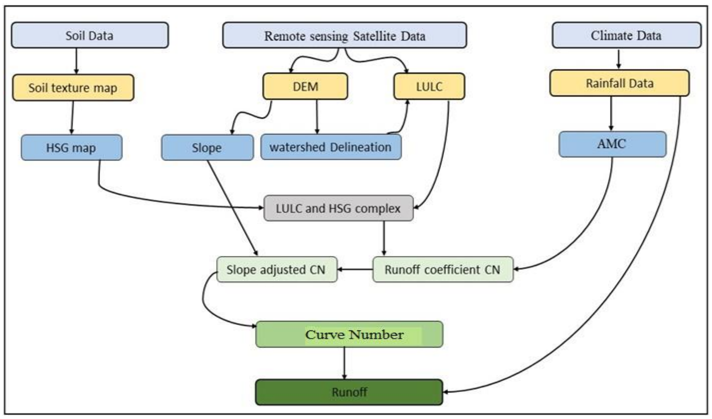


Figure 2. Methodology Employed in the Study.

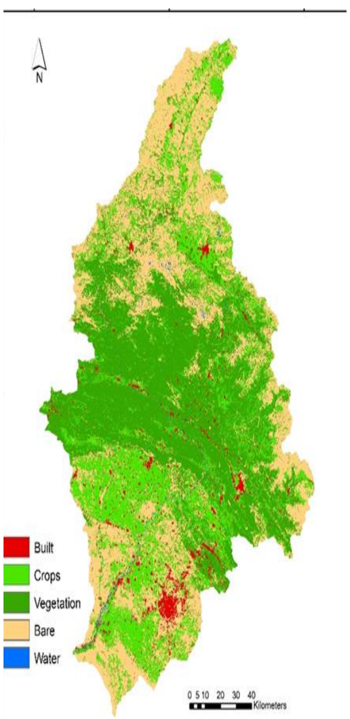


Figure: 3 land use land cover

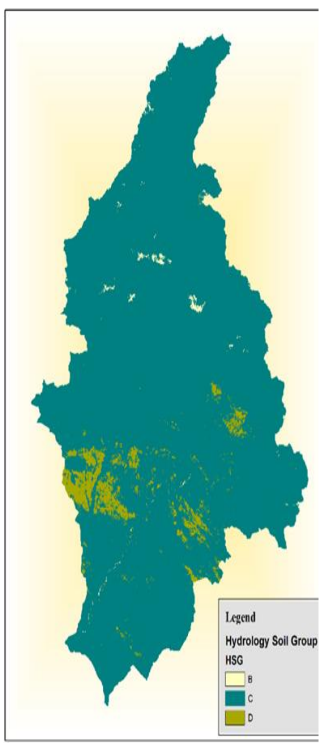


Figure: 4 hydrologic soil group

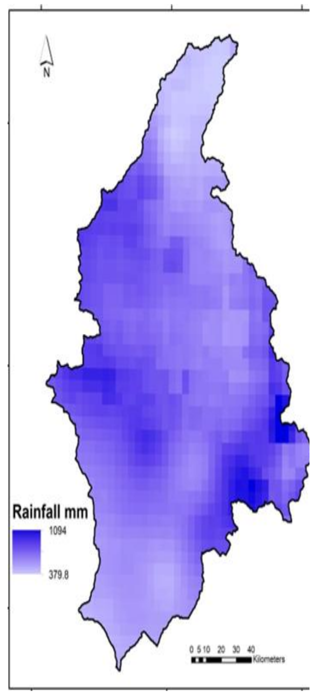


Figure 5: Rainfall from 1981 to 2021

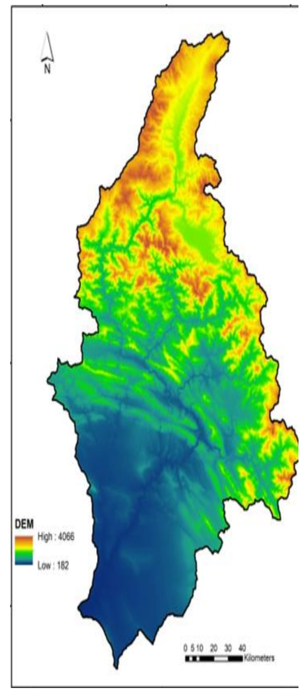


Figure 6: Elevation of Greater Zab Basin

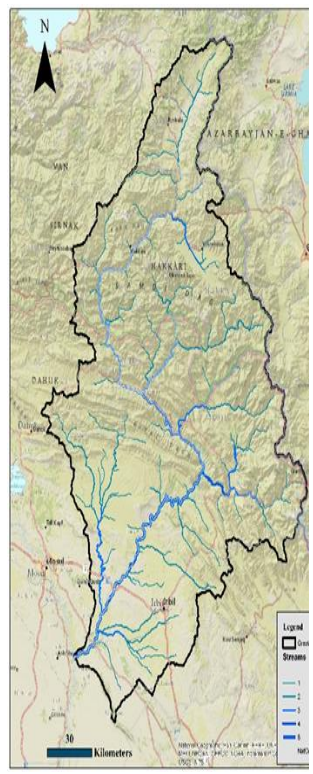


Figure 7: Stream Order

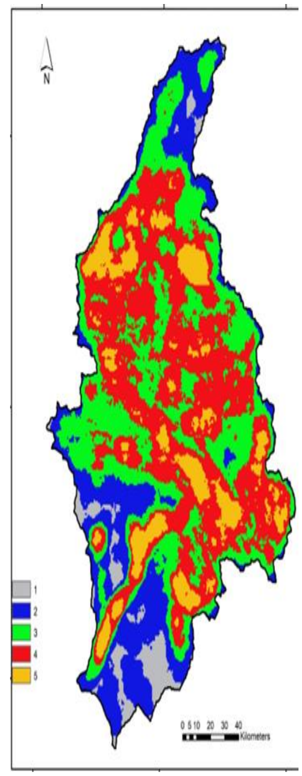


Figure 8: Drainage Density

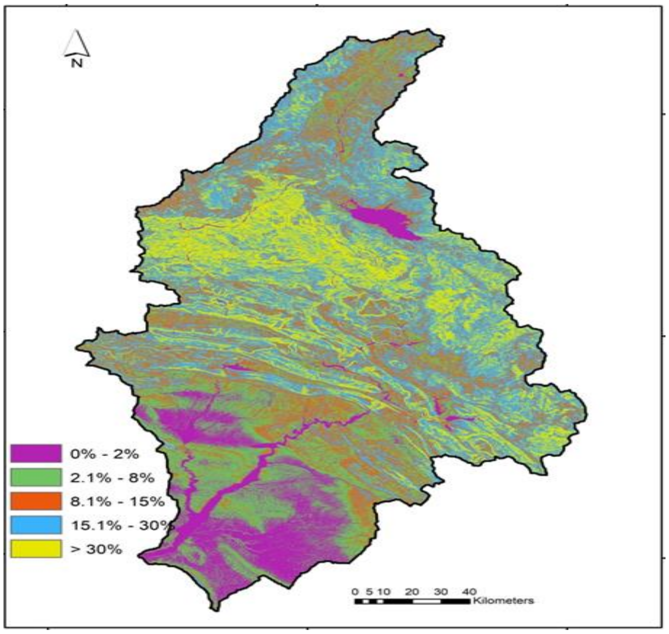


Figure 9: Slope of study Area

2.3 Assessment of Surface Runoff

The NRCS-CN, formerly known as the SCS-CN method, is a widely used technique that explains the relationship between runoff and rainfall. It was first published by the Soil Conservation Service of the U.S. Department of Agriculture in 1956, and has its roots in the work of Mockus in 1949. This method assigns a numerical value called the CN to land cover, soil type and prior rainfall, which are the primary catchment factors contributing to the production of direct runoff. Initially developed for small agricultural watersheds in the USA, the SCS-CN approach has been adopted by professionals worldwide due to its simplicity and minimal input data requirements (Caletka, 2021; Hawkins et al., 2010). However, the method has been modified over time to enhance its accuracy in different environments and address its limitations.

The NRCS-CN technique is a simple method that only requires two inputs: rainfall and curve CN. It operates on the basis of two assumptions. The first assumption is that the ratio of surface runoff to maximum rainfall (as expressed in Equation 1) is equivalent to the ratio of infiltration and potential maximum retention (S). The second assumption pertains to the initial abstraction (Ia) and the possible maximum retention (S). In line with Jat and Kumar (2017), the water equation balance reveals that the proportion of runoff and productive rainfall is equal to the ratio of actual retention to potential retention (Jat & Kumar, 2017).

$$Q = \frac{(P-Ia)^2}{(P-Ia)+S} \qquad (1)$$

where Q = Runoff depth (mm), P = Rainfall (mm), the maximum retention after runoff starts *(S)*, and the initial abstraction *(Ia)*.

$$I_a = 0.2\ S \qquad (2)$$

The proportion of 0.2 is seldom changed.

Equation (3) establishes a connection between the potential maximum retention after runoff starts, represented as S, and the characteristics of the watershed's land use/vegetative cover and soil.

$$S = \frac{25200}{CN} - 254 \qquad (3)$$

2.4 Antecedent Moisture Condition (AMC)

The surface runoff is measured differently depending on the amount of prior precipitation, with higher runoff occurring after significant rainfall events. In the watershed, the AMC II condition is considered normal for modelling purposes. Runoff curve numbers based on LULC and soil type are used to model the AMC II, AMC I (dry), and AMC III (wet) conditions (Figure 8; Tables 4 and 5).

Table 2, published by USDA in 1986, displays the CN values related to the AMC-II condition. In order to determine the surface runoff depth, hydrological equations are employed, which rely on the curve number to assess the watershed storage (S) and rainfall amount (P). Thus, to use Equation (3), the S value must be calculated for each AMC condition, as clarified by (Kumar et al., 2021; Patel et al., 2017). Table 2 provides a summary of the hydrologic condition outcomes for the three AMC states along with their corresponding curve numbers.

Table 2. shows the classification of Antecedent Moisture Conditions (AMC) for the corresponding curve numbers.

AMC Group	Class Name Conditions	5-Days Antecedent Rainfall (Mm)	
		Dorman Season	Growing Season
I	Dry: Cultivated soils are dry but not wilting.	< 13	< 35
II	Average conditions.	13-28	35-53
III	Wet: Saturated soils from recent rainfall and low temperatures.	More than 28	More than 53

2. **Results**

3.1 Land Use Land Cover (LULC)

The land use and land cover map were used to reclassify the Greater Zab basin area into five categories, namely built, crops, vegetation, bare land, and water. According to the classification results, vegetation covers the largest portion of the Greater Zab River basin, occupying an area of approximately 9,384 km^2 (35.6%). Bare land accounts for roughly 8830 km^2, while water bodies cover an area of 93 km^2 (0.4%), and built-up areas occupy 1158 km^2 (4.4%). Figure 3 and Table 3 provide the land use land cover data used in this study.

Table 3: Land use land cover of Greater Zab

LULC	Descriptions	Area (Km2)	Area %
BUILD	Settlements, Industrial Areas, Roads	1158	4.4
CROPS	Agriculture and Fruit Trees	6858	26.1
VEGETATION	Pasture, Forest, Grass and Riparian Zones	9384	35.6
BARE	Farmland, Rocks and Barren Lands	8830	33.5
WATER	Rivers, Water Bodies, Snow	93	0.4
TOTAL		26,323	100

3.2 Hydrologic Soil Group (HSG)

The Global Hydrologic Soil Groups provided the soil texture map, which was resampled to 30m. Figure 4 and Table 4 show the soil texture map, while Table 5 shows the hydrologic soil groups (HSG) for HSG B, C, and D. The moderately well-drained to well-drained soils in group B showed a modest infiltration rate. Group C's soils indicated moderately fine to moderately rough textures, with a moderate rate of water transfer, while group D's soils indicated high runoff (Table 4).

Table 4: Soil texture classes that typically comprise hydrologic soil groups (USDA, 2009)

Type	Soil Texture Class	Runoff Potential
B	Sandy loam, Loamy sand	Moderately low
C	Clay loam, Silty clay loam, Sandy clay loam, Loam, Silty loam, Silt	Moderately high
D	Clay, Silty clay, Sandy clay	High

The soil textures map was used to classify the Greater Zab basin into three hydrologic soil groups (HSGs): B, C, and D (as shown in Figure 4). HSG-B covers an area of approximately 102.684 km^2, accounting for just 0.3% of the total basin area, while HSG-C covers 96.1% of the total coverage. The prevalence of HSG-C indicates that the soil in the basin has a somewhat fine texture, which leads to a slow speed of water movement and absorption when fully saturated. HSG-B, on the other hand, has a reasonable absorption rate when fully saturated and consists mostly of moderately deep to deep soil, moderately well to well-drained soils with moderately fine to moderately coarse textures. HSG-D, which covers the remaining area of the basin, consists of soils with sandy or gravelly textures that allow for rapid infiltration and drainage. Understanding the characteristics of each HSG is important for predicting the hydrologic behavior of the Greater Zab basin.

Table 5: Hydrologic Soil Groups Classes

Hydrological Soil Group	Area (Km2)	Percentage %
B	**105**	**0.3**
C	**25265**	**96.1**
D	**953**	**3.6**
Total	**26,323**	**%100**

3.3 Estimation of Rainfall-Runoff in the Greater Zab Basin:

The overall results of the study, obtained by applying the NRCS-CN method, are as follows: Curve Number of the study area varies between 48 to 100 (Figure 10), over the past four decades, the Greater Zab basin has experienced an average annual surface runoff depth of 60.1 ± 95.1 mm, as depicted in Figure 11. The research conducted currently indicates that between 1981 and 2021, there was rainfall ranging from 379.8 to 1094 mm, with an average of 634.5 ± 117 mm., indicating a significant potential for water harvesting in the region, and the runoff depth ranged from 0 to 726 mm. The large areas of the study have low runoff depth potential, ranging from 0 to 35 mm. However, in some small parts of the area, high runoff depths between 361-726 mm have been recorded.

Figure 10: Calculated Curve number

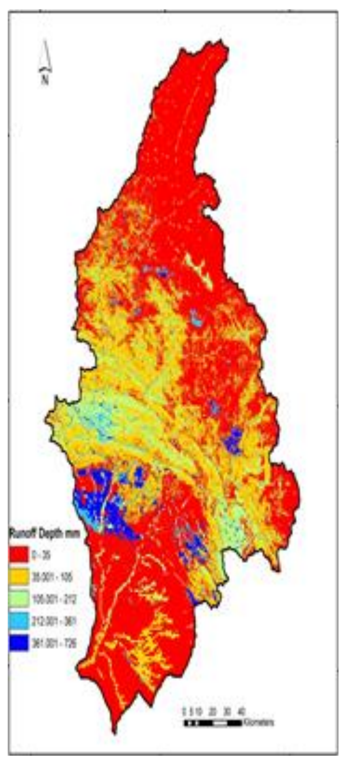
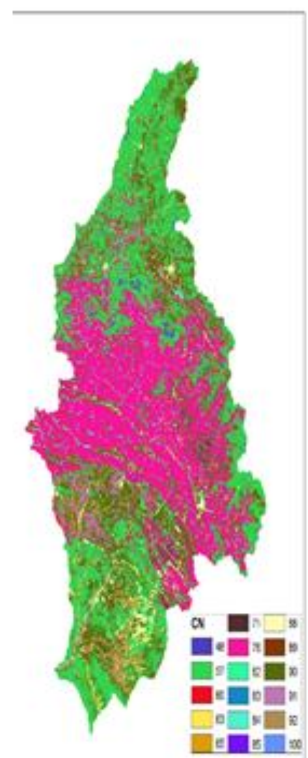


Figure 11: Runoff depth (mm)



3.4 Identification of Suitable Sites for Rainwater Harvesting Structures

The study employed appropriate standards for rainwater collection, which were based on a thorough examination of relevant literature. The study took into account a variety of factors, including soil types, amount of rainfall, incline, drainage areas, and land use/cover (LULC) map, in order to identify appropriate locations for the installation of rainwater harvesting structures.

A combination of remote sensing and GIS-based Analytical Hierarchy Process (AHP) analysis was used to determine the ideal sites. This involved the integration of five different layers, which included LULC from Sentinel 2, a soil map, and digital elevation models (DEMs) to derive slope map and drainage map. Weighted Overlay was used for the multi-criteria analysis in ArcGIS to assess the suitability of the identified locations for rainwater harvesting.

In this study, five different categories were used to evaluate the appropriateness of sites for water harvesting, including excellent, good, moderate, poor, and unsuitable. The central portion of the study area was found to have a high concentration of sites that were either excellent or good for water harvesting. Based on Figure 12, it was determined that only a small portion of the study area (4.3%, or 1124 km2) had excellent or good suitability, while a larger portion (48%, or 12642 km2) had moderate suitability. Meanwhile, 38.9% (10236 km2) and 4.3% (1141 km2) of the study area were classified as having poor and unsuitable conditions, respectively.

The results of the study indicated that areas with high levels of rainfall were more suitable for water harvesting, as the surplus rainfall could be effectively utilized as runoff. Additionally, the slope of the land was found to be a crucial factor in determining the suitability of sites for water harvesting. Areas with gentler slopes were deemed more suitable for this purpose, as they facilitated better runoff harvesting. Conversely, steeply sloped areas were found to be unsuitable due to the uneven distribution of runoff and the significant amount of earthwork required. The study area was divided into five slope categories, ranging from flat to mountainous, and it was found that the southwest portion of the study area had gentler slopes, while the north and northwest had steeper slopes and deep valleys.

In general, the research utilized sophisticated methods and evaluated various factors in order to pinpoint appropriate locations for implementing structures that capture rainwater, which can have significant benefits in addressing water scarcity issues in the study area. The slope of the study area significantly influences rainwater harvesting suitability. The study recommends identifying sites with a gentler slope for rainwater harvesting structures to enhance runoff harvesting and address water scarcity issues.

Table 6: Percentage and area of suitability classes of the study area.

Suitability Class	Percentage (%)	Area (km2)
Built-up	4.5	1,179
Unsuitable	4.3	1,141
Poor	38.9	10,236
Moderate	48.0	12,642
Good	4.2	1,097
Excellent	0.1	27
Total	100.0	26,323

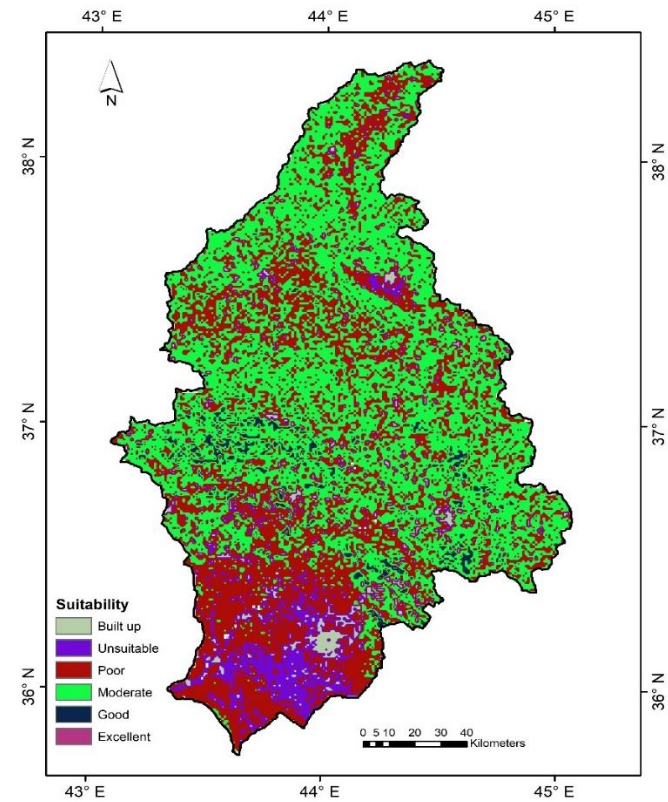


Figure 12: Map of Potential Rainwater Harvesting for the Study Area.

4. Discussion

The Kurdistan region of Iraq depends heavily on the Greater Zab basin for agriculture, industry, and domestic use. Therefore, accurately estimating the surface runoff in the region is critical for efficient water resource planning and management. To achieve this, the Natural Resources Conservation Service Curve Number (NRCS-CN) was used to estimate the surface runoff in the Greater Zab basin. Analysis of the land use and land cover (LULC) map showed that vegetation covers the largest part of the basin, occupying about 35.6% (9384 km2) of the area. Bare land accounts for roughly 8830 km2, water bodies cover 0.4% (93 km2), and built-up areas occupy 4.4% (1158 km2). The soils in hydrologic soil group (HSG) B have a moderate infiltration rate, while HSG-C soils have moderately fine to moderately rough textures and a moderate rate of water transfer. HSG-D soils have high runoff. The results obtained by applying the NRCS-CN method showed that the average annual surface runoff depth for the last 40 years in the Greater Zab basin is 60.1 ± 95.1 mm. The study revealed that the rainfall from 1981 to 2021 varied between 379.8 to 1094 mm with an average of 634.5 ± 117 mm, and the runoff depth ranged from 0 to 726 mm. The large areas of the study have low runoff depth potential, ranging from 0 to 35 mm. However, in some small parts of the area, high runoff depths between 361-726 mm have been recorded.

According to a study conducted by (G. R. F. Ibrahim et al., 2019) on appropriate sites for rainwater harvesting in Dohuk Governorate, it was determined that 15% of the study area was highly suitable for water harvesting, while 13% had good suitability. (Hameed, 2013) also conducted a study and found that 36% of the study area was suitable for water harvesting, with 14% being moderately suitable and 33% have very low suitability. Our study, however, found that only 4.3% of the study area had excellent or good suitability for water harvesting, while 48% had moderate suitability. These results indicate that there is considerable potential for water harvesting in the Greater Zab Basin if appropriate locations can be identified and utilized.

The study's findings are significant for ensuring the sustainable management of water resources in the Greater Zab basin. The prevalence of HSG-C indicates that the soil in the basin has a moderately fine-to-fine structure, which means that water transmission and infiltration are slow when the soil is completely wet. Consequently, management techniques that enhance infiltration rates, such as rainwater harvesting and conservation agriculture, could be implemented to enhance water availability in the basin.

However, this study has some limitations that need to be acknowledged. First, the NRCS-CN method used in this study relies on some assumptions and simplifications. Additionally, the study did not consider the effects of climate change and land use changes, which are likely to have a significant impact on the hydrological behavior of the basin in the future. Therefore, future studies should aim to address these limitations and incorporate more advanced methods and models to improve the accuracy of the runoff estimation and assess the impact of changing environmental conditions on water resources in the Greater Zab basin.

In conclusion, this study provides valuable insights into the hydrological behavior of the Greater Zab basin. The findings can be used to guide the sustainable management of water resources in the region and provide a basis for future studies on the impact of climate and land use changes on the hydrological cycle of the basin. The potential for water harvesting in the region is significant, but it is important to identify suitable sites and use appropriate techniques to ensure that the harvested water is stored and used effectively.

5. Conclusions

To sum up, this research emphasizes the significance of precise evaluation of surface runoff within the Greater Zab basin in order to efficiently plan and handle water resources. The use of the Natural Resources Conservation Service Curve Number (NRCS-CN) method enabled us to estimate the average annual surface runoff depth for the last 40 years in the basin. The study showed that based on a combination of AHP and Weighted Overlay methods, approximately 52% of the study area exhibited favorable or moderate conditions for water harvesting. The findings indicate that the basin possesses noteworthy prospects for water harvesting, particularly if suitable locations are identified and utilized. The findings of this study can be used to guide the sustainable management of water resources in the region and provide a basis for future studies on the impact of climate and land use changes on the hydrological cycle of the basin.

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