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SITE SELECTION OF A RAINWATER HARVESTING STRUCTURE IN AL-MUHAMMADI VALLEY IN ANBAR PROVINCE, IRAQ USING REMOTE SENSING AND GIS TECHNIQUES

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MOHAMMED ABBAS KHUDHAIR

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IN
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Approval of the Graduate School of Natural and Applied Sciences, Atilim University.

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ABSTRACT

SITE SELECTION OF A RAINWATER HARVESTING STRUCTURE IN AL-MUHAMMADI VALLEY IN ANBAR PROVINCE, IRAQ USING REMOTE SENSING AND GIS TECHNIQUES

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Rainfall is a key source in diminishing the problem of water scarcity in arid and semi-arid regions. Rainwater harvesting is an essential tool for rainwater conservation. An appropriate location for rainwater harvesting structure plays an important role in increasing the water availability and improving the water resources planning. This study aims to select the suitable location for a rainwater harvesting structure using a suitability model generated with ModelBuilder in ArcGIS. Six thematic layers, i.e. soil structure, slope, drainage density, vegetation cover, distance to roads, and runoff depth, are considered to find the proper site for the rainwater harvesting structure. The method is applied to the Al-Muhammadi Valley of the Al-Anbar Province of Iraq. Analysis of the results showed that 12% represents the suitable zone of the total study area, 42% represents medium suitable area, and 46% represents unsuitable areas to implement the rainwater harvesting structure. This study finds that the GIS tool is flexible, cost effective and time saving for screening large areas. The application of this scheme should be included in any policy adoption for site selection for rainwater harvesting.

Keywords: Remote sensing, GIS, Rainwater harvesting, Al-Muhammadi Valey

ÖZ

UZAKTAN ALGILAMA VE CBS TEKNİĞİNİ KULLANARAK IRAK'IN AL-MUHAMMADİ VADİSİNDE YAĞMUR SUYU TOPLAMA YAPISININ YERİNİN BELİRLENMESİ

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Yağış, yarı kurak ve kurak bölgelerde su kıtlığı prsorununu azaltmada kilit bir kaynaktır. Yağmur suyunun toplanması, yağmur suyunun korunması için önemli bir araçtır. Yağmur suyu toplama yapısı için uygun bir yer, suyun mevcudiyetinin arttırılmasında ve su kaynakları planlamasının iyileştirilmesinde önemli bir rol oynamaktadır. Bu çalışmanın amacı, ArcGIS'te ModelBuilder ile oluşturulan uygunluk modelini kullanarak yağmur suyu toplama yapısı için doğru yerinin belirlenmesidir. Yağmur suyu toplama yapısının en uygun yerini belirlemek için çalışmada toprak yapısı, eğim, drenaj yoğunluğu, bitki örtüsü, yollara uzaklık ve akış derinliği olmak üzere altı tematik katman kullanılmıştır. Bu yöntem Irak'ın Al-Anbar eyaletinin El Muhammadi Vadisi'ne uygulanmıştır. Sonuçların analizinden, yağmur suyu toplama yapısının yeri için çalışma alanının %12 si uygun alan, %42 orta uygun alan ve %46 lık bölümününde uygun olamayan alanı temsil ettiğini belirlenmiştir.

Bu çalışma, Coğrafi Bilgi Sistemlerinin geniş alanları taramak için esnek, uygun maliyetli ve zaman tasarrufu sağlaması açısında uygun bir araç olduğunu göstermiştir. Bu yöntemin uygulanması yamur suyu hasadı için yer seçiminde

Bu planın uygulanması, yağmur suyu hasadının yer seçimi politika kabulüne dahil edilmelidir.

Anahtar Kelimeler: Uzaktan Algılama, CBS, Yağmursuyu hasadı, Al-Muhammadi Vadisi

To my family …

To my supervisor ….

To IALD …

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LIST OF ABBREVIATIONS

RWH	Rainwater Harvesting
GIS	Geographic Information Systems
MCE	Multiple Criteria Evaluating
GWMP	Geographical Water Management Program
NE	North East
MCE	Multiple Standards Assessment
FAO	Food and Agriculture Organization
NDVI	Normalized Difference Vegetation Index
SRTM	Shuttle Radar Topographic Mission
USGS	United State Geological Survey
Q	Depth of Runoff
CN	Curve Number
P	Depth of Rainfall
S	Potential Maximum Retention Depth after Runoff starts
Ia	Initial Abstraction
SCS	Soil Conservation Service
DEM	Digital Elevation Model

CHAPTER 1

INTRODUCTION

1.1.The importance of water harvesting

The scarcity of water resources in the western desert of Iraq is the primary concern that limits the application of water management and plans [1]. This has affected the well-being of citizens, their productivity, health, and environment since rainfall is considered a significant natural resource in dry and semi-dry areas. The benefit of collecting rainwater in these regions, where rain often falls during a few months of the year, is of greater importance than its counterparts in the humid areas. Its importance increases in areas where there are no less other sources, such as groundwater or transported water, and this becomes the most feasible way to ensure human and animal life [2] The water harvesting process is the key to better-using rainwater for domestic and agricultural purposes, reducing the impact of drought and using runoff water beneficially.

The selection of suitable sites for rainwater harvesting (RWH) using different technologies in large areas is the biggest challenge [3]. Locating site selection requires the gathering and extracting of different data, i.e., hydrology, soil, climate, topography, agronomy, and socio-economic [4]. Different criteria and techniques have been applied for choosing appropriate sites for rainwater harvesting structures [5]. The clarity in the decision making process for siting? The rainwater harvesting structure will become more and more vital, especially in data-limited areas. GIS can bring clarity to the decisions revolving around site selection for the rainwater harvesting structure [6], [7], [8], [9], [10] and [11]. GIS and geospatial data are essential steps to maximize the availability of water and the productivity of land [12]. Many studies applied GIS and remote sensing data for siting a rainwater harvesting structure [13]. GIS and remote sensing have successfully targeted locations for the rainwater harvesting structure [14]

This study focuses on identifying suitable locations for rainwater harvesting structures using GIS and remote sensing data in the western desert of Iraq (Wadi Al-Muhammadi).

1.2 Problem Statement

In arid areas, civilization relies mostly on the availability of water. Water availability in these areas is mainly correlated with short-duration and high-intensity precipitations. Besides, most precipitation events place only over a short interval in a year. The evaporation operation, moreover, detriments conditions, as it brings about the loss of water resources.

The Western Desert of Iraq is one of the regions classified as an arid region, which is facing tremendous pressure to deliver and manage water resources. Water availability in this region is considered an essential factor that directly affects both socio-economic development and ecosystem health. Rainwater harvesting is one way to overcome the problem of water availability via the collection and conservation of this precious natural source and thus to ensure continuous supply throughout the year

Soil type is one of the critical information needed for any activity. Thorough and comprehensive information on the soil in both the spatial and temporal domains can assist in sustainable hydrological, environmental, and agricultural development. The hydrological process, including surface runoff and infiltration, depending on the type of soil. Therefore, soil type is vital in determining the potential volume of surface runoff and for selecting the best location for an RWH structure. Conventional soil sampling and laboratory analysis are generally time-consuming, costly, and limited in their ability to retrieve temporal and spatial variability, especially in large-scale areas. However, if no other contemporary alternatives to the traditional planning processes of RWH planning are explored, it becomes impossible to find suitable solutions for development projects of such resources in arid areas [15].

As is well known, traditional techniques for RWH start with identifying the needs and setting the goals to be planned. Based on the identified needs and goals, RWH planning will progress to the phase of determining alternative and feasible sites. Nevertheless, in developing countries, RWH planning is often hindered due to the

lack of necessary information. Fortunately, with advances in modern technology that have enabled access to geospatial data, it has become possible to improve the RWH planning process instead of just relying on traditional approaches.

When these data are insufficient or of low quality, decision-making related to the planning of the RWH structure becomes difficult, especially when data such as field data, maps, aerial topography, and aerial imagery, (which have been crucial for RWH planning in the past) might not be available in developing countries. However, with the availability of geospatial data and the promising potential of the Geographic Information System GIS, the situation in developing countries has changed for the better. These developments have significantly assisted issues related to the planning of RWH via facilitating data collection and reducing its cost in comparison with traditional approaches. The major research question problem for this research is, therefore, "How can we effectively use the wealth of remote sensing data available to create a more efficient and effective planning process for rainwater harvesting in arid regions?"

Two minor research questions are derived from the major research question:

1- What are the valuable data for RWH quantifications and planning?
2- How do we arrange tools to convert and manipulate these data for the purpose of RWH quantifications and planning for decision support in an arid region?

2.1. Objectives of the Study

This study aims to combine and apply meteorological, hydrological and geological data to generate more efficient and effective planning for RWH and decision support systems. This study emphasizes the use of a Geographic Information System (GIS) to manage and successfully utilize remote sensing data for RWH in arid and semi-arid regions with limited data. The fundamental objective is to prove that the remote sensing data coupled with GIS are the most potent and reasonably cost-efficient methods or tools that can help in assessing potential RWH sites in the Al-Mohammadi Valley of the West Desert of Iraq. In addition, it aims to evaluate rainwater harvesting possible and produce reasonable maps for water harvesting in the Al-Mohammadi Valley in the Al-Anbar Governorate of Iraq.

CHAPTER 2

LITERATURE REVIEW

This chapter has four parts, which will be arranged as follows: Usage of GIS in water recourses, history of the rainwater harvesting, a system of rainwater harvesting, and similar research studies.

2.1 GIS in Water Resources

Water resources managers around the world have access to a large amount of meteorological, hydrological and agronomy data these days. With such data, they can manage and understand the world more easily. Developing countries can put into practice shrewd resource planning and management now with the availability of these data in which, it was prevented by the unavailability of the data required in earlier years. In this way, developing countries have started to think about correct water resource planning and management as indispensable to exploiting natural resources in these areas [16].

Thus, the GIS is considered an essential tool to use, interpret, and transform this information into a meaningful form. Due to its qualities, the GIS has especially become an essential tool for water resource planning because it can be seen, bright, and easily changeable. GIS has become a significant tool in understanding and pondering the eternal problems troubling water resource management around the world. GIS technologies assist in the collection and organization of data to address these difficulties and to understand their spatial relationships.

GIS can be defined as "a tool for planning development and environmental control as well as an instrument of decision support. On the one hand, it consists of a geo-referenced database; on the other hand, it involves techniques for data acquisition, actualization, processing, and visualization of results. The semantic data are geometrically related to a homogenous geo-referenced coordinate system, allowing controlled interrelation of information [17].

Lucidity during the process of decision-making has become increasingly vital for all nations as far as water resources are concerned, especially in arid regions. As a result of this, more efficient and active rainwater harvesting planning is essential. In developing countries, the areas lacking the available metrological, hydrological and geological data, needs tools and plans that use available remote sensing data to support the decision-making process of managing water resources.

GIS can shed light on the decision process for water resources by allowing for improved database organization and storage. The collection of multiple base maps and extraction of data such as terrain slope, land cover/land use, drainage networks, and channels are required for studies on water resources. Developing this data can be both time and labor consuming, as it involves aerial photographs and paper maps, particularly when the topographic map must be obtained from different sources at various scales. Therefore, the use of GIS would enhance the development of this data, making it less time consuming and more amenable to the user [18]. Base map means considered maps resulting from some criteria taken in the process of rainwater harvestings, such as runoff map, slope and land cover

2.2 History of the Rainwater Harvesting

Due to its accessibility and the need for water to live, the RWH system has been used for many years. Although, formerly, RWH was used to gather water for different reasons such as livestock watering, human use and agriculture, most research has concentrated only on its agricultural use.

For thousands of years, a plethora of ancient and indigenous water harvesting systems have been established in many countries around the world, e.g. Jordan, Syria, Palestine, Iraq, Tunisia, Saudi Arabia, China, Mexico, Yemen, etc. [19]. The RWH structure in Jordan is said to have been set up over 9000 years ago in the Southern Jordanian Edom Mountains. Although the appearance of the rainwater harvesting system changes greatly in different places around the world, their goal is to create an optimum process to gather the small amount of rainfall each year to stay alive.

Finally, RWH came to be not only a source of water, but also a practical method in increasing the yield of agricultural lands. Since the 1960s, researchers have researched all areas of RWH for agriculture. Former studies tried to understand the different kinds

of RWH and the amount of water balance related to this topic [20]. All these studies show that evaporation, surface storage and infiltration in the collection area are the important factors in the design of a RWH system. Many researchers have used different methods to increase the capability of the collection area to produce runoff. These methods include vegetation management, rock removal, compaction and surface treatment [21]. Recently, the economic efficacy of RWH projects has been thought about for agriculture [22]. To select fitting sites and techniques for RWH in a small area, field surveys are the best and most widespread methods. Surveys and analyses for carrying out the essential work for RWH could be expensive when there is a large area. The site selection for RWH in any area, therefore, presents us with a significant challenge [23].

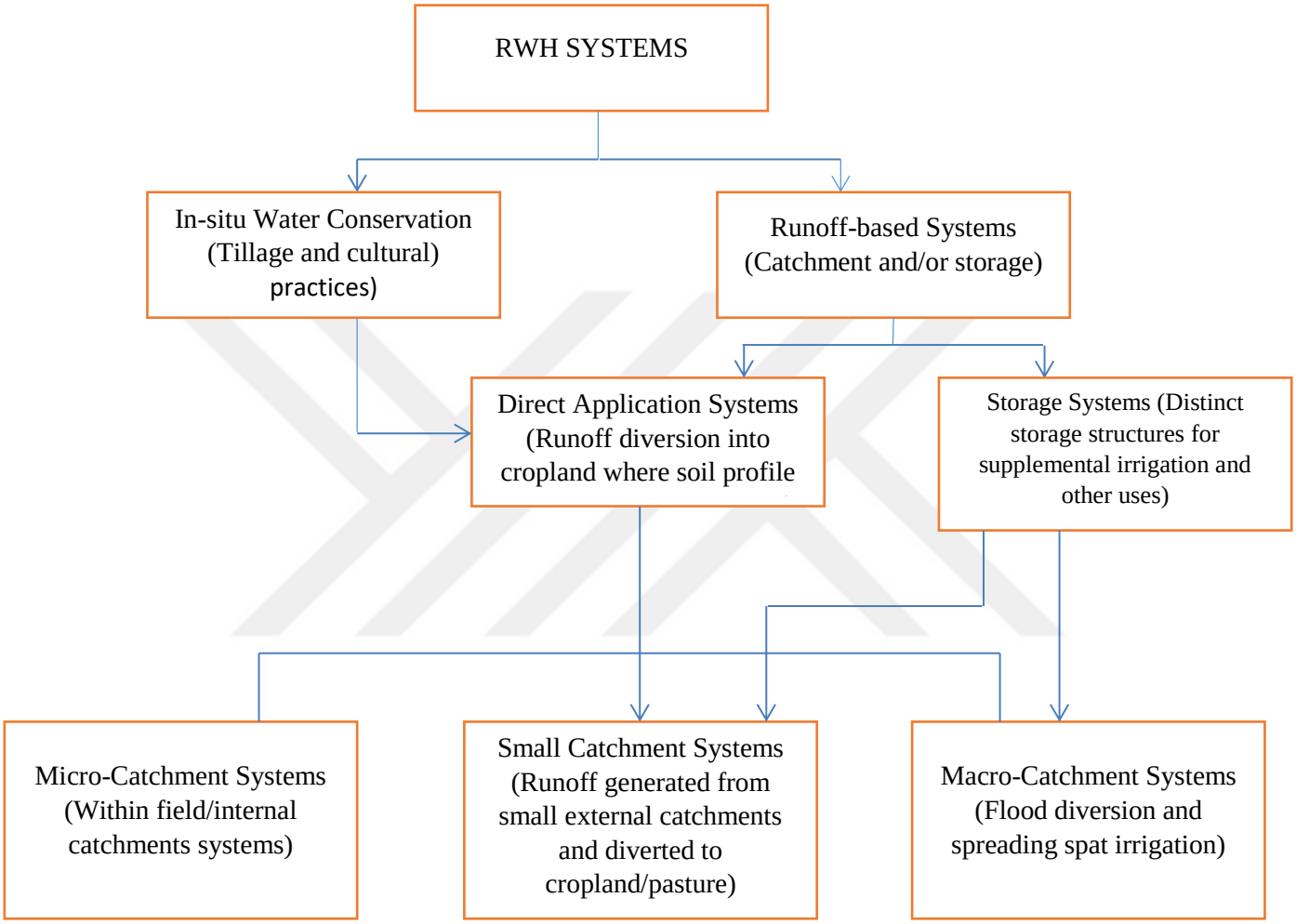
Since 1980, the RWH scheme has received renewed interest. Advances in computing knowledge, the Geographic Information System and remote sensing have increased the capability of using modern techniques to identify possible sites for rainwater harvest. This has led to an abundance of reports on RWH site selection using different criteria.

2.3 System of Rainwater Harvesting

The rainwater harvesting system is controlled by the reservoir in which the runoff is generated and the usage area or receiving area, which is the area where the runoff is collected [24]. Rainwater harvesting can be grouped into two classes:

1- Micro-catchment: rainfall is retained where it falls, and water collected in the field is immediately used. The layout of this system consists of small semicircular pits, semi-circular bunds, strip catchment, meskat-type systems, and contour bunds [25]. The area of micro-catchment is less than 1000 m^2 [26].
2- Macro catchment: a macro-catchment area system ranges from 0.1 hectares to several thousand hectares. The macro-catchment may be found near or away from the area to be used [25]. This system is put into action by intermediary water storage outside the area to be used. The slope of the macro-catchment area ranges from 5 to 50%. This system needs a place for storage and infrastructure for transport such as a natural stream, channels, or gullies for transport to transform the water storage in the area to be used [27].

The two reservoirs shown above are suitable for arid and semi-arid regions where rainfall is sporadic [20]. Rainwater collection could be significantly increased by applying specific systems such as macro rainwater harvesting. Fig 2.1 shows the components of an RWH structure and the relationship between the Runoff and RWH.



Figurer 2.1 components of an RWH structure

2.4 Similar Research studies

In this part of the chapter, studies similar to the present study but differ from the present study in terms of locations and methods are.

The strategy for water harvesting in arid environments was developed in Western Asia and North Africa. This study focused on the limited resources to improve agricultural production through water production in arid and semi-arid regions. Most rainwater is lost due to evaporation in dry environments, so rainwater harvesting is very low. The improvement of the agricultural sector in these areas depends on the concentration of rainwater through surface runoff of crops. Besides, the study found that more than 50% of the lost water can be stored at minimal cost. The problem of the drought was revealed in the central Rift Valley in Ethiopia. The study used a suitable model of geographic information systems to create appropriate maps combining various factors by evaluating multiple criteria (MCE). Small watersheds were used to identify areas suitable for collecting water [28].

A study was carried out using free available remote sensing and GIS products to find rainwater harvesting sites on Unguja Island, the main island of Zanzibar (Tanzania). Micro and macro watersheds were used to map the suitability of rainwater harvesting and to identify several potential collection sites by combining remote sensing data, GIS, hydrological modeling, and an analytical hierarchy process using multiple criteria assessment [20]

Some tests have already been done on the effect of total watersheds on agricultural production in the Chome-Makania catchment in the Panjani Basin in Tanzania. They stated that the use of extra runoff water in the dry period had increased yield production by more than 120% compared to crops that received only rainwater. Weerasinghe et al. (2011) developed a spatial analysis model called Geographical Water Management Capabilities (GWMP) to determine suitable locations for a water supply management application. A possible model for managing geographical waters was made in two different areas of study: the Nile catchments (Egypt) and the Sao Francisco catchment (Brazil), which has different geographic locations and climatic conditions. Form results were checked against field data. The correlation between current regional reservoir sites and dams was found to be 83% using the potential geo-water management model [29]

In the basalt aquifer /Azraq basin NE of Jordan, 72 suitable places were constructed to harvest water by using Buffering, Union, and arithmetic operation in GIS to analyses the data based on different socio-economic and physical criteria [30].

In northern Jordan, by using GIS, weighted linear combination and Boolean techniques were used to find the most suitable site to harvest water. The results were 25% of the area of study had a high possibility of establishing water harvesting [31].

One hundred eighteen suitable locations for water harvesting in the arid regions (Badia) of the Jordan Valley were identified using geographic information systems and prior knowledge where 200 researchers were consulted from the local communities, where they provided advice and expertise about the most important possibilities for establishing water harvesting basins through their experience in managing water resources in the dry areas in which they live. This study also relied on some crucial physical parameters for water harvesting. These criteria include: slope, precipitation sizes, soil texture and distance to water (valleys) [32]

Using the theory of the unit hydrograph, the volume of harvest water was calculated, and through recurrence and statistical analysis, the maximum harvest water was determined for the return period (5, 10, 25 years). With the Geographic Information System (GIS), several maps have been prepared for the best harvest water area that can be used to design agriculture and irrigation projects in the Iraqi Western Desert. The study indicates that there is a potential possibility to use harvest water in the Western Iraqi desert, especially in Houran and Ghafaf Wad, due to high rainfall and low losses [33]

Using the Geographical Information System (GIS) and the Multiple Standards Assessment (MCE) as decision support tools to choose the most suitable location for rainwater harvesting in the Houran Valley, selection criteria are determined in terms of both quality and quantity and are based on regional analysis using geospatial data and hydrological and climatic information freely available. Qualitative standards mean the identification of suitable valleys based on a visual interpretation of satellite imagery. Other qualitative selection criteria relate to distance from settlements and infrastructure. Quantitative approaches are expressed in terms of indexes that synthesize the effectiveness and feasibility of possible interventions: evaporation index (d); calculated as a benefit/cost ratio (c) in terms of volume of water that can be

stored against the size of the dam; hydrological index (1/P), based on analysis of watersheds contributing to each site; ability (s) of soil water retention, estimated from analyzing vegetation patterns using satellite indicators. The methodology applied in the Houran Valley in western Iraq allowed the allocation of 53 sites, of which only 32 had passed the proposed selection criteria. The 32 sites are ranked according to the highest score. The results helped to organize subsequent field surveys, thus significantly reducing survey time and cost [34].

Depending on available data to decide the amount of runoff that can be harvested, a new hydrological study was conducted to measure the data of a meteorological station in the region using a hydrograph for analysis. For the period 1971-1976, the study showed wadi Al-Ghadafi was the best region for water harvesting according to the number of floods in the catchment area (44 floods) with water volume (1047*106 m^3), and average water harvest (7098.64 m^3/km^2). Next is wadi Horan, where the number of floods in the catchment area was 33 with water volume (2033.29*106 m^3), and average water harvesting (6115.16 m^3/km^2). Then, Wadi Ubyaid, where the number of floods in the catchment area was 21 with water volume (405.197*106 m^3), and average water harvest (2493.52 m^3/km^2). The last one is wadi Tubul where the number of floods in the catchment area was 18 with water volume (909.36*106 m^3), and average water harvest (2231.6 m^3/km^2) [35]

CHAPTER 3

METHODOLOGY

In this chapter, the methodology of the study is presented in three parts. In the first part, the study area is described in detail. The second part is related to hydrological modeling and application of hydrological model Arc-GIS for the calculating of the considered criteria of the study area. The material and methods and applied criteria with their results will be taken in the third part.

3.1 **Study Area**

3.1.1 Al- Anbar

Al-Anbar Governorate is an Iraqi governorate located in western Iraq. It is one of the largest Iraqi provinces, with an area of one third (1/3) of the total area of Iraq. It covers an area of 138,500 square kilometers and has a total population of one million and 600,000 people, according to the census of January 12, 2014. It is bordered to the north by Salah El-Din and Nineveh governorates, the Syrian Arab Republic to the northwest, Jordan to the west, and Baghdad Governorate to the east. It is bounded on the south by the Kingdom of Saudi Arabia and the southeast by Karbala and Najaf governorates Fig 3.1.

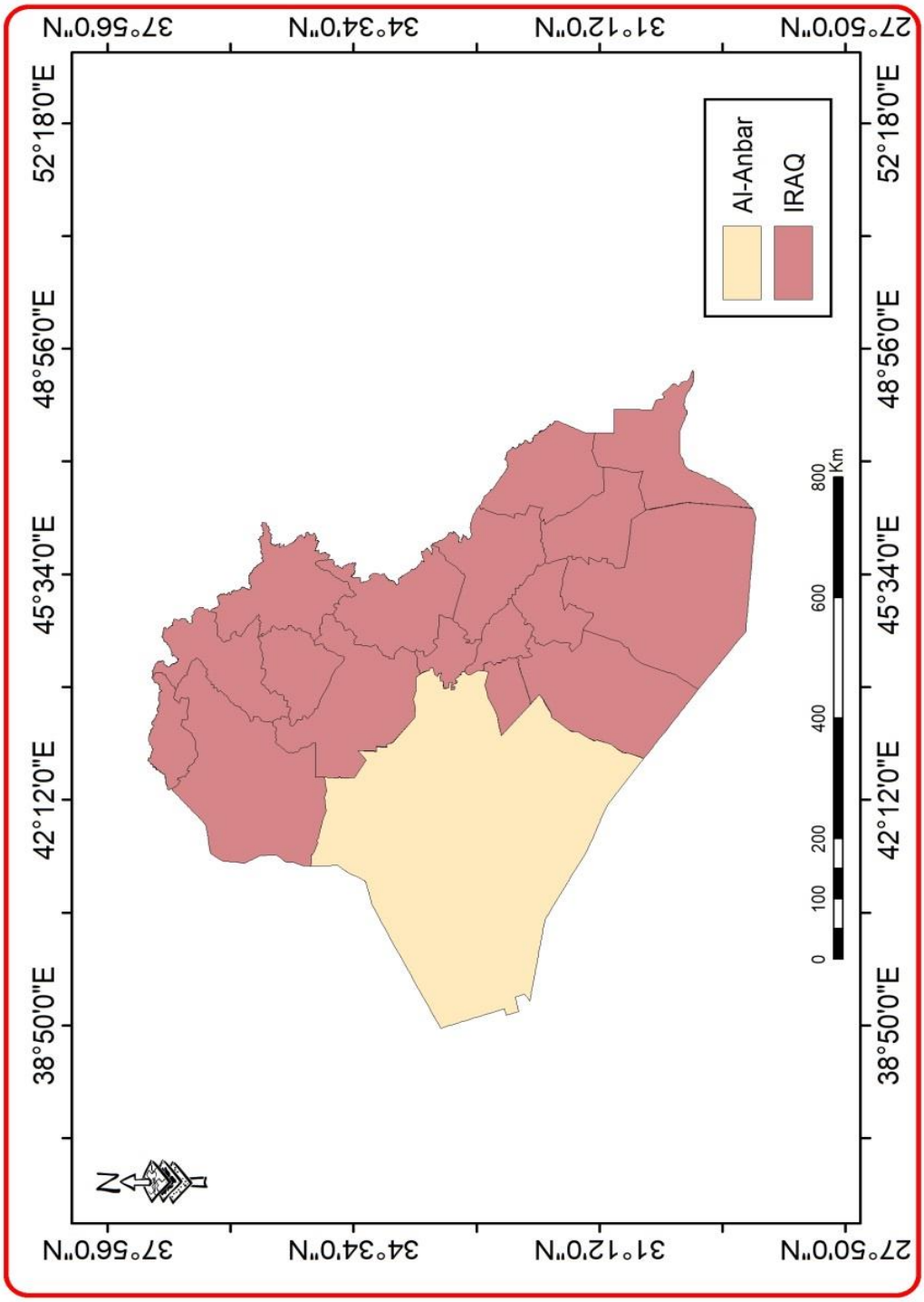


Figure 3.1 Al-Anbar Governate on Iraq map

3.1.2 Al Muhammadi Valley

Al-Muhammadi Valley basin is administratively located within Heat district of Anbar Province, with the coordinate of 39º 38′ 11″ to 40º 46′ 46″ N latitude and 34º 17 ′ 41 ″ to 32º 47 ′ seven ″ E longitude as shown in Fig.3.2. This area was selected because of the current orientation of Al Anbar Governorate to harvest rainwater in the desert that extends to this region for rainwater harvesting and the possibility of investment in the future. Al-Muhammadi valley is located to the west of the Euphrates River. It is bordered to the north by the Al-Baghdadi Valley, to the northwest by the Houran Valley, to the west by the Amij Valley, and the south and southwest by Gadaf valley. Accordingly, it is located in the northern Badia plateau within the lower valleys of the natural divisions of this plateau. Al-Muhammadi valley stretches long from southwest to northeast. The total length of the Al-Muhammadi valley is 7117 km; the basin area of the Valley is 5332 $km^{2,}$ and the number of the stream in the basin is 13238.

The climate of the study area is characterized by its semi-arid climate, low rainfall, and the high contrast between night and daytime temperatures and low humidity. In summer, the temperature rises to 52ºC, and in winter it drops to 0ºC. The wind has northwesterly and southwesterly, sometimes with a top speed of 21 m/s. The average annual rainfall in winter is 95 -115 mm, which approximately 49% falls in winter; the average annual evaporation is 3200 mm. The highest and lowest elevations are 1552 m and 571 m, respectively above sea level. In this study, the average rainfall (P) for years (2013-2019) is 110 mm.

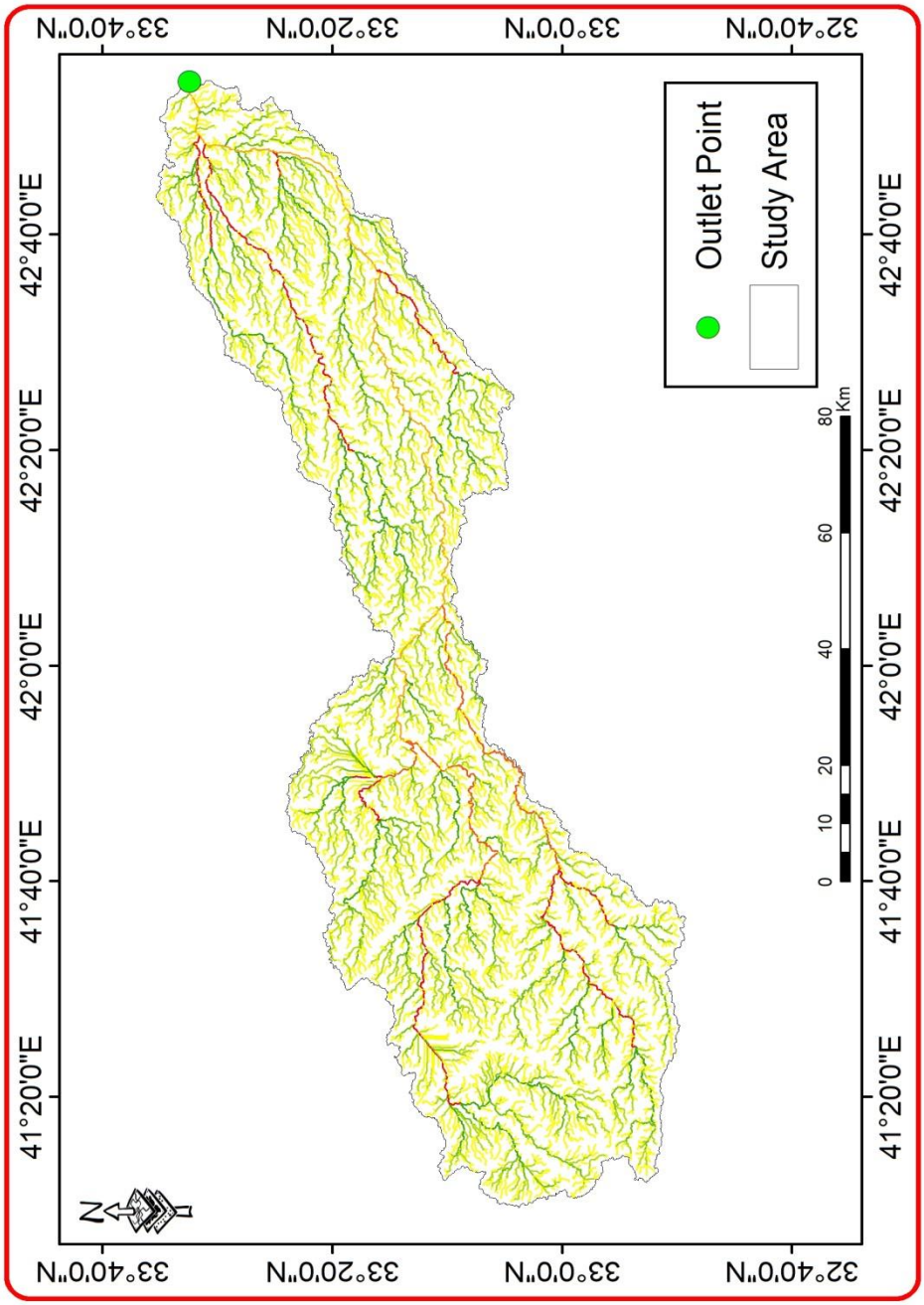


Figure 3.2: Study Area (Al-Mohammadi Valley)

3.2. Geographic Information Systems

These are tools for collecting, entering, processing, analyzing, displaying, and producing geographic and descriptive information for specific purposes. The significant benefit of applying geographic information systems in the water field lies in that it enables workers in the water field (hydrogeological, hydraulic, trade, law) to link geographic information such as water basins with graphic details such as rain, water level rise and use this information together to conduct analyzes to benefit Including in building dams and reservoirs. It also helps in studying the state of groundwater, over pumping, seawater intrusion, and the impact of population gatherings on water. There are many programs that integrate with GIS.

In this study, six criteria were taken for the rainwater harvesting by GIS, which is: soil structure, slope, drainage density, vegetation cover, distance to roads, and runoff depth. Raster and Food and Agriculture Organization (FAO) Map of the Anbar city used to extract the criteria maps of the study area, as shown in Fig 3.3

In the first step, Raster is used to extract the stream order map by the stream order commend. After that, the basin catchment area is calculated by watershed order in GIS by selecting the outlet point of the basin. Slope map is extracted by slope order in GIS; drainage density is calculated by fishnet order for dividing the bowl to squares. By Buffer order, the left and right distance to the roads is calculated according to [36], [37] and [38].

In the second step, the FAO map is used to extract the hydrological soil group and the soil texture by Extract by Mask order. By the hydrological soil group, soil texture, and applied Eruptions 4.2, a runoff depth map is extracted. As for the Normalized Difference Vegetation Index (NDVI) map is calculated by Equation 3.5 by GIS.

Finally, all maps are combined and given each plan a classification and weight according to [36], [37] and [38] by Overly Weight order in GIS; the results of the combining operation is the selected site for the rainwater harvesting RWH.

3.3 Material and Methods

Data used for this study are divided into three major classes, i.e., satellite images, metrological data, and soil characteristics. Satellite images consist of Landsat image 8 2019 and Shuttle Radar Topographic Mission (SRTM), provided by the United States Geological Survey (USGS). Daily and monthly precipitation data between 2013 and 2019 are also used. The geo-reference of the satellite image is WGS-84 datum projected zone 38. The soil data are categorized concerning the FAO global map.

Locating suitable sites for rainwater harvesting is a multi-factors problem and multi-objective. The primary and secondary data of remote sensing were used to prepare the thematic input database using ArcGIS. Four significant steps adopted in this study were given as follows:

1- Selection of criteria

2- Suitability level assessment of the criteria for rainwater harvesting.

3- Assignment of weights to these criteria.

4- Generate maps using GIS tools.

The flowchart describing these steps is given in Fig 3.3

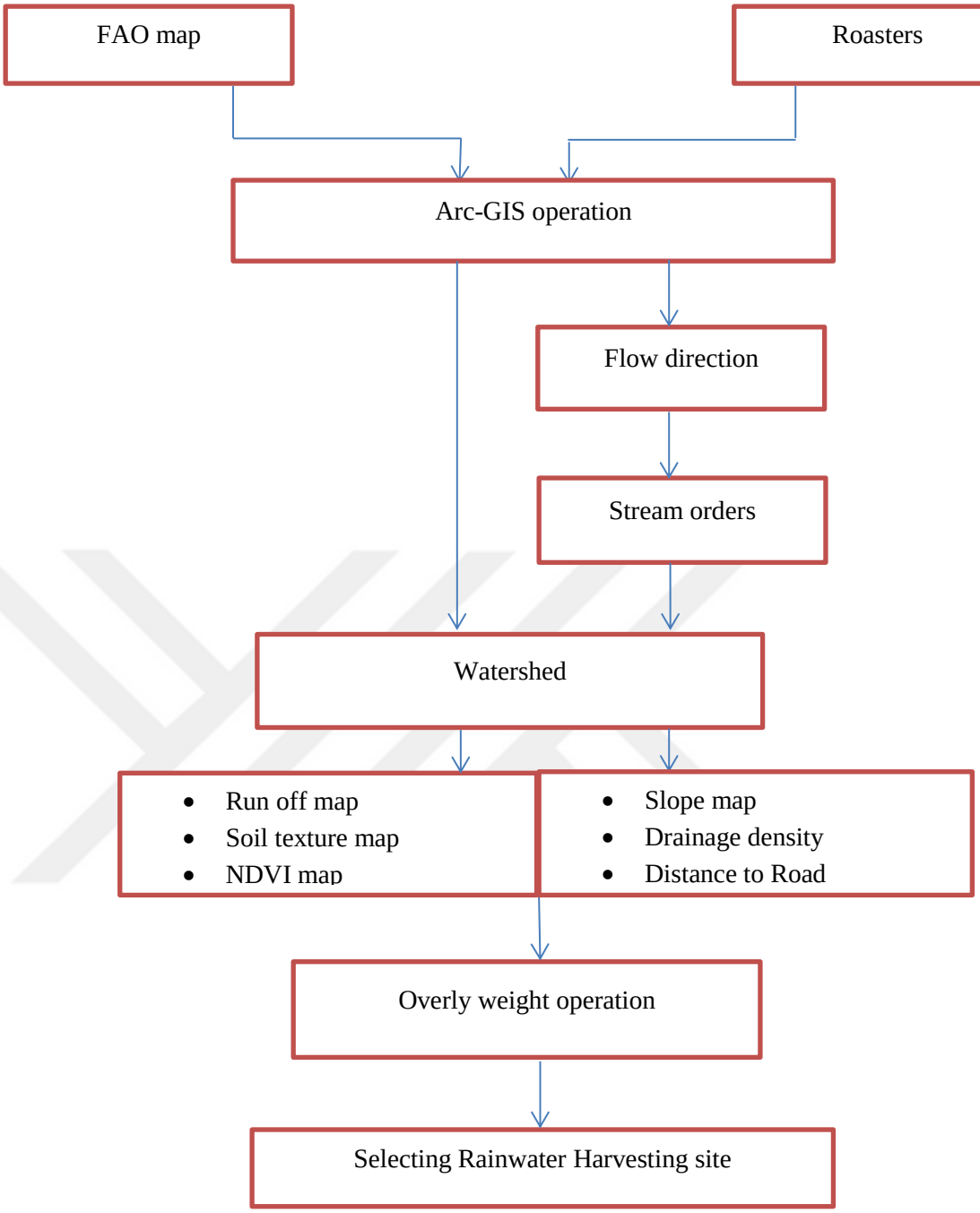


Figure 3.3 Flowchart for the rainwater harvesting by GIS

After the rainwater harvesting operation and selecting the suitable site, small dams or medium dams must be built to store this water that will be collected. Still, in this study, the construction and determination of the dimensions of barriers are not included; it is limited for selecting the suitable site.

3.3.1 Selection Criteria

According to six factors listed by Food and Agricultural Organization (FAO), i.e. (Hydrology, climate, topography, soils, socioeconomic, and agronomy) which mentioned by FAO [3], six of these criteria were used based on the literature review, natural of the study area, expert judgment. These criteria were adopted to determine the most suitable place for a rainwater harvesting using the ArcGIS Software includes: runoff, slope, soil texture, vegetation cover, land cover, drainage density, and distance to the roads.

3.3.1.1 Runoff

Rainfall is the major component in any water harvesting systems. More rainfall in any particular area means higher possibilities of harvesting part of it. Surface runoff in arid and semi-arid environments is one of the most critical water resources and sources of water for rivers, lakes, and streams. It is also considered one of the most enormous weights in the criteria taken in rainwater harvesting [39]. The integration of hydrological soil map and land use land cover was used to generate the curve number map. The runoff depth was calculated by the following formula [40]:

$d_{SR} = [\frac{(P-Ia)^2}{(P-Ia)+s^2}]$…… 3.1

Ia =0.2S …….. 3.2

Where

d_{SR} is the depth of runoff in mm

P is the depth of rainfall in mm

S is the potential maximum retention depth after runoff starts in mm, and Ia is the initial abstraction in mm [41].

And S is defined by Equation 3.3 in terms of Curve Number (CN) [41]

$$S = \frac{25400}{CN} - 254 \ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.3$$

The composite Curve Number CN is defined by Equation 3.4

$$CN_{composite} = \frac{(A_1 * CN_1)+(A_2 * CN_2)+(A_3 * CN_3)+(A_4 * CN_4)+(A_n * CN_n)+\cdots}{A_1+A_2+A_3+A_4+A_n+\cdots} \ldots\ldots\ldots 3.4$$

In which, $A_1, \ldots . A_n$ are the area of each type of soil cover, and $CN_{1,} \ldots CN_n$ are the curve number of each type of soil cover.

The Soil Conservation Service (SCS) model relies on the Runoff Curve Number (CN). CN is a number whose value ranges between 0-100, which expresses the water response of the components of a basin between high and low permeability. The more benefits go towards 100, the surface of the basin is of low permeability. When values get close to zero, the basin surfaces will become highly permeable to water. These values are extracted from the classification of the basin by four types of soils, which are divided according to the speed at which water moves through it (D, C, B, A), which are called (Hydrological soil group). Each type has its characteristics (D, A) two extreme cases (A) flow and values) C and B) two medium states with deficient surface flow, (D) very high surface flow, according to Table 3.1

Table 3.1 Hydrological Soil Group [42]

Class soil	Flow depth	Soil type
A	Few	A deep sand layer with very little clay and silt
B	Medium	Sand layer, the lowest depth of class A with an average leaching rate
C	Above medium	Clay layer, limited depth with an average leaching rate or a rocky layer covered with a layer of soil.
D	High	A thick clay layer, covered with a shallow layer of fine silt or a bare rocky layer

3.3.1.1.1 Calculation of CN Value

Depending on the FAO global map, the results of the hydrological group of the study area appeared as containing three types of soils, as shown in Fig 3.3. One of the requirements of the SCS method for estimating the volume of flow is to divide the soil of the study area into three types, and as it is shown in Table 3.1 and it is called the hydrological group of the soil.

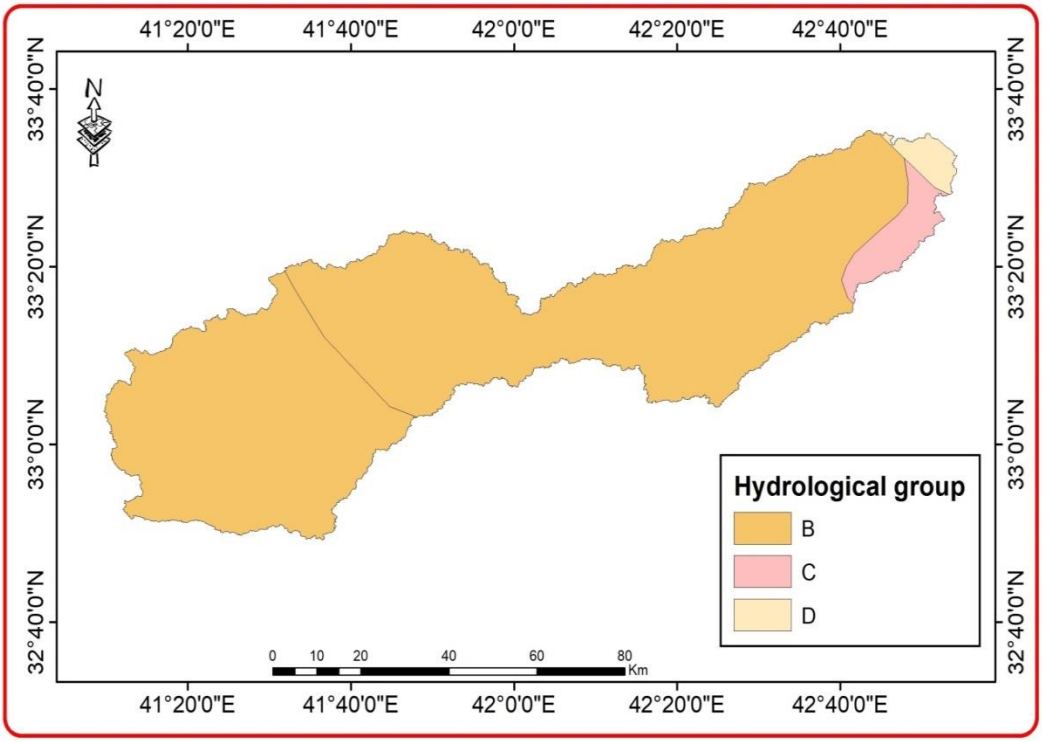


Figure 3.4 Hydrological Soil Map of the Study Area

Those soil groups in the study area can be explained as:

1- Soil Class B: This soil consists of rough tissue to medium roughness and has medium depth, and the permeability ranges from medium to good and extends in the form of a narrow strip. As for its area, it represents 4052.32 km^2 of the basin and 76% of the total basin area.

2- Soil Class C: represents the soil mixture consisting of silt and has a permeability ranging from weak to good. And its color tends to be from pale brown to dark

brown, occupying the southeast, near the downstream point of the study area with an area of 693.16 km^2, which constitutes 13% of the total area of the basin

3- Soil Class D: Considered one of the most essential categories of the study area because it is responsible for the emergence of most surface runoff of the study area. It occupies an area of 586 km^2 and a rate of 11% of the total area of the basin, which is the least able to absorb water and spread in the northern half of the basin.

They were considered forcalculating of Curve number relied on the classification of land cover and determination of soil quality based on an interest formula Soil Conservation Service (SCS). The CN curve number tables of the study area basin are according to the natural characteristics of the basin. From Fig 3.4, three types of hydrological soil maps showing valley basin cover were distinguished. Table 3.2, also describes land cover of the hydrological soil groups defined as: farmland and grass, barren soil, and water and moist soil. As shown in Fig 3.5, there are four zones in the basin of the Valley which have different land cover types.

Table 3.2 Land cover and corresponding Hydrological soil group [42]

	Hydrological Soil Group			
Land cover	A	B	C	D
Farmland and grass	72	81	88	91
Barren soil	77	86	91	94
Water and moist soil	100	100	100	100

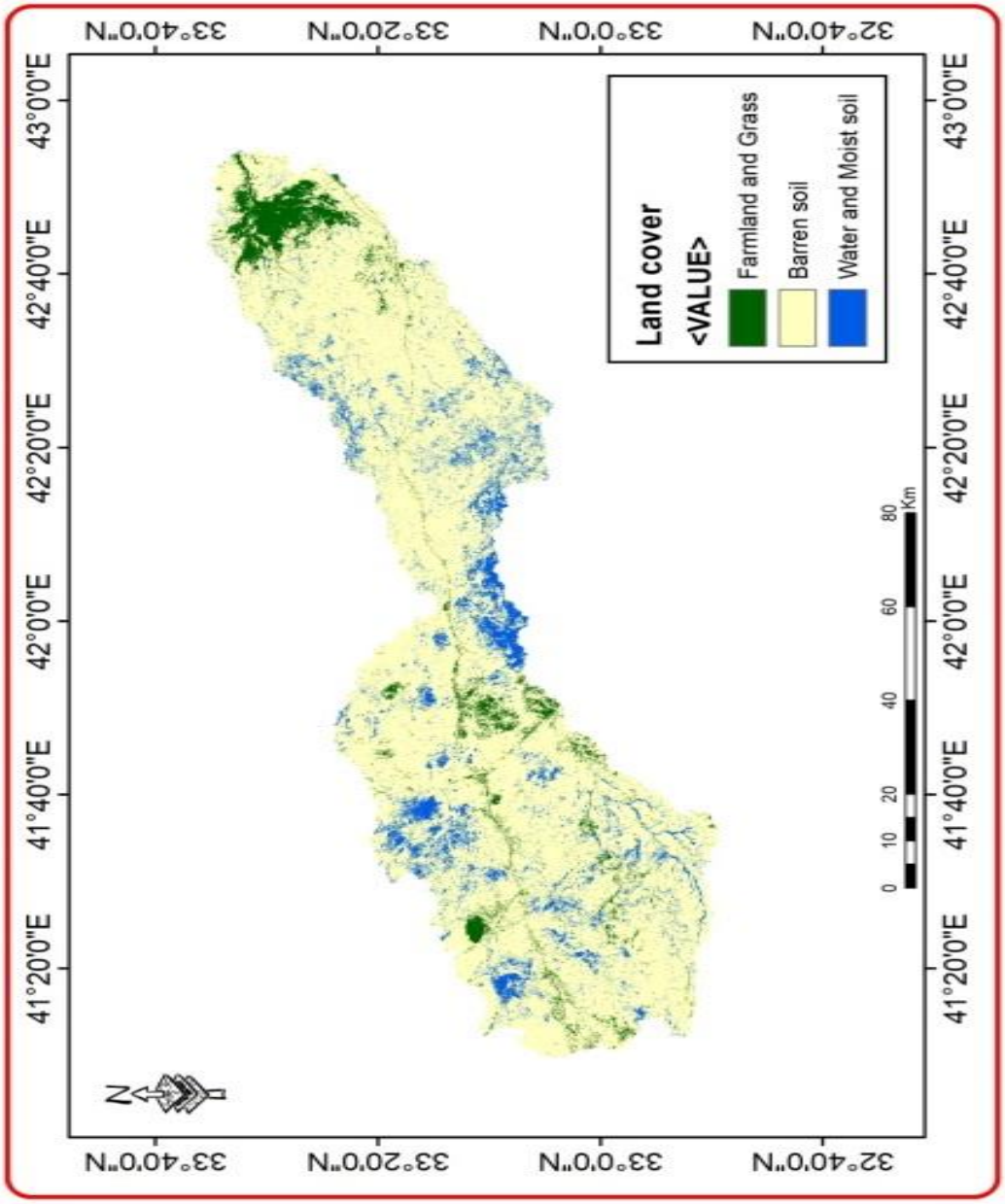


Figure 3.5 Land cover of the area study by GIS

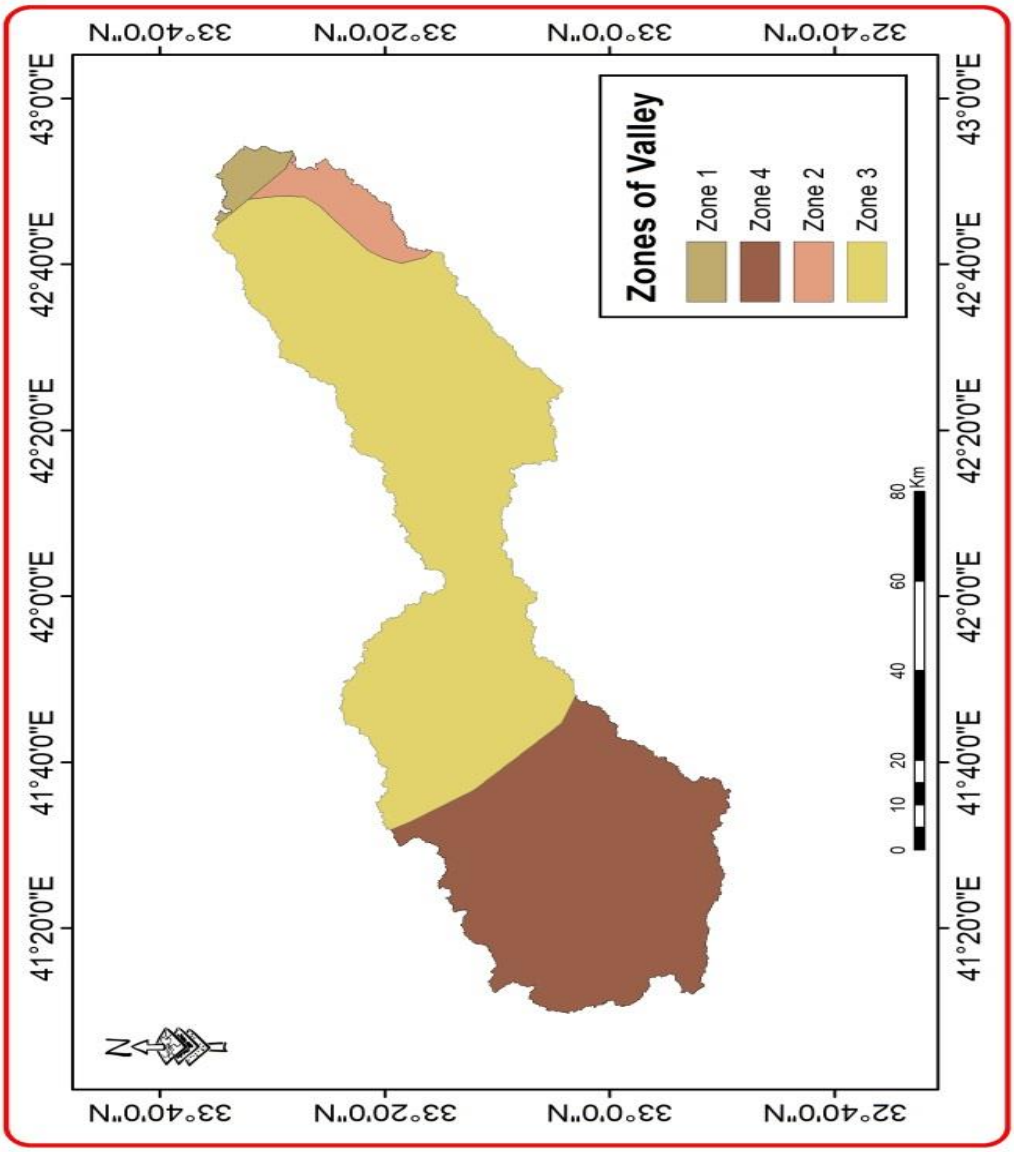


Figure 3.6 Zones of the study area by GIS

Because there are more than one soil covers in each area of the basin, it is necessary to calculate the CN composite for each zone [43]. By GIS, areas are calculated for each region and also areas of the land cover for each zone and given in Tables 3.3 and 3.4. Using Equation 3.4, CN composite values for each zone of the basin are extracted as shown in Fig 3.6. According to the FAO map, the basin has four zones, as shown in Fig 3.4; there are three classes of hydrological soil in four zones

Table 3.3 the area for each zone

Zone	Area	Area %
1	586.52	11%
2	693.16	13%
3	2292.76	43%
4	1759.56	33%
Total	5332	100%

Table 3.4 Curve number for zones, according to land cover for each zone

Zone 1	Barren soil	Farmland and Grass	Water and moist soil	Total
Area	404.69	117.304	64.51	586,052
Area%	69%	20%	11%	100%
CN	94	91	100	-
Zone 2				
Area	346.58	242.61	103.97	693.16
Area %	50%	35%	14.5%	100%
CN	91	88	100	-
Zone 3				
Area	1100.52	573.19	619.04	2292.76
Area %	48%	25%	27%	100%
CN	86	81	100	-
Zone 4				
Area	967.76	439.89	351.91	1759.56
Area %	55%	20%	25%	100%
CN	86	81	100	-

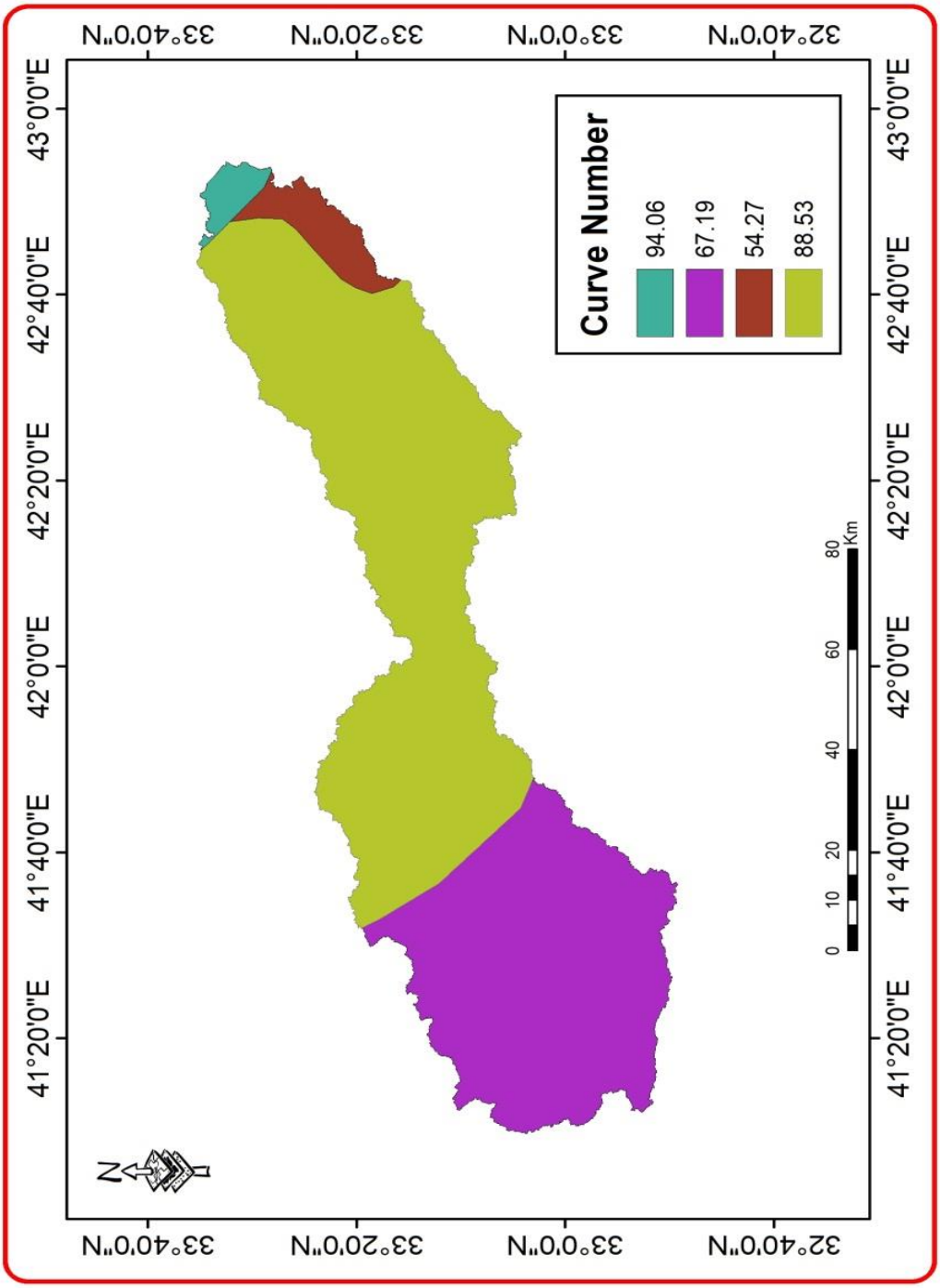


Figure 3.7 Curve number of the study area by Equation 3.4

3.3.1.1.2 Calculation of Maximum Potential Retention after Runoff Starts

It is the maximum possibility to retain water in the soil or to trap water in the soil after starting of the surface runoff. It is a parameter that describes the condition of saturated soil after the drainage and the Infiltration process. The thickness of the water-saturated layer varies depending on the type of soil and the extent of its ability to absorb more water during the rain wave. Therefore, the coefficient (S) is related to the kind of soil and the land cover, which is reflected in the values of the curve number... The coefficient (S) is calculated by Equation 3.4 and given in Fig. 3.7 for the study area. The small value (S) indicates the low possibility of soil retaining water on the surface of the land after the runoff, which leads to an increase in the amount of running water on the surface [43]. Observing equation 3.3, it turns out that the number (254) represents the median value of the coefficient (S), as the soil's ability to conserve water increases as the value of (CN) decreases, and vice versa, if the value of (CN) increases.

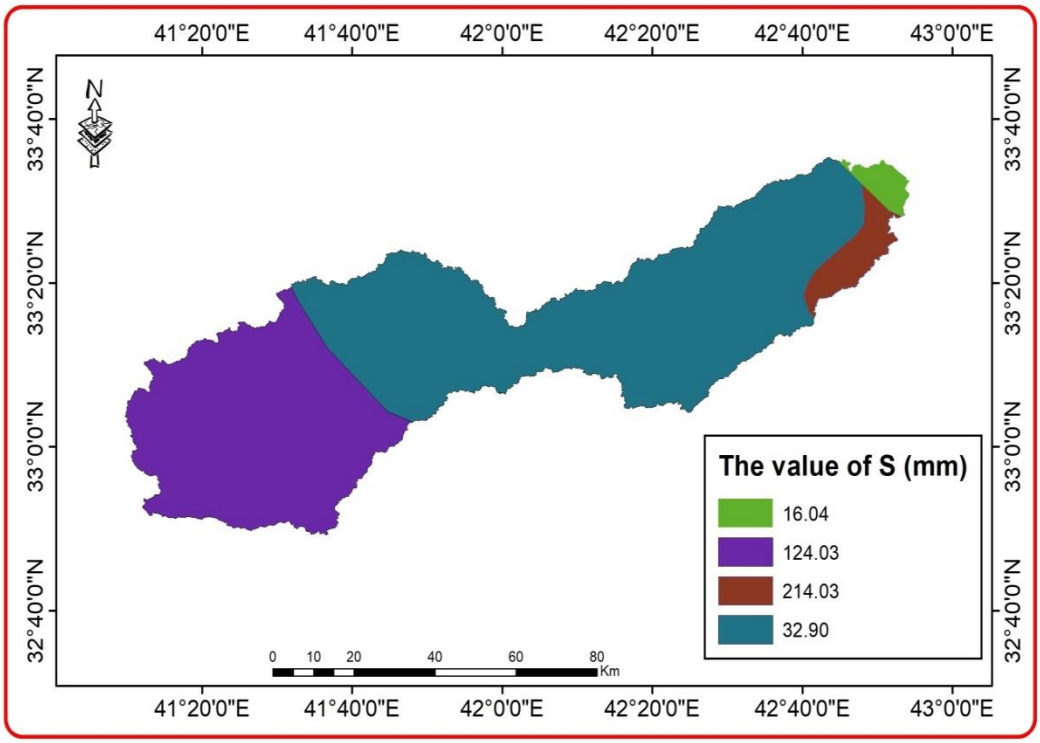


Figure 3.8 Values of potential maximum retention after runoff start for the study area

3.3.1.1.3 Calculation of Initial Abstraction Value

The initial abstraction coefficient (Ia) shows the amount of water loss before runoff through evaporation, or what the plants encounter from rainwater or water collected in the ground depressions. It is calculated in Equation 3.2. The low values of (Ia) indicate the lack of rainwater loss after the surface runoff, which helps to accelerate the process of surface runoff. On the other hand, the increase of the value (Ia) indicates the loss of large amounts of rain and thus a decrease in the number of running water on the surface. The initial abstraction coefficient [43], Ia, for the basin Al-Mohammedi value are shown in Fig 3.8.

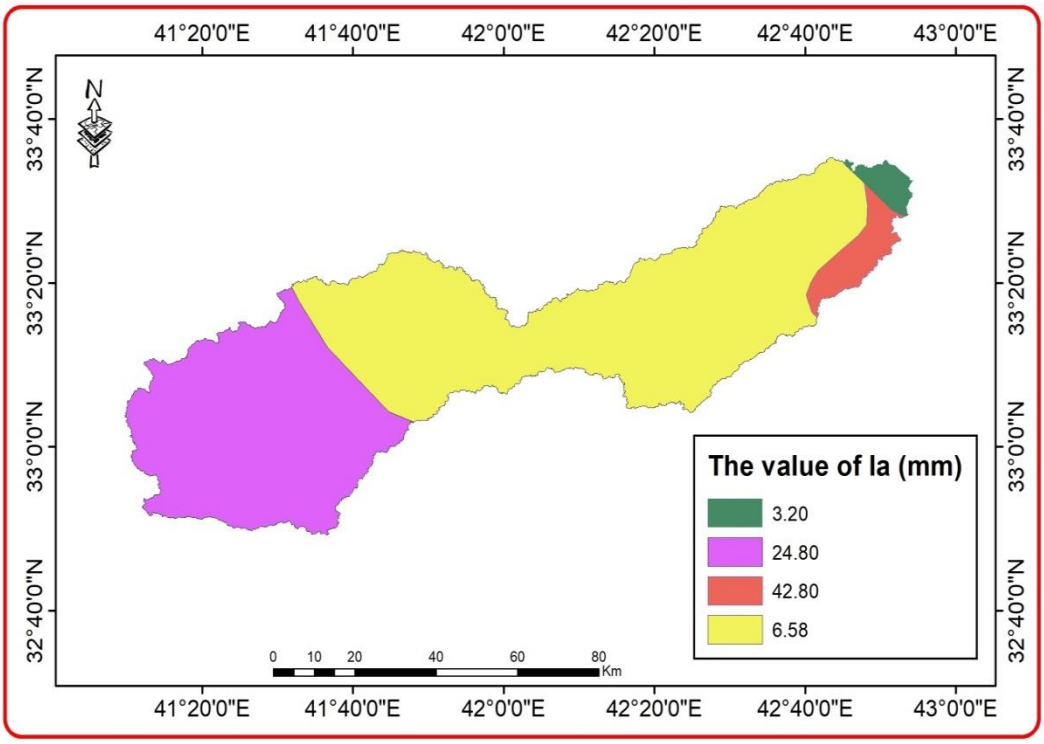


Figure 3.9 Initial abstractions values

3.3.1.1.4 Calculation of the Depth of Runoff

The surface runoff is expressed to be the part of rain precipitation that exceeds the absorptive capacity of the soil as a result of increased precipitation rates and moves on the surface of the Earth. It takes several levels according to the geomorphology of the Earth and its slope until it reaches one of the streams and flows into it and becomes

part of it. Accordingly, the flow is determined by a period of time it begins with rain falling to the surface of the Earth and ends when it flows into the watercourse. The runoff depth of the entire Al-Mohammedi basin was calculated by the average rainfall (P) for years (2013-2019) [43], it was 110 mm. After extracting CN for each zone of the basin, Equation 3.1 was applied to obtain the depth of flow for each zone, as shown in Fig 3.9.

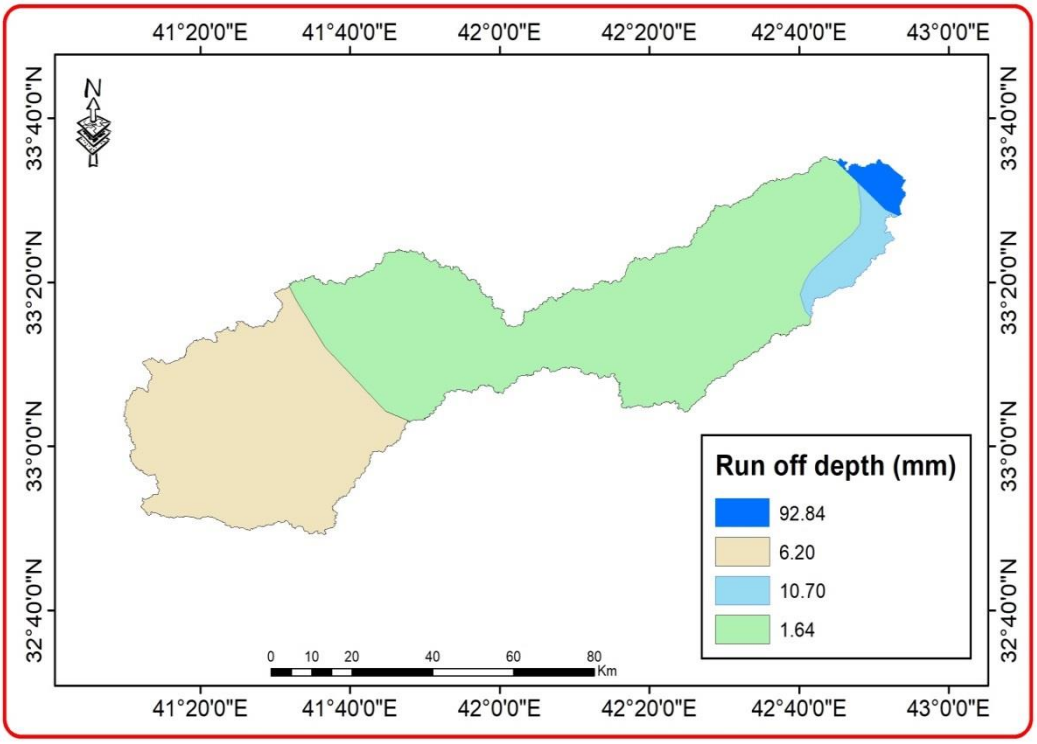


Figure 3.10 Values of Run off depth of the study area

3.3.1.2 Slope

The Generation of the runoff is based on the slope, which is considered as an important role that influences the speed of water flow and the amount of sedimentation [44]. The areas of rainwater harvesting should be < 5% because substantial earthwork prerequisite and these areas are susceptible to high erosion rates due to irregular runoff distribution [45]. The slope map was generated by using Digital Elevation Model (DEM) with 30 m resolution after sinks and flat areas removed by using Arc-GIS. The slope map was classified into for classes, as shown in figure 3.10. Table 3.5 shows the slope classification considered in rainwater harvesting.

Table 3.5 Slope classification [42]

Number	Slop category	Slop %
1	Flat	0-3
2	Undulating	3-5
3	Rolling	5-10
4	Hilly	>10

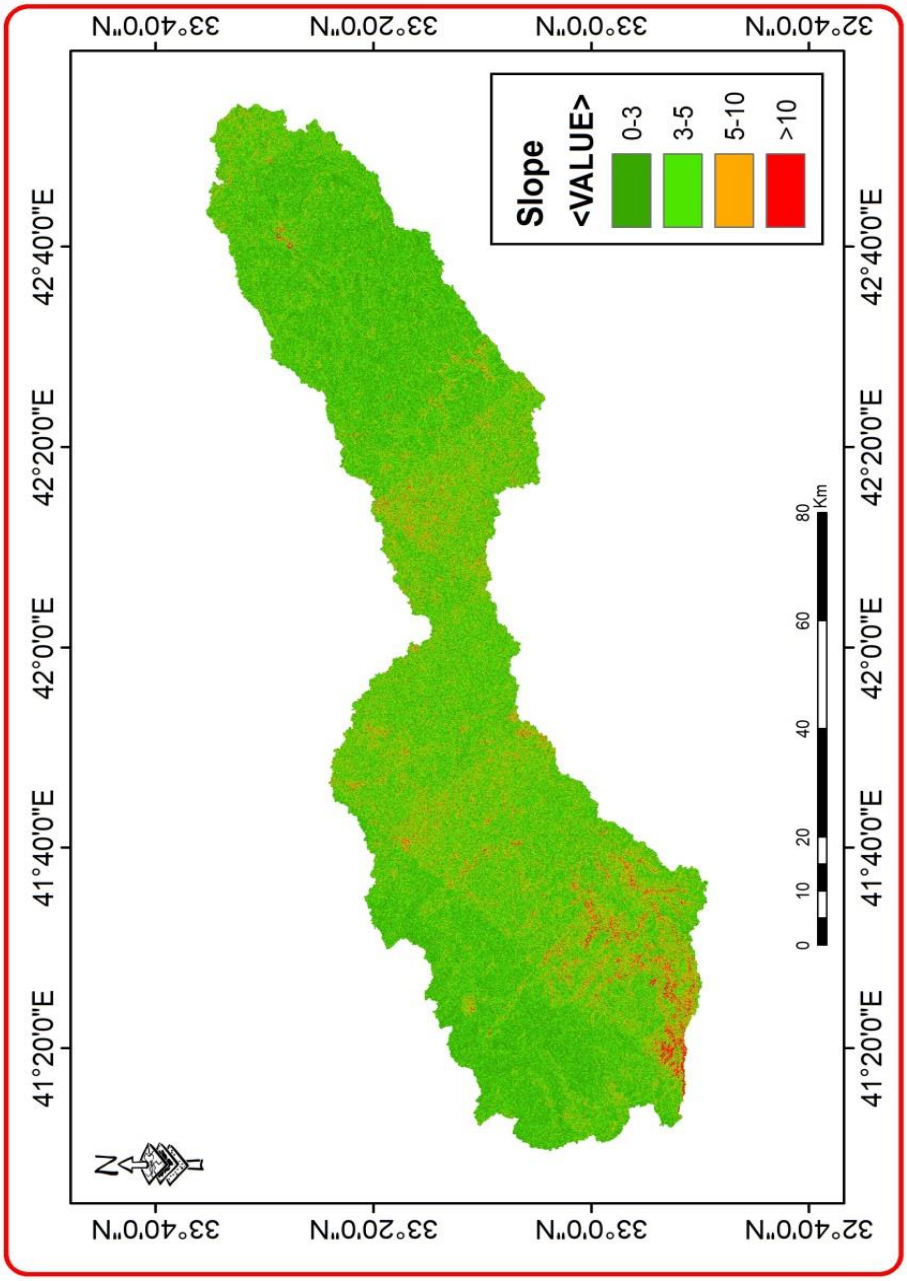


Figure 3.11 the slope of study area

3.3.1.3 Soil texture

Soil is one of the most important criteria that determine the appropriate site for rainwater harvesting, which affects the surface runoff and the rate of infiltration. Fine and medium-textured soils were more desired for rainwater harvesting [45]. Clay soil can hold the harvested water due to low permeability. Therefore, sites with these types of soil are the best for water conservation [44]. Thus soil texture is considered one of the most important criteria for selecting sites for rainwater harvesting. The soil texture map was categorized with reference to the FAO global map using the Geographic Information Systems Program [3]. The result was that the basin has four types of soil which were: clay loam, loam, sand clay loam, and silty loam, as shown in Fig 3.11

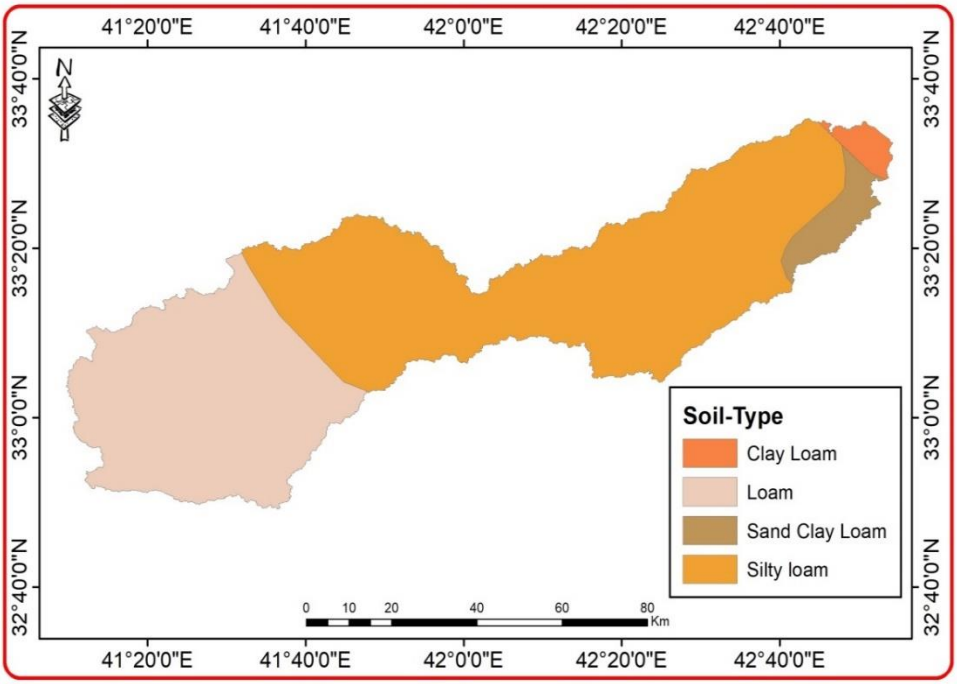


Figure 3.12 Soil textural group distributions in the study area by GIS

3.3.1.4 Soil texture

The vegetation index is a quantitative measure to measure the biomass. It usually consists of the sum of several spectral ranges. The indicators are formed through a mixture of spectral values that were added in a way that aims to produce one value that

indicates the density of the vegetation in each cell. Plant plays a significant role in the infiltration capacity of the soil [47]. Thus, the runoff amount can be affected directly by the vegetation index. The sun sends its rays to the planet Earth, where everything that can be seen falls under the visible range. What matters most in the study is the invisible clot represented in the infrared images of the satellite, which reflects a large part of the plant. (NDVI) is based on the reflection of near-infrared and red radiation, referring to it from measuring the vegetation activity. It can be extracted through the following equation [48]:

$$NDVI = [\frac{NIR-RED}{NIR+RED}] \quad \ldots\ldots\ldots\ldots\ldots\ldots \; 3.5$$

NIR = Near-Infrared Spectroscopy.

RED = Red light.

NDVI always ranges from -1 to 1. But there isn't a distinct boundary for each type of land cover. The increment in the positive value of NDVI is an indicator of the amount of green vegetation, while negative and near-zero values of NDVI indicate non-regulated features, which include other features such as rock, soil (barrier surfaces), and water. Table 3.6 shows the spatial distribution of vegetation cover in the spring session for the study area. Employing the Geographic Information Systems Program, the Equation 3.5 was used to extract the results of the vegetation cover of Al-Muhammadi basin, and the values of the vegetation cover of Al-Muhammadi Valley were (-0.25 - 1), as shown in Fig 3.12

Table 3.6 NDVI ranges describing surface cover of the study area [49].

NDVI ranges	Vegetation coverage	Vegetation Density	Land evaluation
Negative value	0-20	Very low	Very deteriorated
0.0 - 0.19	21-40	Low	Weak
0.2 - 0.49	41-60	Medium	Moderate
0.50 – 0.79	61-80	Good density	Well
0.8 – 1.0	81-100	High density	Excellent

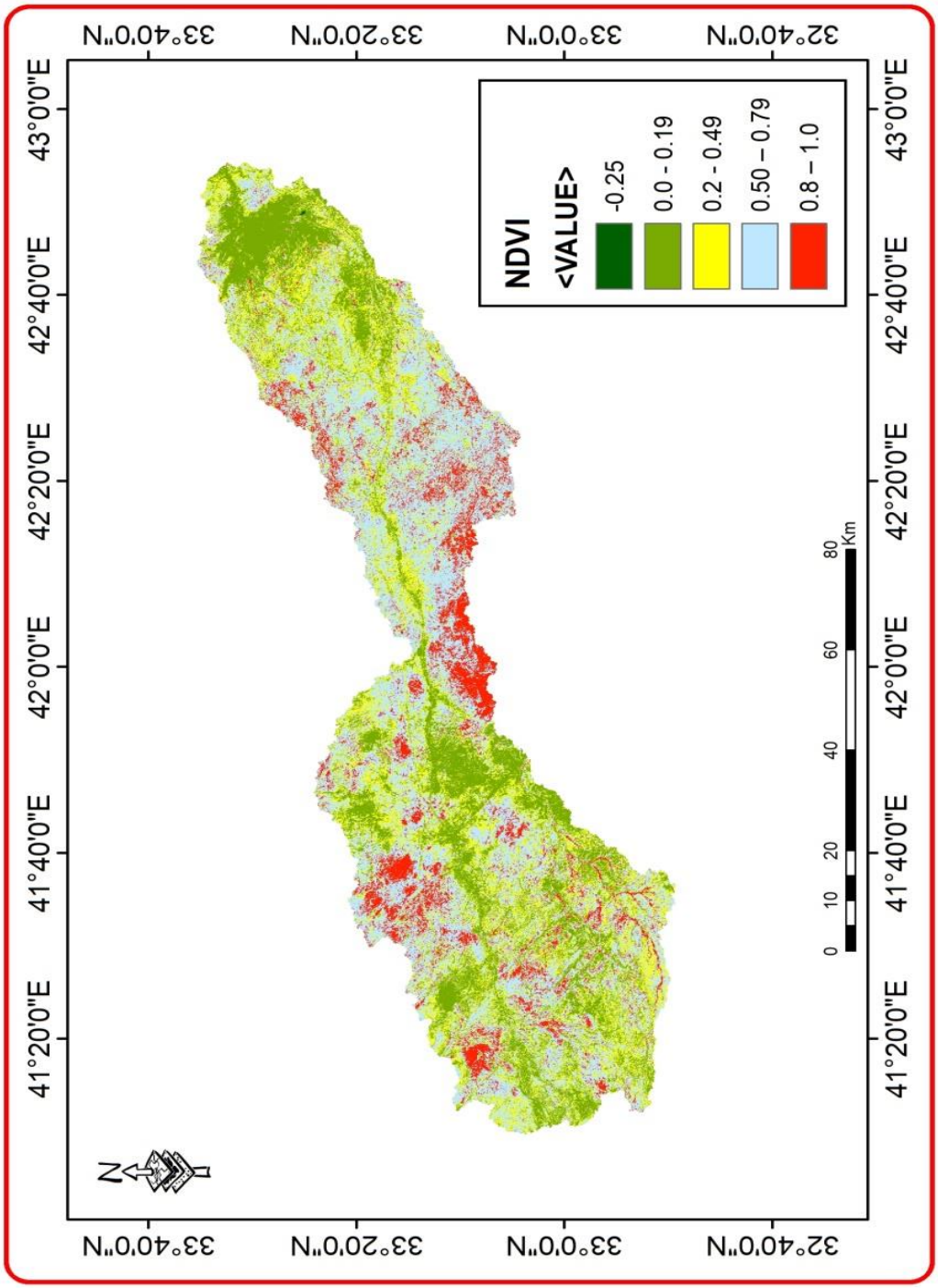


Figure 3.13 Classification of NDVI of the study area by GIS

3.3.1.5 Drainage Density

It is the relationship between the total lengths of valleys in the basin, and its area, the density of drainage is linked to several factors, including the nature of the rock formation, which is reflected in the infiltration of water into these rock layers as well as the vegetation. As the climate and surface shape are responsible for drainage density at 97% [44], the density of the drainage is divided into two types, which are the longitudinal and drainage density. It means that the ratio of the lengths of the channels in the basin over the area of the basin, and to know the longitudinal density which is as a significant role in the erosion and sedimentation processes. The longitudinal drainage density of the Al-Mohammedi Valley Basin reached 1.33, as waterways of various levels increase the pelvic area through erosion, which leads to changing water dividing lines, whose effectiveness increases with increasing numbers. The density of the numerical drainage intake is the density of the number of waterways in a single survey unit; it is the ratio between the numbers of channels in all their grades to the total area of the water basin, its value is for the Al- Mohammedi Valley basin 2.48

Drainage configuration reflects the subsurface hydrological formation and surface features. It shows the nature of surface material and closeness of the spacing of channels. The lesser the drainage density, means lower runoff and vice versa. The distribution of streams orders is every (1600) m^2 as square shapes in the drainage density map. Landsat image eight was used to extract a drainage density map of the study area. The distribution is different due to the density of water flow about each square, as shown in Fig 3.14.

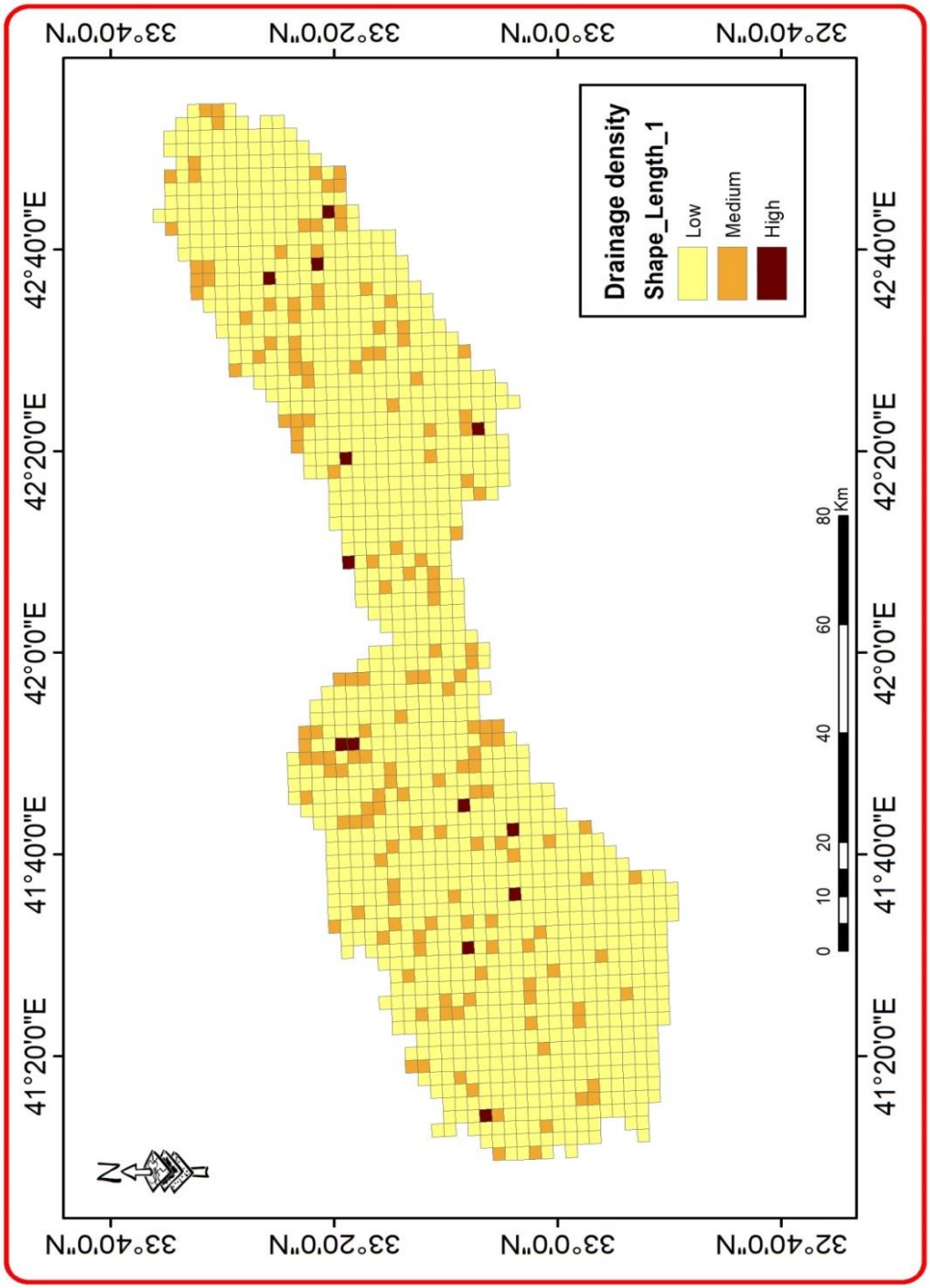


Figure 3.14 Drainage density of study area

3.3.1.6 Distance to Roads

The distance of the site selection for rainwater harvesting from the main road and communications network is considered as a tremendous socio-economic value for the local community. People can move their trucks and tankers from one place to another through these roads or when moving with their livestock to search for grass and water. The site must not be far from existing roads to reduce the cost allocated for infrastructure. Additionally, this increases accessibility to the rainwater harvesting sites. For the study area, three roads pass through the Muhammadi valley. According to scales suggested by [37], [38] and [39], the buffer zones were delineated to the right and left of the road that passes through the Al-Muhammadi valley, with a magnitude of (<500, 500-1000, 1000-2000, 2000->2000) m to determine the shortest distance that reaches the most suitable place for building dams. As shown in the Figure 3.15, the first value represents the best possible distance in which the rainwater harvesting structure can be established, and it is the shortest distance; the last value is not suitable for the rainwater harvesting structure to be constructed because it will be expensive to transport building materials to the site

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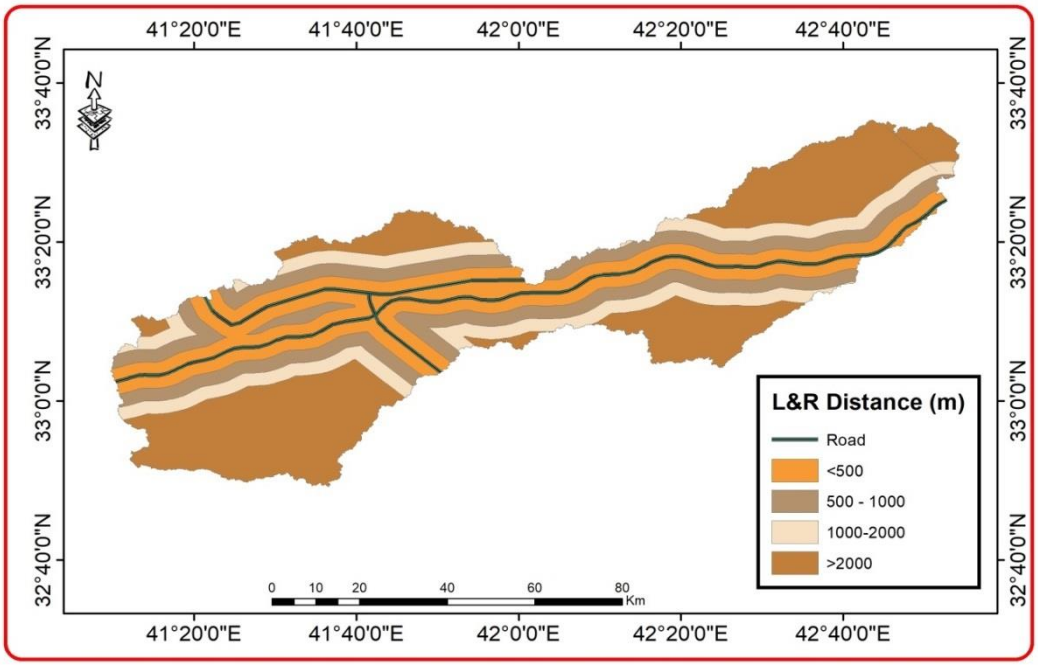

Figure 3.15 Left and Right distance to Road by GIS

3.3.2 Assessment of Suitability Level for Rainwater Harvesting Criteria.

Due to the different scales and measurements, each criterion has been categorized for all the different approaches suggested. The factors listed in Table 3.7, were utilized to classify the pixel values according to scales indicated by [37], [38] and [39] literature. All maps were created for each factor with pixel values. The suitability values were categorized into three classes: high, medium, and low. In GIS operations, the numerical values are used to get the results in some criteria that have numerical values such as the runoff depth, but in soil, texture map does not have numerical values. Therefore, it is classified as a numerical value, clay loam has number 1, and silty loam has number 4.

3.3.3 Assignment of Weights to Criteria

After creating the criteria for Overly Weights by GIS, each approach was given according to its priority in the water harvesting process. In the reclassification process, the high number is given to the approach most affecting the water harvesting. As for providing weights to the considered criteria, the high pressures are given to the standards that have a high impact on the determination process for rainwater harvesting, as shown in the table 3.9. The ratings, Weights, and justifications for the factors could be adopted by regions that have similar environmental and physical conditions which is the case in most arid regions everywhere the world. Therefore, this study adopted the weights and ratings utilized by [37], [38], and [39] literature.

3.3.4 Generating maps with GIS tools

The database adopted for identifying a suitable location for rainwater harvesting is developed using ArcGIS together with raster and vector database. A suitable site model is generated utilizing Model Builder in ArcGIS to the appliance process for locating suitable sites for rainwater harvesting. The suitable areas for rainwater harvesting are identified via reclassifying all the layers of criteria and gathering them by raster calculation tools in the spatial analyst tool model. Each criterion is reclassified as numeric values to the study area and assigning suitability rates basedon Table 3.7.

Table 3.7 Classification and weighting for every criterion based on the literature [37], [38], and [39]

Criteria	classify	weight
Runoff (mm):		6
High	3	
Medium	2	
Low	1	
Slope:		5
1) 0-3	4	
2) 3-5	3	
3) 5-10	2	
4) >10	1	
Soil texture:		4
Clay loam	4	
Loam	3	
Sand clay loam	2	
Silty loam	1	
NDVI:		3
Vegetation	2	
Barren soils	1	
Drainage density:		2
High	3	
Medium	2	
Low	1	
Distant to Roads (m):		1
<500	4	
500 – 1000	3	
1000 – 2000	2	
>2000	1	

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Suitable Places

The selection of proper sites for rainwater harvesting plays a vital role in maximum water availability and recharge to groundwater. The process of locating a rainwater harvesting structures relies on the characteristics of the watershed. These characteristics are the source that suggests the process of location in a suitable way. In this study, six thematic layers, such as soil structure, slope, drainage density, vegetation cover, distance to the roads, and runoff depth, are considered to recognize the proper site for rainwater harvesting structure. The spatial analysis of runoff and slope are correlated. The drainage augmented with slope. The runoff depth enlarged in the direction of the downstream area. Each pixel has various scores for the six main layers when using them in the ArcGIS model. As shown in Fig 4.1, the result of this model produced a map which has three category zones aimed at rainwater harvesting: suitable, medium, and not suitable. The generated map shows that the downstream zones of the catchment are appropriate to implement rainwater harvesting structures. The proper zone represents 12% (539.84) km^2 of the total study area. While only 42% (2239.44) km^2 represents the suitable medium area for rainwater harvesting and 46% (2452.72) km^2 represents unsuitable areas to implement rainwater harvesting structure. The suitable major area has a slope between (1-3) %, and the main soil texture varied from clay loam to sandy clay loam as well as which has the highest runoff depth. The results of this study are compatible with the study, which showed that the zones having soil such as clay loam combined with a gentle slope are appropriate for implementing rainwater harvesting structure.

For a long time, earth dam is the most suitable and commonly utilized in the study area, after determining the most appropriate place to harvest the rainwater, a dam must be built to store this water that will be collected.|The application of six criteria and the ModelBuilder in ArcGIS software are conducted to find the appropriate zones for dams. Based on the estimation of available runoff, potential dam locations could be

chosen. To minimize the dam dimensions and costs, suitable locations are selected in a suitable area based on visual interpretation.

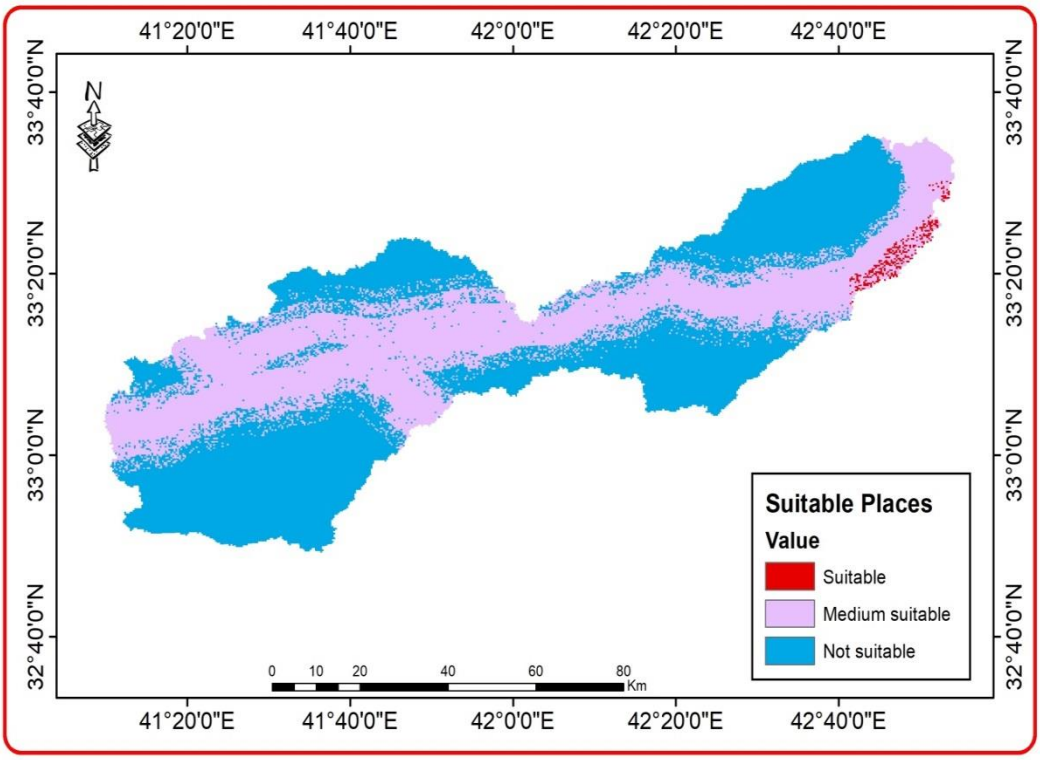

Figure 4.1 the suitable places of the basin by GIS

It is noted that the map of suitable places is close to Distance to Road map with the few weights given to Distance to Road map since the roads created in the Valley are constructed on flat ground where there are no high slopes, this means, the clarity of these areas on the final map will be more accurate than others. Suitable places map has a medium resolution, which is 30 cm/pixel.

4.2 Site selection

The success of the determination of suitable sites for rainwater harvesting depends not only on biophysical characteristics but also on the inclusion of socioeconomic criteria,

which is significant for gaining meaningful information to improve the effectiveness of locating the rainwater harvesting structure. However, in this study, the socioeconomic criteria is not considered. Topographic data is the most important in determining the suitable location for the rainwater harvesting. The topographic characteristic of the rainwater harvesting system is the length of the seasonal drainage network, which is characterized by a reduction and valley narrow cross-section.

To get started with the first steps of the rainwater harvesting process, a high-precision DEM was extracted by the geographic information systems GIS, as shown in Figure 4.2 for the study area to obtain topographical characteristics such as the slopes and drainage network.

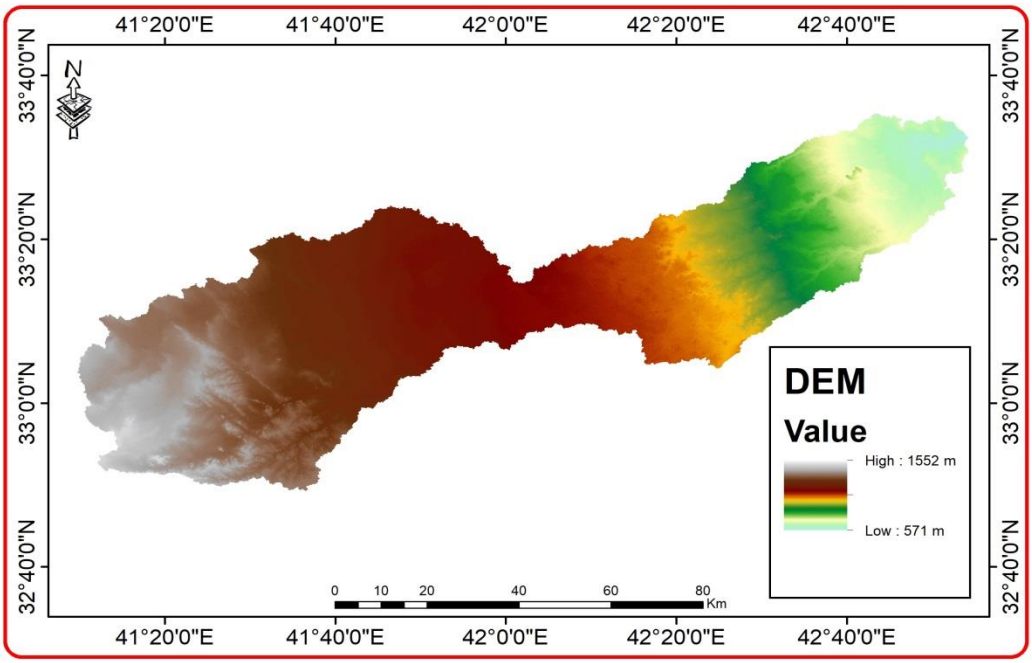

Figure 4.2 DEM of Study Area by GIS

4.2.1 Topographic Characteristics in Site selection

The narrow width of the Valley and the height of tenocious walls are among the essential characteristics that must be considered as the structure build of RWH

structure, the cost of the building will be lower, because of the dimensions of the structure are reduced [50]. Retaining walls are natural walls that are usually of natural rock, and these are highly resistant to the momentum of the water. At this stage, DEM was used by GIS from SRTM, and satellite images 2006 are used as input data. As for the slope of the study area, for terrain with slope values less than 10˚, this improvement was found to be minimal [44]. Besides, the majority of the study area is flat. Therefore, a 30 m precision Digital Elevation Model (DEM) was used to create the slope map for this study. The sink and flat areas were removed in selecting a specific site suggestion to keep the water flowing continuously to the catchment outlet. Still, in the Overly Wight operation, the flat area is considered.

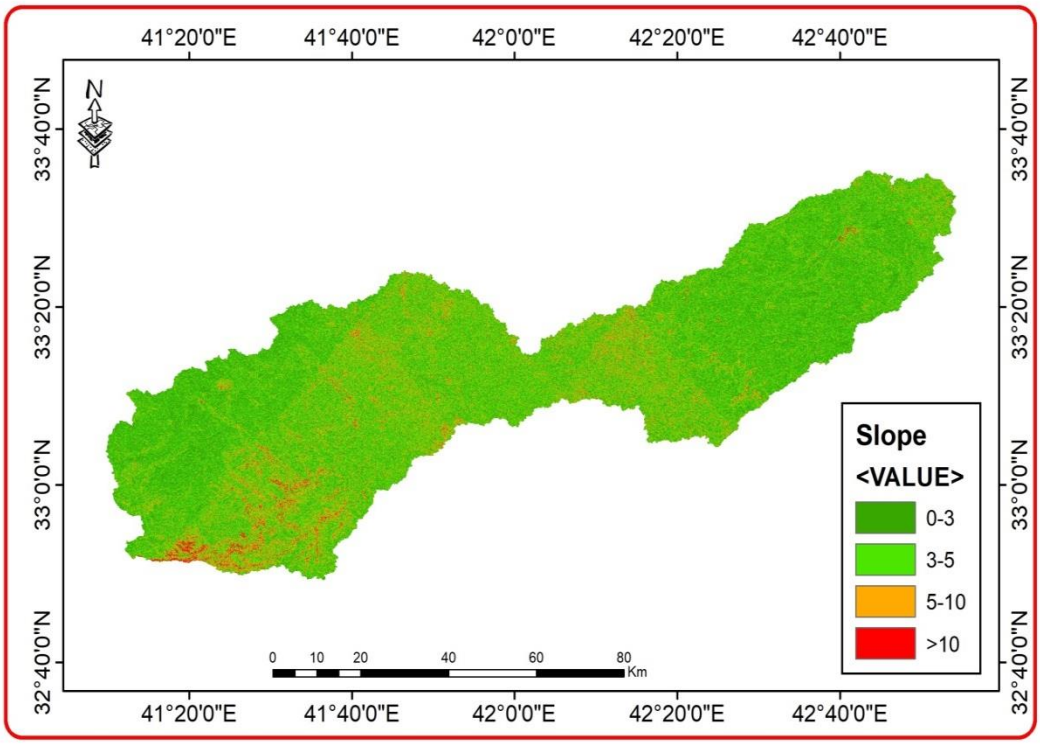

Figure 4.3 Slope of the Study Area

The essential characteristics to consider in building an RWH structure are the width of the Valley, the height of tenacious walls, and narrow canyon. If all these conditions are available on-site, the cost of RWH structure construction will be reduced due to the reduction of structure dimensions. In this step, GIS was used to select the most

suitable Valley, where DEM was extracted from the Shuttle Radar Topography Mission (SRTM) data and satellite images 2006 used as input data. The identification process is conducted via the visual interpretation of satellite images. As shown in Fig 4.4, the Global Mapper Software can provide a 3D topographical map and cross-section elevation for the RWH location and Valley.

The specific site in a suitable place, which represents 12% from the total area, is suggested by combining the DEM map, the appropriate places map, and slope map in GIS. By the Global Mapper Software and visual interpretation of these Maps, the narrow canyon is selected to be the suggested site, as shown in Fig 4.4.

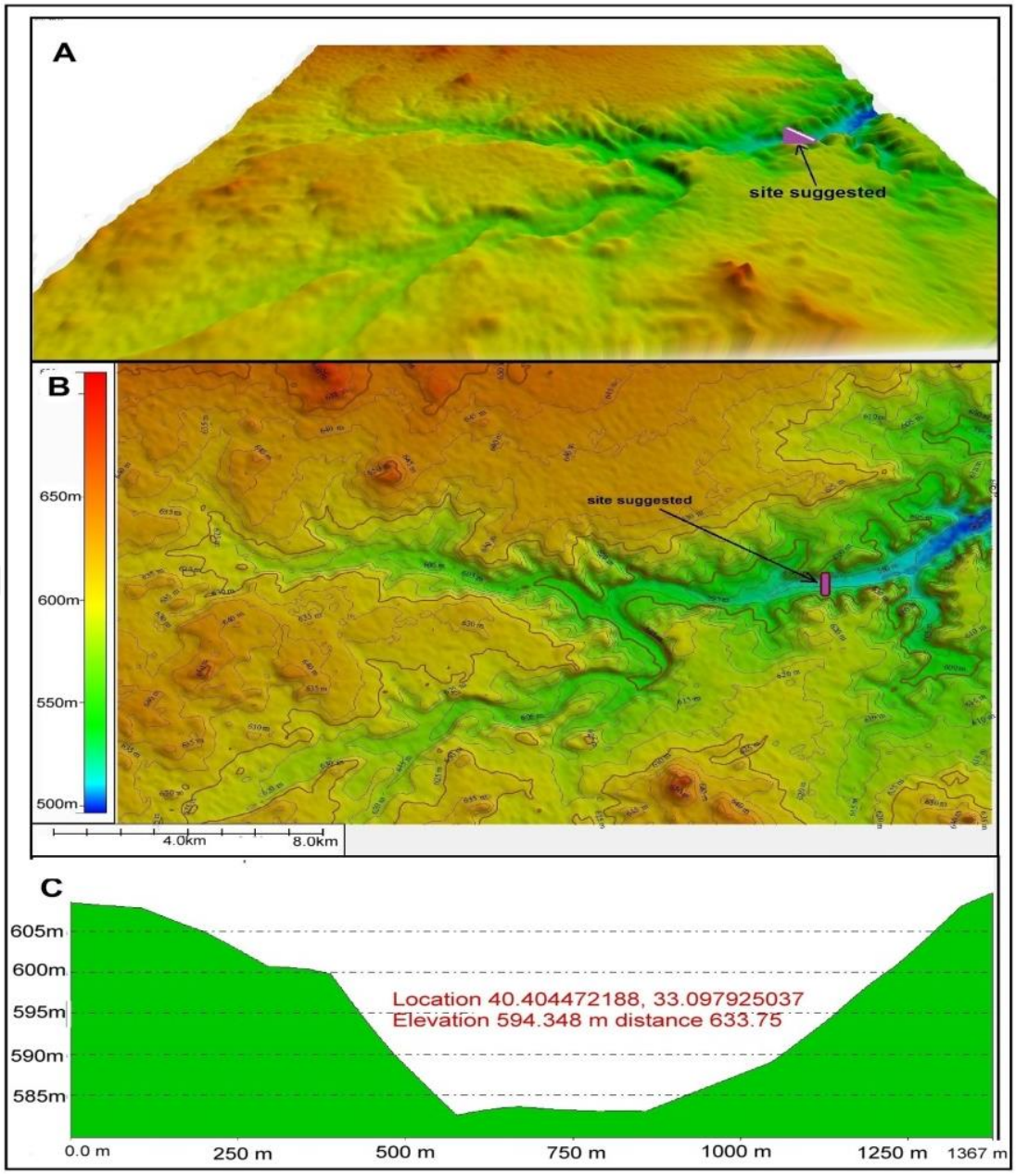

Figure 4.4 Cross section for suitable site by Global Mapper

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Water scarcity is the dryness of the region, its lack of water resources and its lack thereof. This drought has many causes, including the lack of falling rainwater or the absence of a water source close to the region such as a river or a well. It has tremendous and harmful effects facing the ecosystem, which leads to drought regions on Earth, in the sense that it cannot be used the area for agriculture or even for housing due to the climatic conditions that are in the region.

The western desert is one of the arid regions that suffer from the loss of water resources because of the rain events are short during the year and also because of the evaporation process that occurs. It is difficult to connect and manage water resources in the Western desert. Therefore, water provision is an critical factor that effects social and economic development and the ecosystem; water harvesting is the primary key to overcoming the problem of water scarcity in the Western desert.

The rainwater harvesting system depends on the conditions and standards in each study area. In Al-Muhammadi Valley, six criteria were considered according to the circumstances surrounding the study area, which were: runoff depth, slope, soil structure, vegetation cover, drainage density, and distance to the roads. The runoff depth in the Valley was minimal, due to the lack of rain in the study area; Most of the valley soil texture was loam because the study area is arid. As for the slope, most of the areas of the Valley had 0-3 values, especially the areas that are closed to the outlet point. As for the NDVI, although the area is arid, it contained some water and plants because the Raster was taken in the second month of the year 2019 (February). The value of the drainage density of the basin was 2.48. There are two roads through the Al- Mohammedi Valley, so that was easy to transport the construction materials to the suggestion rainwater harvesting site.

Locating proper sites for gathering rainwater is developed utilizing ModelBuilder in Arc GIS. Six layers, i.e., runoff depth, slope, soil structure, vegetation cover, drainage density, and distance to the roads, are considered to identify the proper site for

rainwater harvesting. The result of this study shows that the suitable zone represents 12% of the total study area, 42% represents a suitable medium area for rainwater harvesting, and 46% represents unappropriate areas to implement rainwater harvesting structure. This study finds that the GIS tool is a precious tool for combining various information to identify a proper location for rainwater harvesting as well as is flexible, cost-effective, and time-saving of screening large scale areas.

The result of a suitable map is very convenient for decision-makers and planners to select sites for rainwater harvesting in large areas quickly.

5.2 Recommendations

The ways and means put forward in this study for RWH planning provide a systematic process of improving much-used techniques of RWH site selection. Some proposals and suggestions to further advance and develop the method for RWH site selection in future research are as follows:

1- Using a better data digital elevation model than the SRTM digital elevation model.
2- I am studying the shape index for any site selection. This should be applied mainly in choosing an optimum site for RWH and in stopping excessive evaporation losses, particularly in arid regions.

Applying the methods developed in this study to create a hydrological soil group and comparing the results with past techniques.

3- İn the future, overseen classification should be used for selecting the sampling sites
4- The database and tools in this study are based on global datasets that are immediately available. Therefore, the processes outlined in this study could be reproduced for any arid and semi-arid region in the world.

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