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Investigation of Suitable Sites for Rainwater Harvesting Planning using Geographic Information System and Remote Sensing Techniques in the Western Desert of Iraq

A THESIS SUBMITTED TO THE DAMS AND WATER RESOURCES DEPARTMENT / COLLEGE OF ENGINNERING / UNIVERSITY OF ANBAR IN PARTIAL FULFILLMENT OF THE REQUIRMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN WATER REAOURCES ENGINEERING

By

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Abstract

The Western Desert is considered as one of the biggest arid regions in Iraq suffering from severe water shortage, mainly due to its climatic conditions and lack of water resources planning and management. Water storage could alleviate the impacts of drought, this may be accomplished by building dams and ensuring water supply. Detecting suitable sites for rainwater harvesting (RWH) to support planning and management of water resources is a complex issue and can be time consuming. The new information technologies, such as Geographic Information System (GIS) and Remote Sensing (RS) data have assisted and simplified the process of site selection for RWH and planning. This study has three objectives: (1) to create digital soil map using Artificial Neural Network (ANN) model integrated with GIS, RS and survey data; (2) to estimate surface runoff for Hijlan, Fahami and Zgadan valleys using the incorporation of the Soil Conservation Service Curve Number (SCS-CN) approach with the GIS; and (3) to detect proper RWH sites by integrating RS and GIS with a multi-criteria decision technique. The results demonstrate that the Radial Basis Network (RBNN) model has proven to be successful in predicting the spatial distribution of clay soil, followed by both silt and sand. It has also been noted that the Root Mean Square Error (RMSE) for clay, silt and sand was 4.2 %, 9.5 % and 11.0 %, respectively. Moreover, spectral reflectance and clay soil were highly related with coefficient of correlation value of (0.749). Furthermore, of the twenty-five samples defined by the USGS, only four samples had minor variations between the estimated and measured soil texture category. The results of the incorporation of the SCS-CN with GIS revealed that the runoff depth ranged from 12.5 mm to 20.3 mm for (48mm) for the maximum storm of rainfall recorded at Haditha station through 2018, while the amount of runoff of the maximum storm were 7,388,700 m^3, 12,750,000 m^3 and 9,851,590 $m^3$for Hijlan, Fahami and Zgadan, respectively. Seven criteria were used in the site selection process: Runoff, slope, soil texture, land use land cover (LU), distance from irrigated lands, distance from residential areas, and distance from roads. The stream order and distance from faults were used in the Boolean overlay method. The results indicated that the final map can be divided into three categories of suitability: (i) Highly suitable with 6% coverage (117 km^2), (ii) Moderately suitable with 4% coverage (78 km^2), and (iii) Least suitable with 90% coverage (1758 km^2) of the basin area. It is indicated that only one earth dam could be executed for every valley. This low data-intensive and cost-effective methodology offered can be adopted in arid regions to embrace RWH as an efficient strategy to handle growing water scarcity.

Keywords: Artificial Neural Network; Boolean; Earth dam; Geographic Information System (GIS); Hydrological soil group; Rainwater harvesting; Remote Sensing (RS); Runoff depth; Soil Conservation Service-Curve Number (SCS-CN); Weighted Linear Combination (WLC)

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Dedication

This thesis is dedicated to my father, who passed away in 16th July, 2020 before I get my degree.

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Abbreviations

Abbreviation	Description
RWH	Rainwater harvesting
GIS	Geographic Information System
SCS	Soil Conservation Service
CN	Curve Number
EPIC	Environmental Policy Integrated Climate
SWAT	Soil and Water Assessment Tool
AGNPS	Agricultural Non-Point Source Pollution
RS	Remote Sensing
SPOT	French Satellite for observation of Earth
ASTER	Advance Spaceborne Thermal Emission and Reflection
ANN	Artificial Neural Network
RBNN	Radial Basis Neural Network
RBFNN	Radial Basis Function Neural Network
WLC	Weighted Linear Combination
AVE	Area Volume Elevation
WOCAT	World Overview of Conservation Approaches and Technologies
USGS	United States Geological Survey
EDC	Earth Resources Observation System Data Center
ASAR	Arid and Semi-Arid Region
HM	Hydrological Modelling
MCA	Multi-criteria Analysis
GPS	Global Positioning System
DEM	Digital Elevation Model
AHP	Analytical Hierarchy process
NDVI	Normalized Difference Vegetation Index
UTM	Universal Transverse Mercator
RMSE	Root Mean Square Error
NRMSE	Normalized Root Mean Square Error
MAE	Mean Absolute Error
NMAE	Normalized Mean Absolute Error
Min Abs Error	Minimum Absolute Error
Max Abs Error	Maximum Absolute Error
R	Correlation coefficient

CHAPTER ONE

INTRODUCTION

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INTRODUCTION

1.1 General Introduction

Water is a key natural resource on earth, especially in arid and semi-arid areas where rainfall is limited. Water deficiency is a universal problem where many areas suffer from harsh water scarcity (Singh et al., 2009). Owing to rapid growth of the human population, water consumption has risen significantly in the last several years. The Food and Agriculture Organization (FAO) reports that world's water demand is increasing twice as high as the population. These detrimental conditions are compounded by excessive use of water such as overuse. Excessive usage leads to a decline in both water quality and quantity (FAO, 2015).

The western desert of Iraq is categorized as an arid area, which is facing great pressure to manage and provide water resource. Water accessibility in this region is habitually related to high intensities and a short period of rainfall. Generally, the nature of arid regions is categorized by an irregular distribution of rainfall in space and time, high evaporation and temperature, and lack of groundwater and surface water resources (Hussin, 2010).

Nearly 70 percent of dry land has been harmfully affected by degradation in soil cover and plant (UNCED, 1992). Desertification is currently a big problem in Iraq’s western desert, and it contributes to displacement of the population. The overall area subjected to desertification in Iraq is approximately at 167 thousand square kilometers, which equals to 40 percent of total area (Al-Ansari et al., 2012).

Iraq has declared a drought situation since 2007, largely due to the decreased precipitation over the past few years (UNDP, 2011). Water scarcity resources and water scarcity for irrigation affects the agriculture sector. Furthermore, the expanded domestic and industrial water use has exacerbated the state of drought. Figure 1.1 illustrates mean annual rainfall for the period (1983-2019) for the western desert of

Iraq. The figure shows the apparent decrease in the amount of rainfall over the past decades.

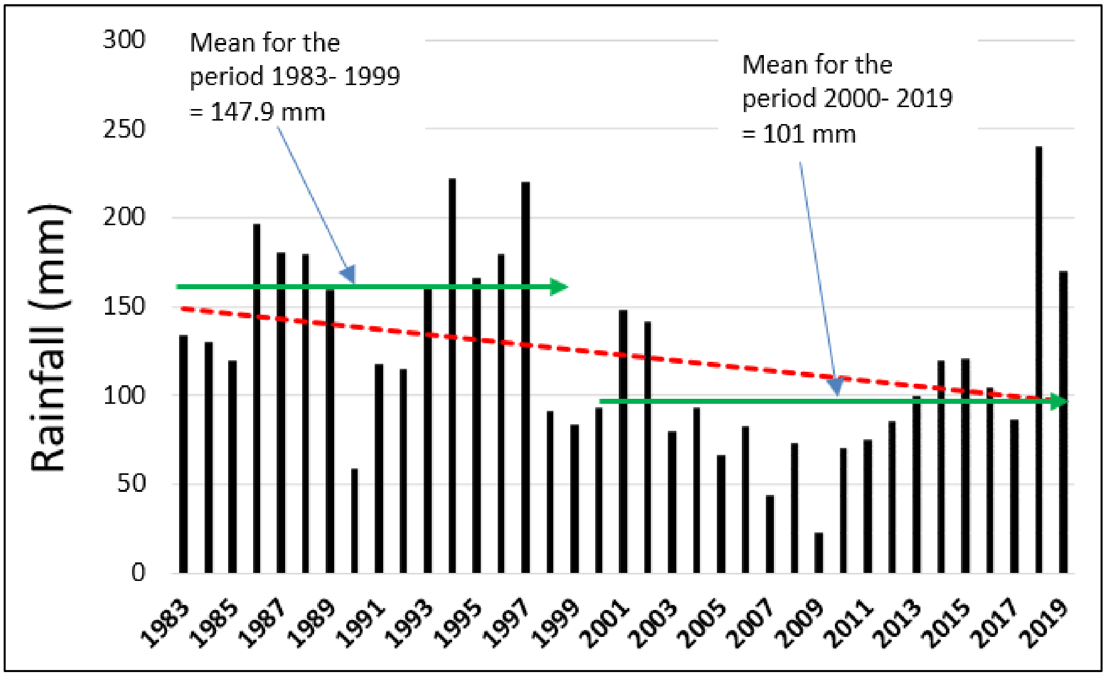

Figure 1.1 Mean annual rainfall for the period (1983-2019) (Haditha station)

Another explanation is that Turkey, Iran and Syria have blocked the tributaries flowing into Iraq with several dams. Turkey, for example, intended to introduce the Southeast Anatolia project (Güneydogu Anadola Projese, GAP), that is to build 22 dams all along rivers of Tigris and Euphrates (Jongerden, 2010). That project was started with building the dam of Ataturk on the river of Euphrates which began in 1992. The lake capacity of the dam is estimated to be seventy billion cubic meters. Turkey began constructing Ilisu Dam which is the second dam from the GAP project on the river of Tigris in 2007, and its storage capacity is measured more than eleven billion cubic meters. Turkey will regulate 80 percent of the flow of the water in the Tigris and Euphrates rivers once all GAP projects have been completed (Yasiri, 2007). Bozorge et al. (2019) showed that the depletion of total water storage is a water shortage index measured for Middle Eastern countries. Their research indicated that there are countries with negative water shortage indices such as Iraq, Lebanon, Syria and Iran.

The Euphrates and Tigris rivers are suffering from a drastic decrease in discharge over the past decade and water quality is declining due to problems with high salinity levels. The decline in flow and water levels in the Euphrates river creates both quality and quantity problems, including increased salinity in the downstream inland delta, total salinity dissolves (TDS) at Heet for example rose from less than 500 ppm to around 700 ppm (Kamel et al., 2013). Figure 1.2 shows the decrease in the inflow discharge of Euphrates river for the period (1933-2019) as mentioned by Sulaiman et al. (2019). While Figure 1.3 shows the increase in salinity levels by drawing the monthly rate of salinity during recent years, as mentioned by Sulaiman et al. (2019) in his study.

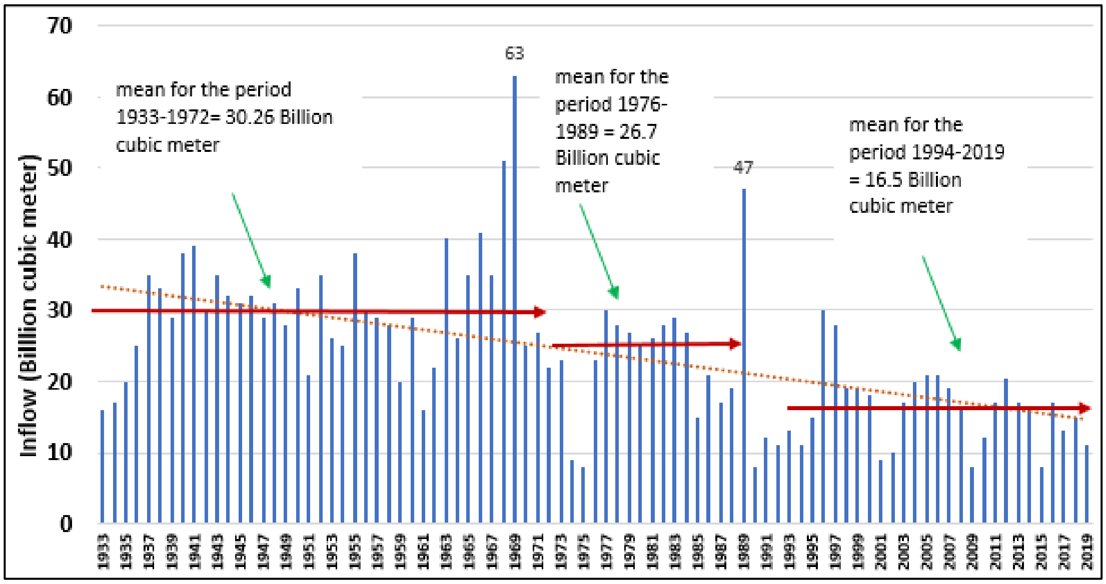

Figure 1.2 Annual water inflow to the river Euphrates (1933-2019) at Qaim station

Source: Sulaiman et al. (2019)

Since 2002 the agricultural sector has withdrawn in production. A study by the Food and Agriculture Organization (FAO) has shown that agricultural production has dropped from about 9 percent in 2002 to 4 percent in 2009. From 2002 to 2009, crop coverage across Iraq decreased by about 40 percent (IAU, 2010). Such drop in production is largely due to inadequate rainfall in recent years response to changing climatic condition.

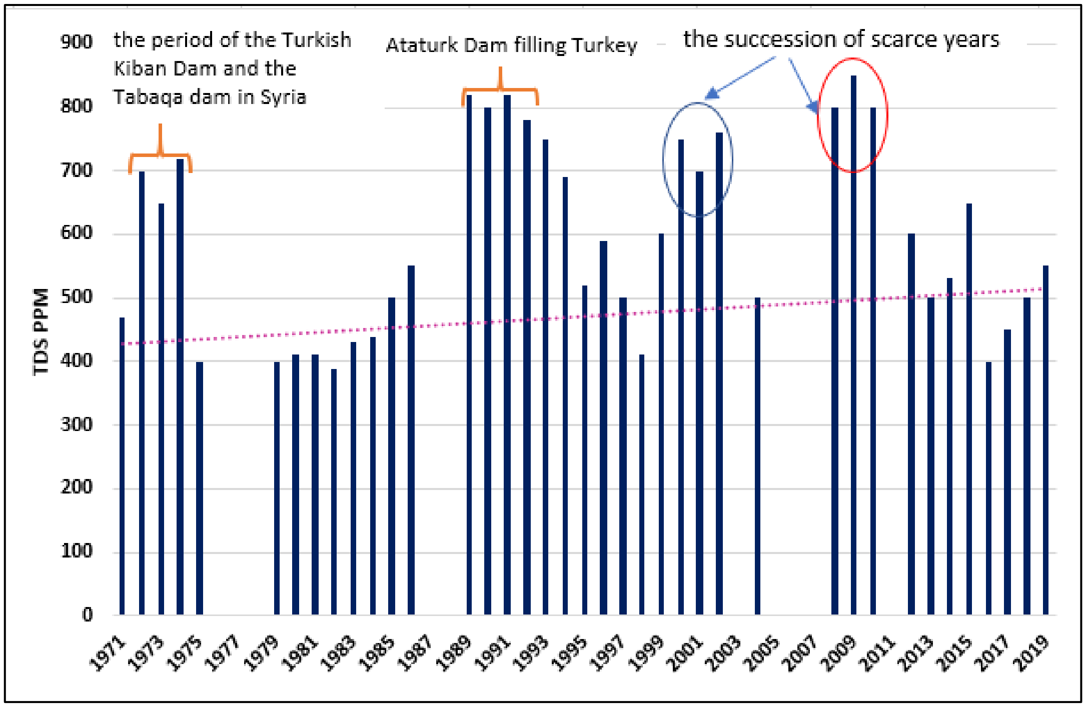

Figure 1.3 The dissolved salinity amount in the Euphrates river (1971–2019) at Qaim station

Source: Sulaiman et al. (2019)

Effective planning and management of water resources for these regions is significant to augment the availability and accessibility of water, along with improving the welfare of life. Nevertheless, the case study has restricted climatic and hydrological data. Hence, an efficient and cost-effective water conservation technique should be presented in this region. (RWH) is considered as the promising technique of water conservation, and it has the capability to affordable, safe, and accessible water for drinking, domestic, and agricultural uses (Agarwal et al, 2001; Sayl at el., 2017; and Sayl, at el., 2016).

The identification of a suitable site for RWH depends comprehensively on different criteria such as climate, soil, topography, hydrology, agronomy, and socio-economic factors (people's experience, costs, workforce, population density, and people's preference) (FAO, 2003). In this context, site election may be problematic and time-consumption particularly, in a wide-scale area with restricted data. The new information technologies such as (GIS) and remote sensing (RS) data have assisted and simplified the process of site selection for rainwater harvesting planning.

1.2 Problem Statements

In arid areas, life depends mainly on the availability of water. Water availability in these areas is mostly associated with short-lived and high-intensity precipitation. However, most occurrences of precipitation occur only over a short period of time in a year. Therefore, the evaporation cycle is harmful to ecosystems as it involves the depletion of water resources.

The West Desert of Iraq is one of the regions classified as an arid region. Rainwater harvesting has been the way to solve the water availability problem by collecting rainwater since it is a freshwater resource, guaranteeing continuous supply of water during the dry season. The main problem with applying rainwater harvesting technique is the West Desert of Iraq suffers from a lack of accurate data related to water harvesting, such as runoff, soil type and texture.

The absence of detailed soil data is a common problem in arid areas, and the identification of soil type based on laboratory tests is considered a traditional method, besides being time-consuming and costly. Thorough and comprehensive information on the soil properties in terms of spatial and temporal form can assist in sustainable hydrological, environmental, and agricultural development. Hydrological processes, including surface runoff and infiltration, also depend on soil texture. Therefore, this parameter is important in determining the potential volume of surface runoff and to select the best location of RWH structures (Jasrotia et al., 2009).

Most of the valleys of the Western Desert of Iraq do not have hydrological measuring stations, such as stations for measuring runoff resulting from the rainstorms. One of the most important criteria for RWH is the surface runoff. Surface runoff has the potential to be available and safe to human needs. Recently, uncalibrated distribution runoff-rainfall models were obtained when runoff data are unachievable to simulate catchment rainfall-runoff response in semi-arid regions (Schulze, R.E., 1994; Hughes, D.A., 1995; Anderson, N.J., 1997). These models all have drawbacks. They need several input factors that reflect different catchment characteristics, and they also do not completely produce spatially distributed predictions of runoff values. This is because data collection for large catchment area is complicated and time-consuming. However, optimized runoff-rainfall model was successfully applied to achieve practical runoff simulation where such data is available in these regions (Ye, W. et al., 1997). The creation and implementation of a large-scale optimized rainfall-runoff model is difficult due to the lack of detailed field data. Water resources management find runoff originating from a watershed a significant factor. Precise measurement of surface runoff and its volume plays a key role in the management of the watershed in arid and semi-arid regions. Nonetheless, large scale runoff estimation was a difficult task. Therefore, more work is needed.

The main research questions of this study are:

- How can a digital soil texture map predicted using GIS, RS and field data?
- Is the use of SCS-CN method integrated with RS and GIS sufficient to estimate the quantities of runoff generated from rainfall in ungauged watershed?
- Is the application of remote sensing data with GIS enough to select and plan suitable RWH sites?

1.3 Objectives

This study aims to integrate and apply different data to produce more effective and efficient planning for identification of appropriate RWH sites. Such study demonstrated use of a GIS to handle and use RS technology for RWH with minimal data in arid areas with success. The main objective is to show that the data of remote sensing combined with GIS seem to be the most efficient and relatively cost-effective methods or resources that can aid in evaluating possible RWH sites in the Fahami, Hijlan and Zagdan valleys of Iraqi western desert. Accordingly, the present study tries to achieve the fallowing aims to:

- Generate a digital soil map based on the spectral reflectance bands with laboratory testing of soil data using the Artificial Neural Network (ANN) model known as RBNN hybrid with GIS model.
- Estimate the runoff volume using the SCS-CN approach combining with GIS for the ungauged catchment.
- Detect proper sites for planning rainwater harvesting (RWH) in the Western Desert of Iraq using both the Boolean overlay and the Weighted Linear Combination (WLC) in the GIS integrated with multi-criteria decision support system.

1.4 Significance of This Study

The Western Desert covers about one-third of Iraq’s territory, and about half of Anbar governor. Research and development strategies and programs need to be searched for these areas which contain a large number of valleys. The central technology nucleus is the availability of freshwater which can be used for a variety of purposes, whether domestic or agricultural. Planning for the harvesting of rainwater in arid regions is an important part of increasing freshwater accessibility and availability as well as improving the quality of life in those areas.

Rainwater harvesting technique depends on several criteria, of which the most significant are soil-related criteria such as soil texture and hydrological like runoff (Sayl, at el., 2016). Whereas the western desert suffers from lack of a detailed soil texture map as well as from field calculation of surface runoff quantities caused by rainfall. Thus farther, this study aims to provide the criteria from the use of GIS and RS to implement the rainwater harvesting technique in the western desert wadis.

The area of study is considered to be an important sector in Iraq's West Desert; it contains three main valleys that receive large amount of rainfall during the rainy season. Hence, this area was selected because of the current orientation for rainwater harvesting and the possibility of investment in the future.

1.5 Limitations of the Study

The most important obstacles in this study are the difficulty of reaching all parts of the study area due to security reasons, as well as the high temperatures in the Western Sahara and the lack of infrastructure there. Due to the ISIS war in this region therefore it is difficult in obtaining more recent data, and there are no continuous data in this period 2014-2019.

1.6 Thesis Outline

This thesis is composed of five chapters. Chapter 1 provides a brief overview of the rainwater harvesting technique in arid and semi-arid areas and water shortage and even the problem statement, study objectives, significance of the study, study area location and outline of study. Chapter 2 explains the useful details of the literature review in relation to rainwater harvesting planning, GIS and RS in water resources management and also Artificial Neural Networks (ANNs). Furthermore, chapter 2 addresses previous studies of rainwater harvesting methods, rainwater harvesting criteria and Area Volume Elevation (AVE) curve. Chapter 3 offers a description of the data sources in addition to the research area's in physical and climatic characteristics as well as providing methodology for detecting suitable sites of rainwater harvesting with a focus on a method for estimating runoff depth for ungauged watershed. In addition, chapter 3 highlights a methodology for incorporating an Artificial Neural Network model, spectral reflectance data with soil field data with GIS to create digital soil texture map. These combined methods and techniques are used to build a framework for developing a comprehensive solution that is easy and inexpensive to define, select, and rank the sites for a suitable rainwater harvesting structure. Chapter 4 presents the results of the application of tools and models in present research, and the discussions. The Area Volume Elevation (AVE) curve established and the location selected and ranked for a proposed RWH structure. The conclusion of present thesis is provided in chapter 5, and recommendations are suggested for future employment.

CHAPTER TWO

LITERATURE REVIEW AND THEORETICAL CONCEPTS

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LITERATURE REVIEW AND THEORETICAL CONCEPTS

2.1 Overview

This chapter is important for the decision makers and planners of rainwater harvesting systems in arid and semi-arid regions because it contains a detailed description of scientific concepts and criteria as mentioned in the previous studies that have the same orientation and similar environmental and physical condition to the study area. This chapter also discusses the effective methods and it provides a general description of modern technologies that help effectively in RWH projects, such as RS techniques and GIS. Moreover, it summarizes several literature studies on the possibility of using remote sensing data to predict surface runoff of watersheds.

2.2 Definition rainwater harvesting

The RWH has long been used as a simple and cost-effective way to satisfy human water demand. Nevertheless, the same systems might have different names in different countries, with others having similar names but in fact they are totally different (Owies and Hachum, 2006). RWH practiced worldwide in several regions and it is used mostly for domestic and agriculture purposes. In all over the world, RWH is an effective strategy for water conservation.

RWH has been an effective source of water in Arid and Semi-Arid regions (ASAR) worldwide to cope with water scarcity. For these regions, the rainwater harvesting method is mainly used when rainfall is intermittent and sporadic. Agriculture runoff and related solutions have particular value in remote and harsh areas where other methods would be either technically impossible, too costly or ill-advised (Soane, 2000).

RWH's main role is to increase the availability of water by collecting rainfall in one region to be used or moved to another (Adham et al., 2016). RWH has various definitions and names, with Geddes as cited by Myers (1975) having given on of the earliest definitions of RWH: “The collection and storage of any farm waters, either runoff or creek flow, for irrigation use”. Critchley et al. (1991) described RWH as the set of productive-use runoff. Gupta et al. (1997) defined RWH as “a method for inducing, collecting, storing, and conserving local surface runoff for agriculture or consumption in arid and semi-arid regions”. Mbilinyi et al. (2007) defined RWH as, “the process of concentrating, collecting, and storing rainwater for different uses at a later time in the same area where the rain falls or in another area during the same or later time”. (Linger et al., 2011) defined the same term as, “the collection and management of floodwater or rainwater runoff to increase water availability for domestic and agricultural use as well as ecosystem sustenance.” The World Overview of Conservation Approaches and Technologies (WOCAT) database (Mekdaschi and Liniger, 2013) defined RWH as “The collection and management of floodwater or rainwater runoff to increase water availability for domestic and agricultural use as well as ecosystem sustenance”.

The amount of maintenance and labor required is different according to different techniques. Nevertheless, financial resources are small, and in an arid area with minimal infrastructure, a skilled labor force is not available. Hence, priority should be given to construction simple systems. Such concrete dams are therefore not included in the description of potential RWH systems for the study area. Critchley et al. (1991) give an overview of the earthworks and stonework required for various methods of water harvesting. Oberle (2004) highlighted the importance of several factors, i.e. water storage capacity, catchment area size, degree of maintenance required and heterogeneity of cultivation area, for a variety of water harvesting systems.

2.3 History of rainwater harvesting (RWH)

Since thousands of years, rainwater, groundwater and wastewater harvesting have been practiced, from the simplest techniques to hug and complex methods such as Roman canals. Ancient evidence has been found for the use of rainwater harvesting techniques in many countries around the world, including e.g. Jordan, Syria, Iraq and Tunisia. It is believed that the earliest signs of RWH were built more than 9000 years ago in the southern Jordanian Edom Mountains (Boers and Ben Asher, 1982).

Water harvesting in Iraq is an old and applicated. Western Desert, Jazeera Desert and eastern Valleys are the region that need to be used for water harvesting. Many Western Desert water storage dams had been installed since the 1970s, these dams are intended to provide habitat and ground water resource recharge (Al-Ansari et al., 2020).

Apart from the northern parts, Iraqi lands are listed as one of the arid and semi-arid regions (P. Buringh, 1960). With a desert area estimated at about half of the country territory and potential water scarcity problems, adapting the correct and economically efficient alternatives for water harvesting in Iraq is vitally important. Some projects were implemented in the western desert, even during the Abbasid era (K. A. Rahi et al., 2005). An interest was expanded on water harvesting until the 1970s, when studies and construction of several dams for water harvesting in the west desert began.

Finally, RWH appeared not only as a water supply but also as an important tool for increasing agricultural land yields. Scientist have been looking at all aspects of RWH for agriculture since the 1960's. Past studies have sought to explain the different forms of RWH and the volume of water balance associated with this topic (Boers and Ben Asher, 1982). These studies demonstrate that surface storage, evaporation and infiltration in the collection area are important factors in the developing an RWH system. The economic performance of the RWH projects for agriculture was considered (Goel and Kumar, 2005; Pandey, 1991; Tain and Liu, 2003). Field survey is a great and most popular methods for selecting the correct sites and techniques for RWH in a specific region. Survey and analysis for the implementation of the necessary work for RWH may be expensive when involving a large area. Therefore, the selection of RWH sites in this field presents a major challenge (Prinze and Wolfer, 1998).

2.4 Remote sensing and GIS in water resources

For water resources managers around the world, a large of data is now available. Such data provided a much more accessible and comprehensible environment. With the availability of these data, smart resource planning and management has become possible for developing countries, which was hampered in the past by the unavailability of the necessary data. Developing countries have thus begun to consider proper water resource planning and management as central to natural resource development in these areas (Lyon, 2003).

GIS is seen in this regard as a major tool for the use, analyses and transforms the bulk data and knowledge into meaningful and useful forms. GIS has developed to be an essential tool for water resource planning based on its qualities, especially since it is visual, clear and easy to manipulate. GIS has become an important tool for recognizing and addressing the ongoing problems plaguing water resource management worldwide. GIS concepts and techniques help to gather and coordinate data to overcome these challenges and to clarify their spatial relations.

GIS is definable 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 georeferenced 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 georeferenced coordinate system, allowing controlled interrelation of information” (Bähr, 1999).

Clarity in the decision-making process for water resources has become increasingly crucial to all nations, especially arid regions. More efficient and effective preparation of rain water harvesting is important in light of this. Data scarce regions, including developing countries, need resources and methodologies that use accessible remote sensing data to support water resource decision making.

GIS will explain the water resource decision process and allow for better organizing and storage of databases. Water resource studies require multiple base map data extraction, such as terrain slope, land cover/land use, drainage network and channels.

Developing this data can be time-consuming and laborious because it requires aerial photographs and paper maps, particularly when the base map must be obtained at different scales from different sources. The use of GIS would therefore greatly simplify the creation of this data, thereby making it less time consuming and more manageable (Cvar, 2014).

The U.S. Geological Survey (USGS) founded the Office Earth Resources Observation System Data Center (EDC) in 1970 as the principle repository of remotely sensed data. Some of EDC’s products relevant to water resources planning are available (Cvar, 2014).

Good water resources and management in all nations and practically in developing nations are becoming increasingly essential for natural resources (Lyon, 2003). Analysis of the data from remote sensing starts with some clarification of the remote sensing system used to generate the data. Such instruments can be lumped into three general categories, depending on the data products’ spatial resolution. High spatial resolution could be regarded as data on a grid of (1-10 m), medium spatial resolution data could be considered with a resolution of (10-250 m), low spatial resolution of (250m to 10 km) (Cvar, 2014).

2.5 Rainwater harvesting systems

The rainwater harvesting system depends on the catchment area where the runoff is produced and the area of consumption or receiving area, which is the region where the runoff is used (Mzirai and Tumbo, 2010). One can divide RWH into two classes:

- **Micro catchment** means that the rainfall is kept where it falls and that the water stored in the field or in the area of utilization can be used. Small semi-circle pits, strip catchment tillage, semi-circle ponds, contour bunds, and meskat-type systems are the properties of this systems (Ketsela, 2009). A micro catchment area is smaller than 1000 m^2 (Zakaria et al., 2012).

- **Macro catchment** includes the harvesting of water from a drainage area of between 0.1 and several thousand hectares. Macro catchment may be near or far from the area of Utilization (Ketsela, 2009). This system is applied outside the consumption area with intermediate storage of the water. A macro catchment area varies from 5 to 50%. This system requires storage structure and transferring infrastructure such as canals, nature streams and ravines to convert water storage into the use area (Zakaria et al., 2012).

The two above are suitable systems in arid and semi-arid regions where the rainfall has an intermittent nature (Boers, 1994). The harvesting of rainwater depends on reliable sources such as seasonal rainfall permanent rivers and is converted to cropped fields or for other purposes through a network of channels (Zakaria et al., 2012).

2.6 Components of rainwater harvesting

All water harvesting systems are composed of the following elements (Oweis et al., 2012):

- **A catchment area**: the portion of the area that received some of the rainfall from. This is also known as the field of runoff. This area can be a few square kilometers to several square kilometers size and it can be agriculture, or rocky, or a paved road or a roof top.
- **A storage facility**: the area where the collected runoff water is stored until it is used for crops, animals and humans. There are two storage types: above ground (like reservoir or ponds), underground storage containers (like cisterns) in the soil profile.
- **A target:** the end point of the system for water harvesting and the use of harvesting water for crop production and domestic use.

2.7 Multi-criteria decision making (MCDM)

The international society describes Multiple Criteria Decision Making (MCDM) as “The study of methods and procedures by which multiple and conflicting criteria can be incorporated into the decision” (Zardari et al., 2015). Developing multi-criteria decision making started in 1971. MCDM's key objective was to offer the decision makers with a mechanism to allow them to step forward in the resolution of a question of multi criteria decision making, taking into account multiple competing criteria. Multiple terms were used with multi-criteria decision making, and that are available as (Multi Attributes Decision Making (MADM), Multi Criteria Decision Analysis (MCDA), Multi Dimensions Decision Making (MDDM), and Multi Objectives Decision Making (MODM) (Zardari et al., 2015).

There are various types of MCDM methods that researchers have frequently used to solve only several real-word multi-criteria problems. That methods such as Analytical Hierarchy Process (AHP), Weighted Sum Model (WSM), Analytic Network Process (ANP) and Goal Programming (GP). Not all methods of MCDM are suggested to solve any issue of multi criteria decision. Only certain MCDM methods could really take the quantitative data to handle assessment of decision-making phase and others may work with both data types (qualitative and quantitative) (Zardari et al., 2015).

There seems to be no specific MCDM method to all decision-making issues that could be superior. Abrishamchi et al. (2005) mentions that choosing a suitable MCDM among a long number of options MCDM methods are itself a multi criteria problem. Guitouni and Martel (1998) have provided some guidelines that could still be useful in choosing a suitable MCDM method. There is a recent report of the MCDM to the water resources planning and management found that MCDM is primary utilized water policy assessment, choice of infrastructure and strategic planning (Hajkowicz and Collins, 2007).

Most MCDM approaches use weights of criteria in their process of aggregation. Such weights to criteria play a significate role in the overall calculation of alternatives preferences. MCDM systems use such weights in various ways, since they have different aggregation laws. To this end, various weighting methods were developed to use them in various MCDM methods. That is important for the decision maker to consider the real meaning of such weights. Various weighting methods were proposed for the assignment of weights to criteria (Stewart, 1992; PÖyhÖnen and Hämäläinen, 2001). The easiest way of assigning weights to criteria is the ‘equal weights method’, which uniformly distributes weights to all parameters. That method has indeed been applied to several issues of decision making (Wang et al., 2009). Also, there are several forms of weighting to assign variable weights to the criteriafor the decision.

2.8 Criteria used for selecting rainwater harvesting sites

The success or failure of RWH systems depends heavily on the selection of appropriate sites and the technical design criteria requirements (Al-Adamat et al., 2012). Three widely used sets of criteria guidelines were established for selecting suitable RWH sites as shown in Table 2.1.

Table 2.1 commonly used guidelines for identifying suitable RWH sites (Adham et al., 2016)

FAO (2003)	**Oweis (1998)**	**IMSD (1995)**
Climate (rainfall)	Rainfall	Not defined
Hydrology (rainfall-runoff relationship and intermittent watercourses)	Drainage system	Drainage system
Slope	Slope	Slope
Agronomy (crop characteristics)	LULC	Land use land cover (LULC)
Soil (texture, structure and depth)	Soil texture	Soil texture
Socio-economic (papulation density, work force, people’s priority, experience with RWH, land tenure, water laws, accessibility and related cost)	Socio-economic (land tenure)	Not defined

Integrated Mission for Sustainable Development (IMSD, 1995) guidelines offer more versatility than two other guidelines with different criteria. For example, different soil textures are given provided for different types of RWH such as percolation tanks that are ideal for sandy soils and ponds for clay soils. Yet slopes up to 15 percent felt ideal for certain techniques. The recommendation on land use are restrictive and propose classes of land use such as desert, scrubland or bare soil. In most cases, these land use classes are not used for agriculture and RWH is small in this area and should not be far from cultivation field. The correct site may therefore be located far from the water with these guidelines (Durbude and Venkatesh, 2004; Kadam et al., 2012 and Kumar et al., 2008). In addition, socio economical requirements are not yet specified in IMSD guidelines and this is one of the main drawbacks compared to two other guidelines.

Oweis (1998) Guidelines are more detailed than IMSD and define criteria common to different types of agriculture such as tree requirements, field crops, and rangelands. In addition, criteria were developed for different types of RWH structures with values for each factor, such as soil texture, mean annual precipitation between 50-300 mm/year, soil depth (<50 cm), slope (<4%) (Al-Adamat, 2008; Bulcock and Jewitt, 2013 and Ziadat et al., 2012). Nonetheless, within Oweis (1998) socio-economic requirements are still minimal, and more socio-economic should be expanded.

Actually, the FAO guidelines (2003) tend to be the most detailed for identifying potential RWH sites compared to other two guidelines, since they include more criteria and broader spectrum applicable to RWH than the others and include specific socio-economic requirements more closely related to local farmers. For example, guidelines from the FAO (2003) find medium textured loamy soil to be the best all otherwise suitable (for agriculture) and mean annual precipitation between 150-750 mm/year is suitable for most RWH techniques. Slope < 5 percent for reservoirs, < 10 percent for percolation tanks and < 15 percent appropriate for dams (Krois and Schulte, 2014; Mati et al., 2006; Munyao, 2010 and Ramakrishnan et al., 2009). Such large ranges and specific interpolations of criteria give the FAO recommendation more versatility and reliability to be approved by big research at ASAR.

Based on studies published in scientific journals, reports of international organizations and information obtained from practitioners, 65 papers were collected, four main groups of designed criteria were categorized as shown in the Figure 2.1

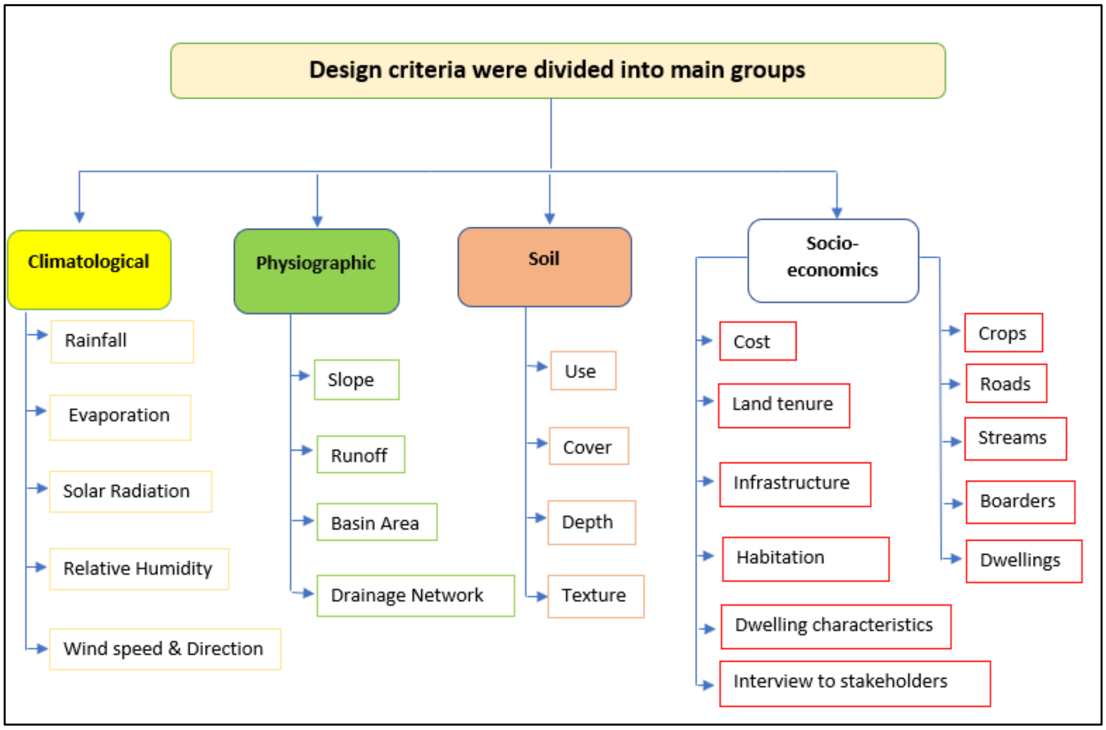

Figure 2.1 Groups of design criteria based on the literature review

Figure 2.2 represents the percentage of researchers who considered each criterion based on the review of 65 studies. It can be observed that the highest percentage of researchers was for the criteria: soil texture 76%, slope 71%, soil coverage 67%, rainfall 66% and soil use 65%.

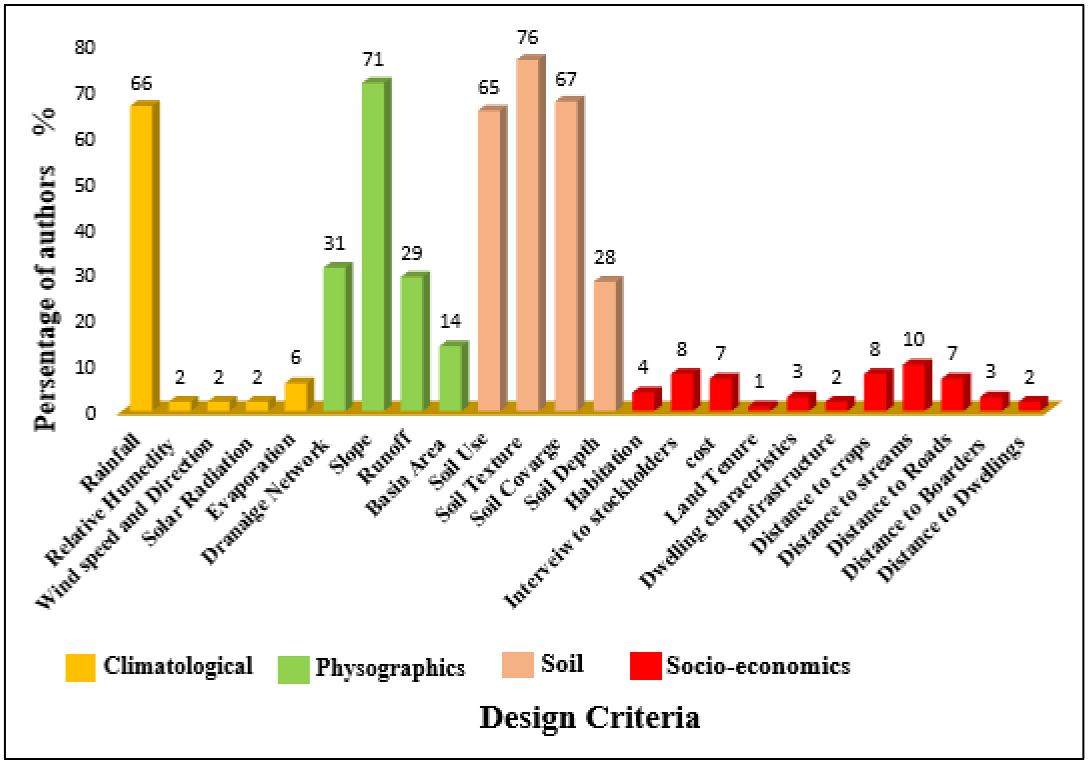

Figure 2.2 Percentage of authors per design parameter

2.9 Methods employed in identifying suitable RWH sites

Different methods can be utilized to incorporate the various criteria into a framework for selecting suitable RWH sites. The methods and tools used to define suitable sites in Arid and Semi-Arid regions (ASAR) can be classified into five main groups based on this review (Figure 2.3) (Adham et al., 2016):

1) Geographic Information System (GIS) and Remote sensing (RS)

2) Hydrological modelling (HM) with GIS/RS

3) Integrated Multi Criteria Analysis (MCA) with Hydrological Model (HM) and GIS/RS

4) Integrated Multi-Criteria Analysis (MCA) and GIS

5) Other methods without GIS

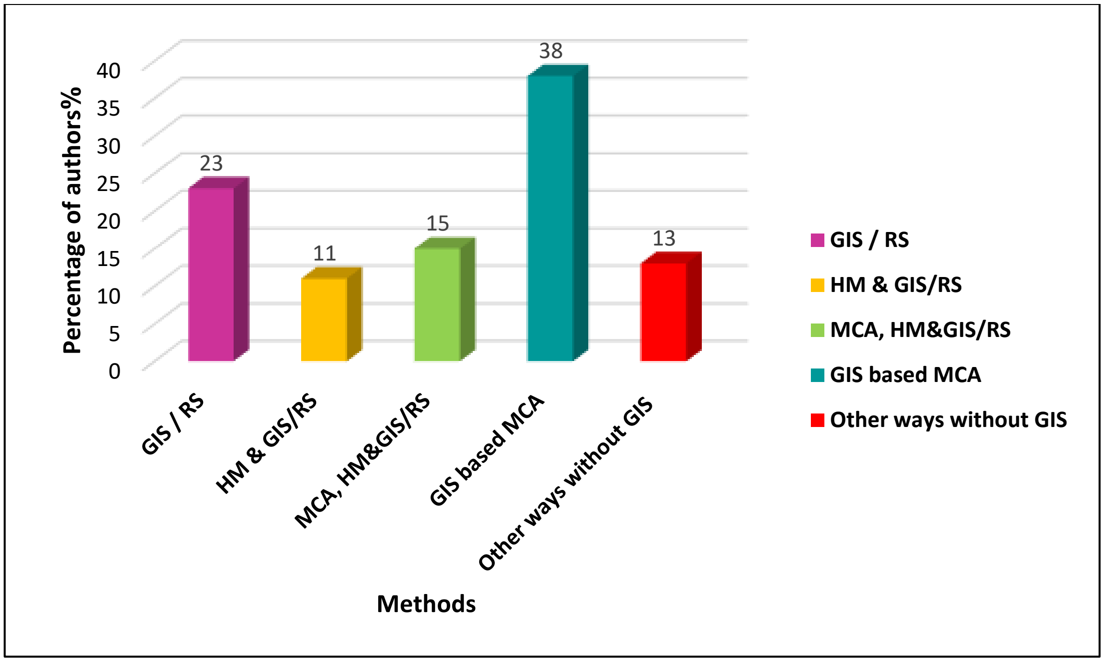

Figure 2.3 Percentage of authors per methods of identifying suitable RWH sites

2.9.1 Geographic information system (GIS) and remote sensing (RS)

There has been significant development in computer technology during the last decades, including services provided by RS and GIS, that provide cost-effective, time-saving methods for identifying suitable RWH locations. RS may be used to extract precise, high-spatial and temporal resolution information. For instance, the land cover details as well as the CN values required to estimate the runoff can be easily extracted using a GIS environment. This is an extremely useful tool, particularly in areas where there is very few available information which is always the case in developing countries. GIS is an instrument for the collection, storage and analysis of spatial and non-spatial data. The applications of spatial analyses with GIS software will produce several thematic layers. Instead, these layers can be combined to classify suitable RWH sites (Adham et al, 2016).

GIS and RS was used by 23% of authors such as (Oweis et al., 1998; Prinz et al., 1998; Mati et al., 2006; Ziadat et al., 2006; Forzieri et al., 2008; Ben Mechlia et al., 2009; Al-Daghastani, 2010; Kamel and Ahmed, 2010; Al-Shamiri and Ziadat, 2012; Salih et al., 2012; Ziadat et al., 2012; Bamne et al., 2014, Sayl et al., 2016; Bakir and Xingnan, 2008; Mbilinyi, et al., 2005).

According to (Mati et al., 2006), the UN Environment Program conducted a study to assess if RWH technologies can be mapped using RS and GIS at continental and country scales. The project produced a total of seventy-three thematic maps, twenty-nine related to rainwater harvesting potential in Africa and forty-four for case studies covering Botswana, Zimbabwe, Zambia, Uganda, Tanzania, Rwanda, Mozambique, Kenya, Malawi and Ethiopia. GIS databases can be obtained from different ways, digital GIS data has been collected from labs, while none-spatial data has been collected from libraries, local and international organizations, individuals and internet. GPS (Global Positioning System) and satellite remote sensing, in addition to data collected from cartographic surveys.

The suitability for various Jordanian rainwater harvesting interventions was determined by GIS method (Zaidat, 2012). The author combined biophysical criteria such as slope, vegetation cover, soil texture and soil depth with socio-economic aspects such as landowners and made some changes to the criteria. Two scores described as the “best” and “second best” choices for each parameter, resulting in more flexibility in assessing an intervention’ s suitability. Data needed for biophysical criteria were derived from separate sources, contour line extract from topographic maps and slope map was extracted from the DEM resolution of 20 m. The ArcGIS is then used to derive slope data, and the grid was translated into polygons to be used in analysis as land mapping units. A field survey was carried out to provide additional data concerning biophysical criteria such as soil texture/depth and surface cover.

2.9.2 Hydrological modeling (HM) with GIS/RS

The best position of RWH system were in areas with the greatest runoff potential and close to drainage system lines. Number of studies used the Soil Conservation Service SCS and CN process, focusing on how much surface runoff a runoff area could produce e.g. (Senay and Verdin, 2004; Gupta et al., 1997; De Winnaar et al., 2007).

A variety of Hydrological models integrate the storm runoff estimation system including KINEROS (Woolhiser et al., 1990), SWAT (Arnold et al., 1996), WMS (HEC-1, HEC-HMS, HEC 2001), and TOPMODEL (Warrach, et al., 2002).

Incorporating these models with modern techniques such as RS and GIS will improve precision and accuracy of runoff prediction, making the detection of possible rainwater harvesting systems more time-efficient and cost-effective (Adham et al., 2016).

Hydrological modeling (HM) with GIS/RS was used by 11% of authors such as (Gupta et al., 1997; Durbude and Venkatesh, 2004; Senay and Verdin, 2004; De Winnaar et al., 2007; Ramakrishnan et al., 2009; Kadam et al., 2012; Ahmad, 2013).

For example, the SCS-CN method was linked with GIS by De Winnaar et al. (2007) to investigate possible runoff harvesting sites in South Africa at a small sub-catchment. They provided information on the spatially clear approach and maps of suitability for RWH sites were presented. GIS has been used as a method for processing, analyzing and handling spatial data. Information of inputs including socio-economic and biophysical data were collected using field survey and available data. In ArcGIS 8.2, a twenty-meter resolution Digital Elevation Model (DEM) has been used to obtain digital images, slope and aerial photographs were also used, and soil surveys were conducted to validate the soil data. A map layers utilized conduct the analysis of suitability included CN map, slope and socio-economic criteria such as distance from crop area and distance from settlement. For each map, the most appropriate scale had been ranked depending on the criteria of each dataset. The final stage was to combine various factors to select the most suitable RWH sites. Results showed that 17 percent of the watershed has high potential to produce surface runoff, while an examination of all factors affecting the position of such system indicates that 18 percent is highly appropriate for RWH.

2.9.3 Integrated multi criteria analysis (MCA) with hydrological model (HM) and GIS/RS

Multi-criteria Analysis (MCA) is a frequently used approach of analysis which integrates the data for the different criteria. Analytical Hierarchy process (AHP) is among the widely used MCA tools for identifying potential RWH locations (e.g. Krois and Schulte, 2014; Munyao, 2010 and Sekar and Randhir, 2007). One of MCA's key principles is to assign a relative importance for each parameter instead of assuming the same importance for all criteria (Banai-Kashani, 1989), then making comparison between two alternatives or more.

Based on the finding of previous studies, MCA could be considered an important method for evaluating problems involving numerous and varied parameters. AHP offers a high degree of versatility in addressing both quantitative and qualitative variables. And more realism is given using MCA instead of assuming the same wight with all criteria, due to the calculation of relative weight to each criterion. It has been discovered that integrated HM with MCA (AHP) and GIS and leveraging the strengths of each instrument is a useful technique not only to locate RWH places but to also estimate the amount of rainwater harvested. So, this integrated approach can be implemented efficiently with minimal details provided to various size areas.

Integrated Multi Criteria Analysis (MCA) with Hydrological Model (HM) and GIS/RS was used by 15% of authors such as (Banai-Kashani, 1989; Jabr and El-Awar, 2005; Sekar and Randhir, 2007; Ramakrishnan et al., 2008; Munyao J., 2010; Weerasinghe et al., 2011; Elewa et al., 2012; Khan and Khattak, 2012; Hameed, H., 2013; Krois and Schulte, 2014).

For example, by combining MCA, GIS and SCS model, Krios and Schulte (2014) proposed a framework for finding suitable location for RWH in the Ronquillo, Peru watershed. The site evaluation process consists of multiple phases: 1) input data and conversion to vector or grid maps, every reflecting a different RWH technique criterion, 2) implemented GIS procedure to construct criteria maps for each RWH technique by reclassifying the spatial maps according to the correct level, 3) adapted pair-wise matrix comparison procedure, recognized as the Analytic Hierarchy (AHP) process to measure the relative weight of each criterion for each RWH technique. Selection criteria is based on guidelines from the FAO which are: slope, rainfall, land use, coefficient of runoff, depth of soil and soil texture. The assessment of predominance of one criterion over the other is based on the literature survey and knowledge of authors. 4) Finally, in GIS the weighted overlay method is followed to evaluate the maps of suitability for each RWH technique. The study showed that Ronquillo watershed is generally better suited for RWH implementation and it suggested that 44 percent of the catchment is best suited for terracing and 24 percent is highly suitable for bundling systems.

2.9.4 Integrated multi-criteria analysis (MCA) and GIS

In general, the application of GIS to combine sets of criteria for selecting appropriate RWH sites has been based on the use of decision rules (Malczewski, 2004). In this approach, there are two common technique methods: first, trying to apply MCA in a GIS platform; and second, trying to apply GIS first, after which weights and total score for criteria are described via the AHP approach.

Integrated Multi-Criteria Analysis (MCA) and GIS was used by 38% of authors such as (Padmavathy et al., 1993;Yusof et al., 2000; Mbilinyi et al., 2007; Ould Cherif Ahmed at al., 2007; Al-adamat, 2008; De Pauw et al., 2008; Kahinda et al., 2008; Kumar et al., 2008; Al-Adamat et al., 2010; Jothiprakash and Sathe, 2009; Kahinda et al., 2009; Moges G., 2009; Tsiko and Haile, 2011; Al-Adamat et al., 2012; Isioye et al., 2012; Mahmoud H., 2014; Mahmoud and Alazba, 2014; Nasrolla et al., 2014; Tumbo et al., 2014; Adham et al., 2016; Adham et al., 2018; Grum et al., 2016; Othman A.A et al., 2020; Shadeed S; 2020; Ibrahim, G.R. et al, 2019).

Testing and validation of earlier studies (Al-Adamat et al., 2010; Kahinda et al., 2008; Kumar et al., 2008) demonstrated that GIS approach to MCA runs effectively which can be used accurately to anticipate potential sites of RWH in arid and semi-arid region (ASAR) areas with insufficient information, such as runoff data. In addition, the combination of Boolean and WLC approaches offers yet another chance to minimize unsuitable zone.

Also, many studies integrating AHP with GIS to classify possible sites of RWH in ASAR areas such as Mahmoud and Alazba, 2014; Tsiko and Haile, 2011; and De Pauw et al., 2008. These studies' validation results confirmed AHP's effective, flexible, reliable, cost-effective, and time-efficient method in combined GIS for analyzing and determining suitable site of RWH in ASAR. In addition, because of its validity in multi-criteria decisions, the AHP method has been selected, using both qualitative and quantitative data and the accessibility of extensive literature discussion of the method (Ould Cherif A. et al., 2007).

2.9.5 Other methods without GIS

Some of the previous studies (e.g., Al Ali Y., 2008; Previati M. et al., 2010; Adham et al., 2016; Glendenning C.G. and Vervoort, 2010-2011; Ventura et. al., 2003; Ventura et. al., 2005; Patrick C. et al., 2007; Botha J.J et al., 2015) did not use GIS and RS, but rather use field models to measure surface runoff or use some types of RWH structures at the downstream of wadis to reserve water, most of which for agricultural purposes.

Other ways without GIS was used by 13% of authors. For example, Adham et al. (2016) presented a study on the establishment of a water harvested model (WHCatch model, Excel MicroVisual Basic) and check it to evaluate and improve RWH's performance under various management and design scenarios in 25 sub catchments of the Wadi Oum Zessar watershed (southeast Tunisia). It found that the results of water harvesting model to be of practical significance since lower user defined models are advocated in data-scarce regions since they require little input data. But in order to verify its applicability the model needs to be calibrated and checked in different regions and with different RWH techniques.

2.10 Area Volume Elevation curve (AVE)

The Area Volume Elevation curve (AVE) can be used as a metric to characterize the surface area and storage capacity of the reservoir at the given elevation of water. Capacity for storage reflects the volume of water that could be contained in a reservoir. A reservoir's AVE curve plays an essential role in determining the reservoir's most appropriate depth, maximum capacity and optimal surface area. Traditional method of determining the AVE curve is expensive, time-consuming, and demand complex tasks. Thus, the GIS could be to evaluate storage and accurately gauge changes in reservoir volume at a lower cost, effort and time. The literature includes numerous past studies on the storage ability of rainwater harvesting systems using GIS such as (Sayl et al., 2017; Zhang et al., 2014; Sattari et al., 2008; Sawunyama et al., 2006; Gupta et al., 1997; Sayl et al., 2016).

Water volume could be performed by using the digital elevation model (DEM) of water reservoir bottom, where water depth map computation means removing the bottom elevation of the reservoir from the elevation of the water level (İrvem, A, 2011). This concept has also been used to evaluate AVE curve, where a script was used in ArcGIS to perform this analysis to provide a simpler and more precise way to evaluate the TIFF DEM. The pervasive use of GIS-dependent digital elevation model maps would also have accelerated environmental and hydrological research (Moore et al., 1991). Storage capacity has been computed using spatial analyst through use of GIS for various dam heights.

2.11 Application Artificial Neural Networks (ANNs) in water resources

ANNs processing simulating human brain conduct to build a type of the system of artificial intelligence. Artificial Neural Networks (ANNs) were used in a wide range of applications in the recent years, including predicting the problems with water resources (Alkaseeh, 2013). Though 1943 pioneered the idea of artificial neurons, such applications are designed since 1986 when back propagation training algorithms of feeding forwarding ANNs was implemented. ANNs can thus be regarded as a fairly new predictive and forecasting tool (Gaur et al., 2013; Maier and Dandy, 2000; Palani et al., 2008).

The neural network could be described as human-brain based model of reasoning. The brain is composed of a tightly interconnected group of nerve cells, named neurons, or simple information processing units.

In ANNs, the data available are used to establish empirical relationships such as (input-output) or (cause-effect) that describe the physical cycle, and these relationships are adapted to specific input data for estimating performance (Alagha, 2013; Sahoo et al., 2006). In addition, the ANNs approach is an appropriate method when there is a large and complex surveillance database. ANN’s capacity to solve complex issues and effective computer system methods for nonlinear and highly complex systems is the product of its ability to simulate human brain activity (Iliadis and Maris, 2007; Rajanayake et al., 2002). ANN relates to the time series black box models and provides fairly versatile and rapid modeling methods.

Owning to its ability to simulate both nonlinear and linear systems without making any assumptions as implied in many traditional statistical techniques, ANN models were more used in different aspects of engineering and science (Rajurkar et al., 2004). ANNs have been used before successfully for rainfall-runoff process, river flow forecasting, water quality estimation criteriaand soil pollution characterization.

There are multiple model forms available for implementation with ANN. Radial-based neural networks (RBNNs) seem to be multipurpose networks that can be used for a range of problems including prediction, classification of systems and modeling. The RBNN models show major benefits over other neural network types with its two-stage training process. The first stage of network training is a clustering process, in which hidden node center positions are determined. Just after clustering process, a nearest-neighbor technique is used to set the radii of the Gaussian functions in the cluster centers. A given Gaussian function's radius is set at the mean rate to both the two nearest cluster centers. Park and Sandberg (1993) showed that the universal approximation of an RBNN model by one hidden layer can be achieved. Even so, it is still uncommon to apply RBNNs to hydrological problems, although it is gaining more attention lately owing to its excellent over feed-forward network. Fernando and Jayawardena (1998) recorded the RBNN performing better than feed-forward network equipped with a back - propagation algorithm. Some studies were conducted using RBNNs to model and predict hydrological processes and to predict sediment transportation (e.g. Agarwal et al., 2006; Firat and Gungor, 2005). RBNN consists of three layers, i.e. an input layer for feeding network feature vectors; a hidden layer where the basis function results measurement is stored and a linear output layer for integrating the basic functions. Figure 2.4 shows structure of the Radial Basis Neural Network (El-Shafie et al., 2008).

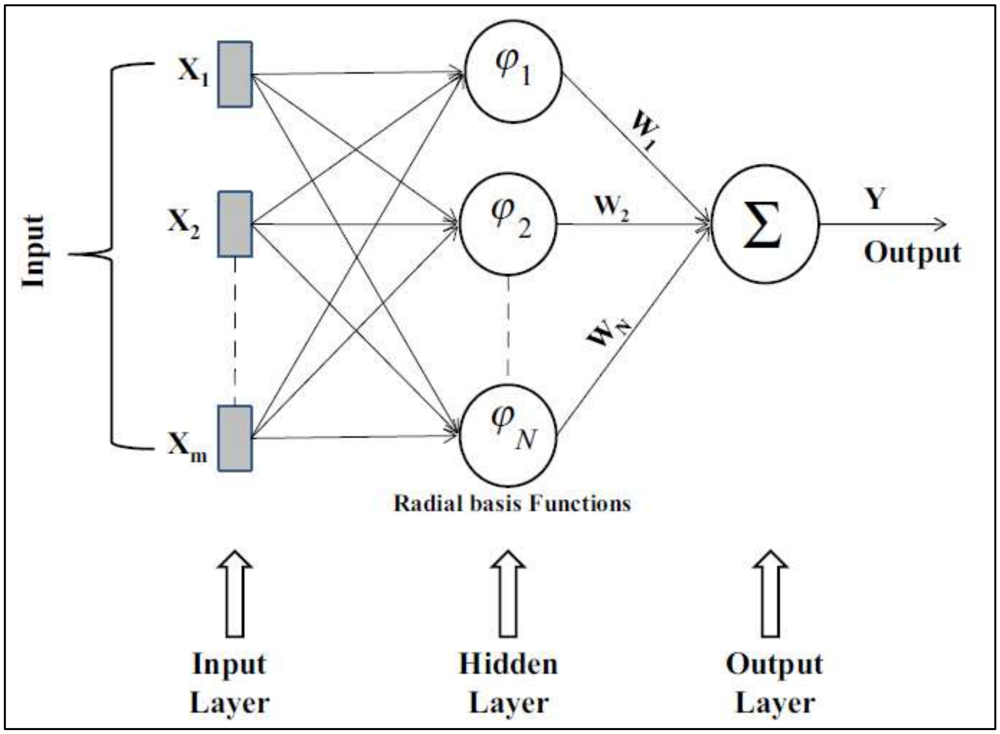

Figure 2.4 Structure of the Radial Basis Neural Network.

Source: El-Shafie et al. (2008)

2.12 Summary

This chapter highlighted the importance of RWH in areas suffering from scarce water and high variability of rainfall such as western desert of Iraq. It discussed the importance of modern technologies such as GIS and RS techniques in addressing the problem of water scarcity by employing these technologies to effectively improve water resources management. The literature review showed that various methods have been used by different researchers to detect suitable sites for RWH. The previous studies on the same topic have left many gaps in the methodologies of selecting suitable sites for RWH in arid regions.

The first gap is that most of them emphasized the importance of soil texture in choosing RWH sites, but at the same time they used soil maps extracted using conventional soil sampling and laboratory analysis. These methods are generally time-consuming, costly, and limited in their ability to retrieve temporal and spatial variability, especially in large-scale areas.

The second gap is that the previous researchers used GIS and RS to determine suitable areas for RWH. The nature of study area needs to erect a simple system such as earthwork throughout the seasonal drainage network characterized by reduction in the cross section of the wadi.

The third gap is that the previous researchers did not use the capability of GIS for runoff estimation in the ungagged watershed.

Finally, the previous researchers did not touch on the importance of the AVE curve, despite being one of the important criteria for selecting dams' locations especially in arid and semi-arid areas.

This study aims to consider all these gaps using remote sensing data integrated with GIS tools.

CHAPTER THREE

METHODOLOGY

CHAPTER THREE

METHODOLOGY

3.1 Overview

This chapter is dedicated to describe the geological, topographical, and hydrological aspects of the study area. Also, in this chapter different data and criteria have been selected in which can be utilized in open source Geographic Information Systems. These data and products discussed in this chapter are utilized as the base data source for the tools and models to develop methods and methodology for detecting of suitable sites for RWH planning.

3.2 Description of Study Area

3.2.1 Location of Study Area

The main study has been implemented in Al-Anbar province, near Haditha city, in the west part of Euphrates river between 33º 50' 0'' to 34º 20' 0'' N and 41º 40' 0'' to 42º 20' 0'' E and has an area 1953.1 km^2 Figure 3.1. It is surrounded from the north by the city of Ana, from the southwest by the Horan valley, and from the west by the Euphrates river. Several valleys are included in the study area: Al-Fahami, Hijlan and Zgadan and with an area 1020, 447.8, and 485.3 km^2, respectively.

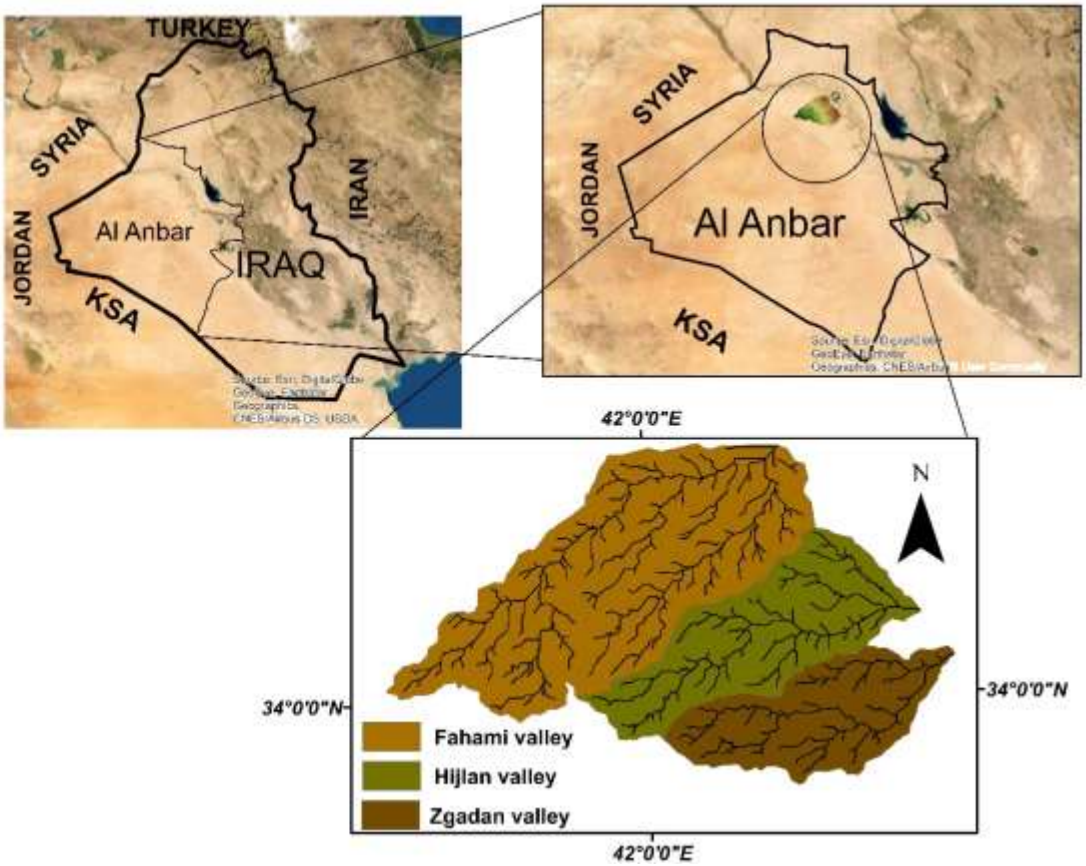

Figure 3.1 Study area location

3.2.2 Geology of study area

Much of Western Desert from the Oligocene has been a region of denudation. Sedimentation happens mostly in sand sheets of valleys and depressions. When water is found available, its soil seems to be immature, very fertile, clayey and calcareous. Geological activity in the Western Desert began in the early 30s of the last century when "Bedwins" recorded gold viewings in the Ga'ara region. The British Site Excavation company began advanced geological work in the Western Desert in the forties of the last century. Just short and dispersed recognition work, such as radiometric vehicle-born traverses, has been carried out. Latest seismic surveys and the oil companies' exploratory deep exploration have shown a very promising potential of gas and oil in that area, which will hopefully push further geological work and a deeper understanding of the Western Desert's underground geology (Burhan S. Izzat, 2007).

The study area lies in the stable shelf that associated with low sediment thickness within the transversal fault system as shown in Figure 3.2. Sedimentary rocks have appeared in several geological formations in the study region, from Alallegosan to Albulastiuosn (Al-Alusy, 2011). The study area falls in the formation of Euphrates and returns such formation to the lower Almallosan age that is situated on the right side of the river as its components strong Limestone, Flint and Tafel stone. Overall, the rock formations situated in the study area which rocks calcareous dolomteh (Al-Sabhani.H. N, 2011).

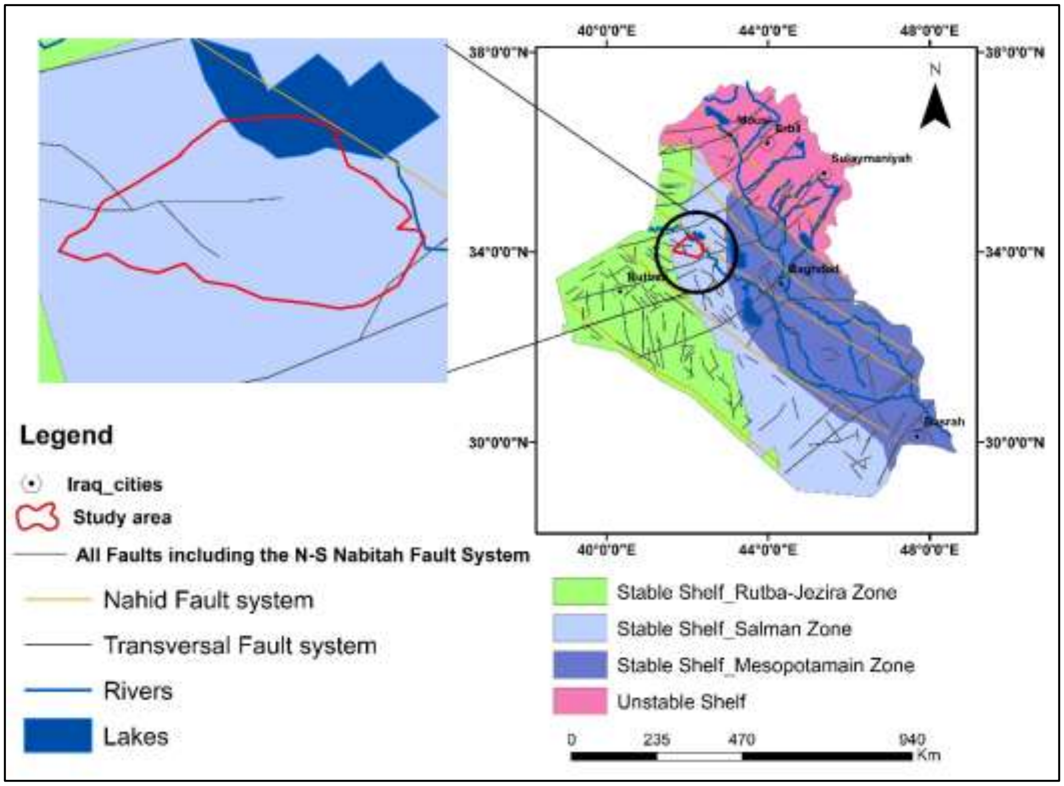

Figure 3.2 Geological map of Study area

3.2.3 Topography

The western desert 's main landscape is plateaus which are dissected by high - density valleys. Some other topographical characteristic is the isolated hills, ranging in height from several meters to even more than 50 m, becoming unique in the flat nature of a region and noticeable from some few tens of kilometers away such as Jabal Anaza, Damloug, Garat Al-Shutub, Tlailat Al-Zurug. One other feature is some depressions, that are either formed by erosion or solution. They come in various shapes and sizes, mostly square, oval and longitudinal. Others are extraordinarily wide and cross some tens of kilometers square like Habbariya, Ga'ara. Deep depressions, such as the Salman Roza sinkhole near Haditha and Um Chaimin, southwest of Rutbah, are also common.

The Western Desert topographic gradient rises by an average of 5 m / km from east to west, with the maximum and minimum points in the region being 987 and 77 m above sea level, respectively, as shown in Figure 3.3.

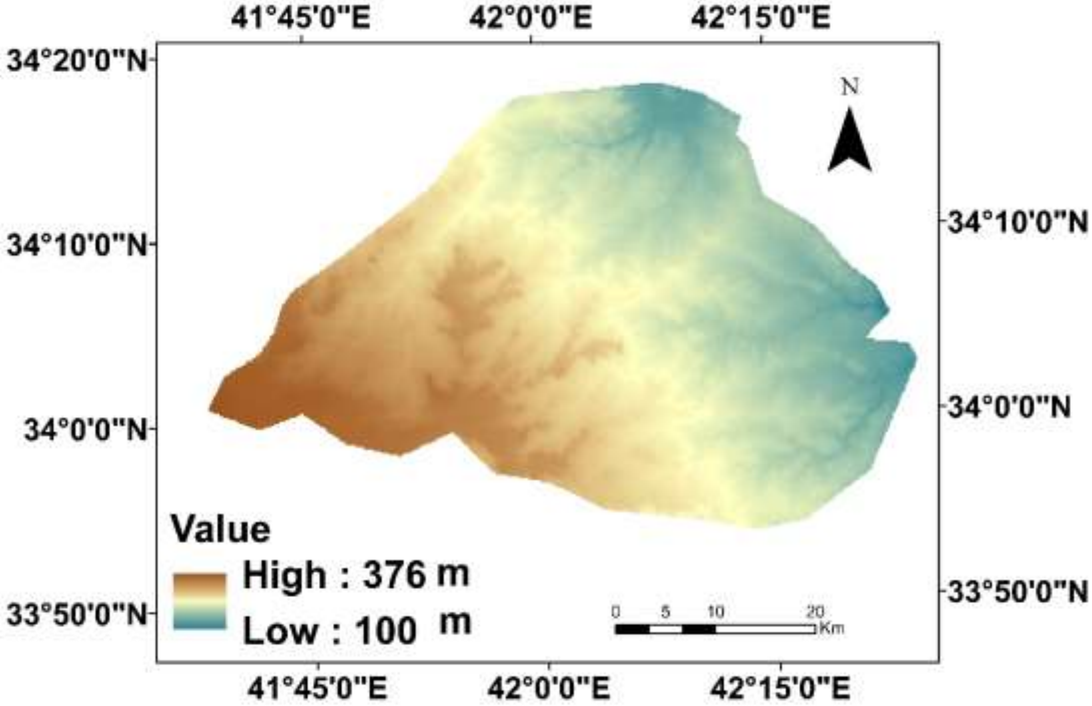

Figure 3.3 DEM of study area

3.2.4 Geomorphology

The Iraqi Western Desert is an easterly and northeasterly sloping plain with a gradient of 5 m / km. The strata dip is nearly horizontal, approaching degrees (1-2).

In west region, the beds dip over all directions around Ga'ara Depression, although the beds dip gently northeastward in the eastern and middle parts. The gentle plain represents the western desert's structural role within the Stable Shelf (Buday and Jassim, 1984).

Rutbah Uplift has played a major role in the Western Desert's historical geomorphology. Based on the current Buday (1980) and Buday and Jassim (1987), during Late Cretaceous the uplift's crest had remained a dry field. Ever since, the steady increase of the elevation has caused the dry land to rise over the entire Western Desert in the form of broad plateaus. At same time, they dissected the plateaus into several parts. Faults, joints, folds, grabens and ring structures are the typical structural features in the west desert.

Most of the study area is flat nature, with the exception of areas which intersect with the major valley and theirs branches which reach heights of more than 30 meter and its considered one of the most essential geomorphology characteristics of the study area representing a most influential water erosion output. In the study area there are many valleys drainage streams accessible and take various paths based on the surface slope, as well as the drainage dendritic pattern and some components are parallel. Such valleys are deep, steep edges, particularly when flowing at the river Euphrates, such edges range from (25-35) m. Plateaus appear in various locations in the study area and usually consist of calcareous rocks and rocks of sand and clay. Having an of elevation is from (10-35) m (Auda, 1986). In the study area, there is a great connection between the slope with the drainage density, the terrain is slowly sloping from the west and southwest towards the north-east and south-east towards the river Euphrates.

3.2.5 Hydrological Features

Many researchers describe the western Iraqi desert climate as arid to semi-arid (Mohammed, 1989; Abdulla, 2002). Iraqi’s western desert climate is hot and dry in summer and moderately cold during humid winter. In winter and spring (October-May), all precipitation occurs (Mohammed, 1989).

3.2.5.1 Rainfall

A large variation in rainfall recorded year after year is a significant characteristics of a rainfall patterns in the study area, which is normally general for all arid areas. Despite the limited and variability of rainfall, heavy rain also occurs in the network drainage of the desert resulting in flash flooding. The rainy season, as shown in Figure 3.4, usually occurs in winter and spring, while dry season occurs in summer. In the study area, the annual average rainfall reaches to 115 mm, with about 50 % occurring in winter, in spring 35% and in autumn 15%. The minimal rainfall is noted very rarely during the warmest parts of the year which are (June, July, August and September).

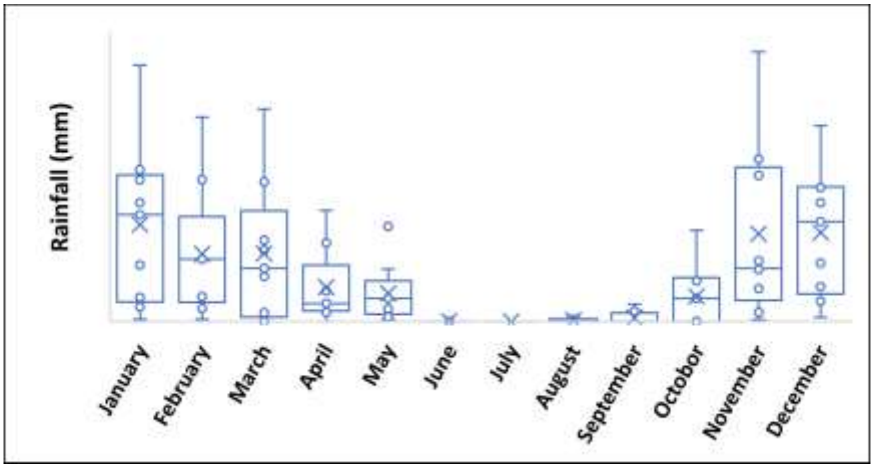

Figure 3.4 Average monthly rainfall for study area at Haditha station

3.2.5.2 Temperature

The study area temperature fits the characteristics of a of a continental hot desert, and is distinguished by substantial year-round variations (Consortium-Yugoslavia, 1977). Annual average temperature significantly varies year after year, in which these averages reflect the area’s general temperature state. The highest monthly mean temperature record in July 35° C, whereas the minimal average temperature record in December 7° C as shown in Figure 3.5. Because of increased radiation, the barren earth surface gets densely heated throughout the day and cools during night.

This procedure contributes to the splitting of the surface of the earth into fragments and blocks.

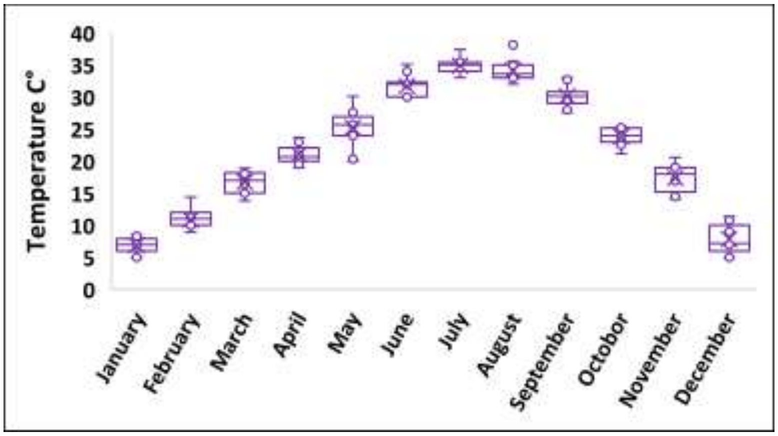

Figure 3.5 Average monthly temperature for study area at Haditha station

3.2.5.3 Wind speed

The wind is among the most excellently known and significant factors of erosion. Throughout the year, air mass circulation is intense in the region, the winds mainly below from west, northwest and north. Particularly remarkable is the comparatively small number of still days, that suggests many continuous air circulations per year. Based on Haditha station data, average wind speed for one year is 3.2 m/sec at which highest monthly mean was 5.5 m/sec in July and the lowest monthly mean 2.2 m/sec in November. Figure 3.6 shows the average monthly wind speed for study area.

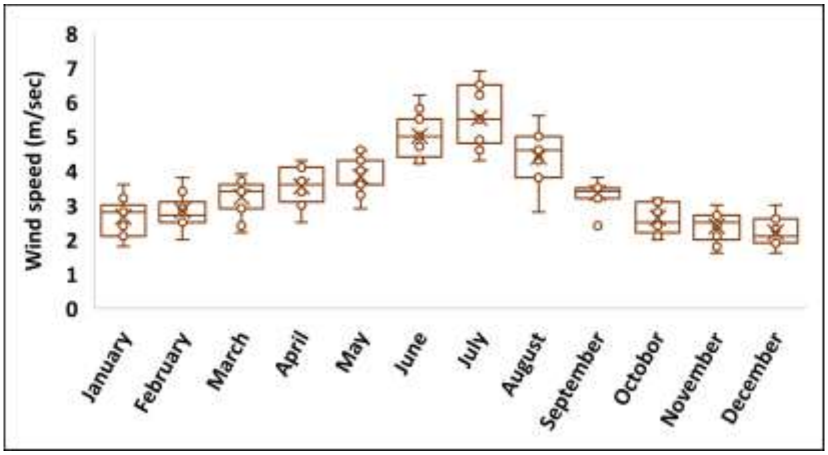

Figure 3.6 Average monthly wind speed for study area at Haditha station

3.2.5.4 Evaporation

Evaporation is an important part of the hydrologist cycle. The rise in temperature may raise the evaporation rate, however such rise is also influenced by wind speed, humidity, net radiation and availability of water (Thompson and perry, 1997). Extreme temperatures and dry conditions result in a high possible rate of evaporation, around 3000 mm per annum. Monthly average evaporations fluctuate month after month. It is clear that such evaporation from April to October reached 75 percent of total annual evaporation, as seen in Figure 3.7, as per the monthly average evaporation values. Maximum monthly average evaporation record in July 480 mm and minimum in December 50 mm.

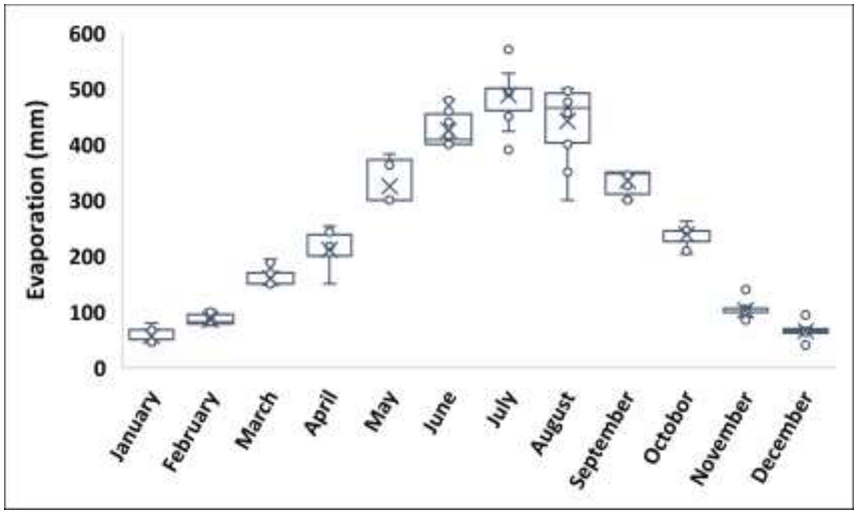

Figure 3.7 Average monthly evaporation for study area at Haditha station

3.2.5.5 Relative humidity

Relative humidity is the ratio of the volume of water vapor currently in the air to the highest volume of water vapor at a given pressure and temperature necessary for saturation. It is also the relation between the water vapor content of the air and its capability (Ahrens 2007). Looking at the average monthly data, humidity decreases relatively in the months when the temperature increases. Each year's humid cycle begins in November and remains with monthly adjustments until the end of May.

Humidity reached the highest value in December (71 percent), where it reports the lowest mean value in July (27 percent), as seen in Figure 3.8.

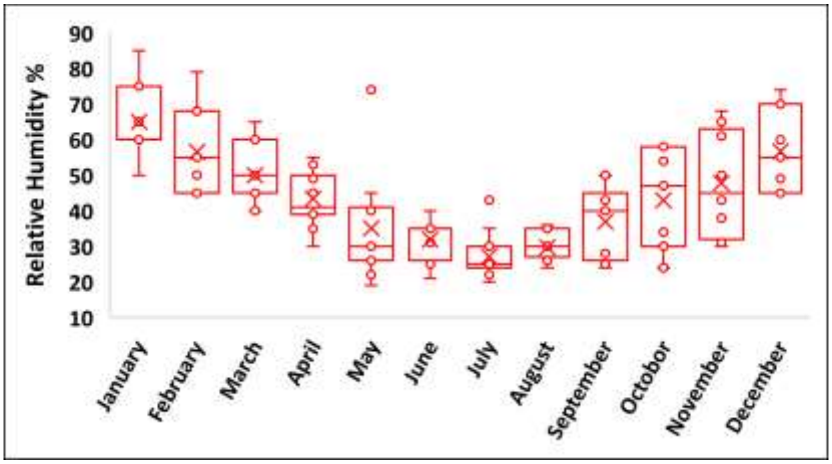

Figure 3.8 Average monthly relative humidity for study area at Haditha station

3.3 Data Collection

The availability of geospatial data and the distinctness of GIS have established the data resources to manage and plan accurately the RWH projects. In the present research, different data were used to deduce the various criteria included in analyses of the suitability of sites such as Landsat 8 image, ASTER DEM, tectonic map. Long-term and reliable daily and monthly precipitation data of 30 years at Haditha station, i.e., from 1989 to 2019, are also used in this study. Extensive soil samples were collected throughout the study area and the soil characteristics were determined using laboratory tests. A detailed description and the main sources of data used in this study are presented in Table 3.1.

Table 3.1 Sources and types of data in present study

Source	**Data**	**Data formatting**	**Derived layer**	**Type**
USGS[1]	Landsat 8 image of June 2019 Landsat 8 image of April 2019	TIFF	Land use/cover Distance from residential areas Distance from roads Distance from irrigated lands	Raster Vector Vector Raster
NASA[2]	ASTER DEM	TIFF	Slope Stream order	Raster Raster
M.S.[3]	Rainfall data	TIFF	Runoff	Vector
G.D.[4]	Tectonic map	Softcopy	Distance from faults	Vector

[1]. **USGS** (United States Geological Survey). Landsat 8 image of June 2019 downloaded from https://earthexplorer.usgs.gov/

[2]. **NASA (**National Aeronautics and space Administration) [US]. ASTER DEM downloaded from https://search.earthdata.nasa.gov/search

[3]. Meteorological station data http://www.meteoseism.gov.iq/

[4]. College of Science Anbar University- Geology Department

According to UTM-WGS84 Zone 37 N projection, the coordinate systems of all the data used were unified. All criteria were extracted through ArcGIS 10.7 package.

3.4 Methodology

The procedure of site selection for RWH projects is a complicated method due to different constraints and criteria that effect straight the decision support system regarding site selection. Thus, the current study proposed a robust technique to facilitate this method that includes two phases: (1) Combines the Weighted Linear

Combination (WLC) and Boolean operators to determine suitable sites according to favorites with respect to evaluation criteria. (2) The proposed sites were compared based on AVE curve, which developed via the integration of DEM generated from ASTER with GIS, to analyze and avoid excessive evaporation losses. The proposed methodology is synopsized in Figure 3.9.

The study area characterized that the financial resources are low and a skilled labor force is unavailable with limited infrastructure. Therefore, the erection of a simple system such as earthwork and stonework should be considered (Critchly et al., 1991). In this context, the potential sites for RWH are limited throughout the seasonal drainage network characterized by reduction in the cross section of the wadi. To retain excellent storage property, the optimum height of the dam must be determined even before constructing the structure of a rainwater harvesting. Naturally, the reservoir shape impacts the evaporation cycle, where a wide shallow reservoir has more evaporation losses than a deep narrow reservoir (Stephens, 2010). The height of the dam has a direct impact on both the surface area as well as the capacity of the reservoir (Sawunyama et al., 2006). Getting such a relationship is critical for practicalities in order to make sure sustainable water extraction levels or assess a sedimentation rate (Haghiabi et al., 2013).

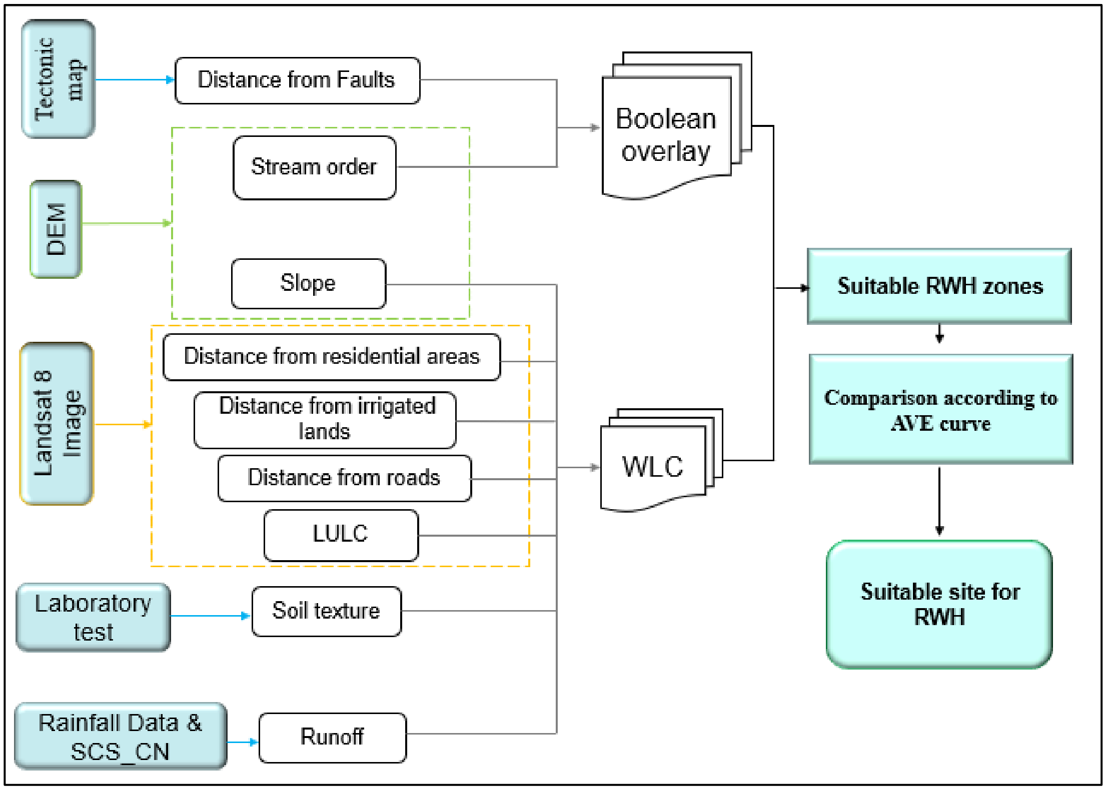

Figure 3.9 Methodology of study

3.4.1 Weighted linear combination criteria

The WLC method integrates the maps by stratifying a normalized score to every category of a specific criterion and give weight to the criteria themselves (Yalcin, 2008) Owing to it is flexibility in choosing the optimal sites, many researchers implemented this method (Baban, S. and Wan-Yusof, K., 2003; Shatnawi, G., 2006; Al-Adamat et al., 2010).

Seven WLC criteria are adopted to recognize the proper location for RWH in the current study. The criteria involve runoff, slope, soil texture, land use (LU), distance from irrigated lands, distance from residential areas and distance from roads.

3.4.1.1 Soil texture

The following approach consists of several steps in the selection, preparation, and modeling of data to achieve the estimated soil texture map. The satellite images of the study area from Landsat 8 in Jun 2019 are prepared (Appendix C). The main idea of the proposed steps shows in Figure 3.10. This steps as following:

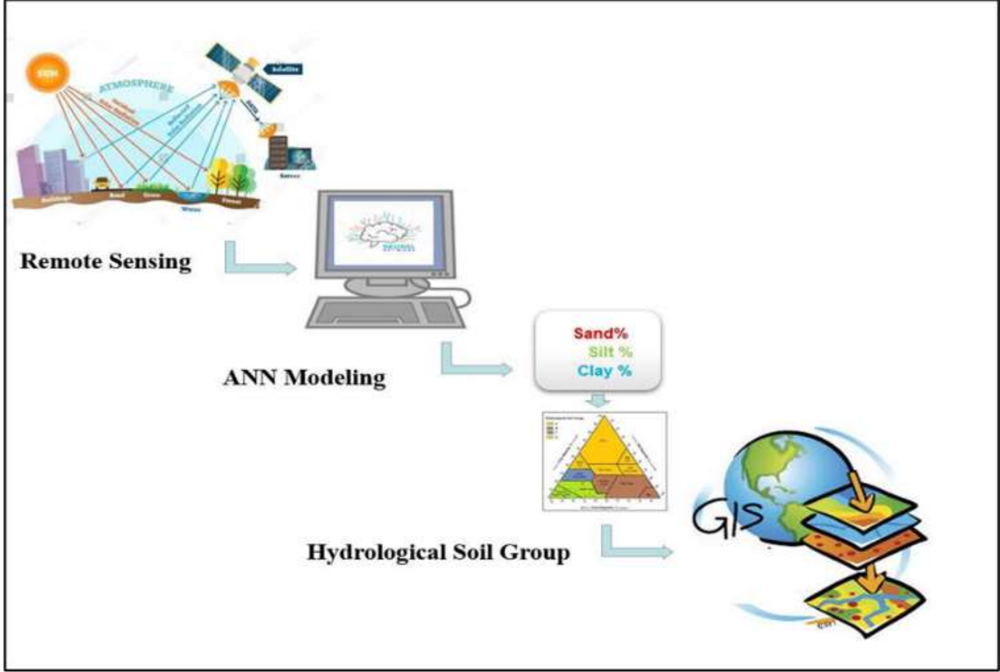

Figure 3.10 The main steps for estimated soil texture map

First step, the unsupervised classification performed after the image was corrected with WGS 84/UTM zone 37 projection. Using the unsupervised classification can be a suitable method for constructing a preliminary map to assemble soil samples. This method would diminish task expenses and time. The selection of the soil sample position is carried out based on certain criteria in order to avoid the errors associated with spectral reflectance and to perform accurate estimation of soil type. Figure 3.11 indicates the selected portion of the study area that carries out the unsupervised classification. In this figure there are nine classes, representing the land cover classes, each class is presumed to be a specific color. That figure shows the number and location of each sample where they were taken in various groups for laboratory research. There are 13 samples in and out of each class. There are 120 samples used with GPS tools to cover the entire study area. For each point, the spectral reflectance for nine bands was calculated using ArcGIS 10.7, and the results of the soil textures laboratory test were used as a database for developing a mathematical model using the RBNN model.

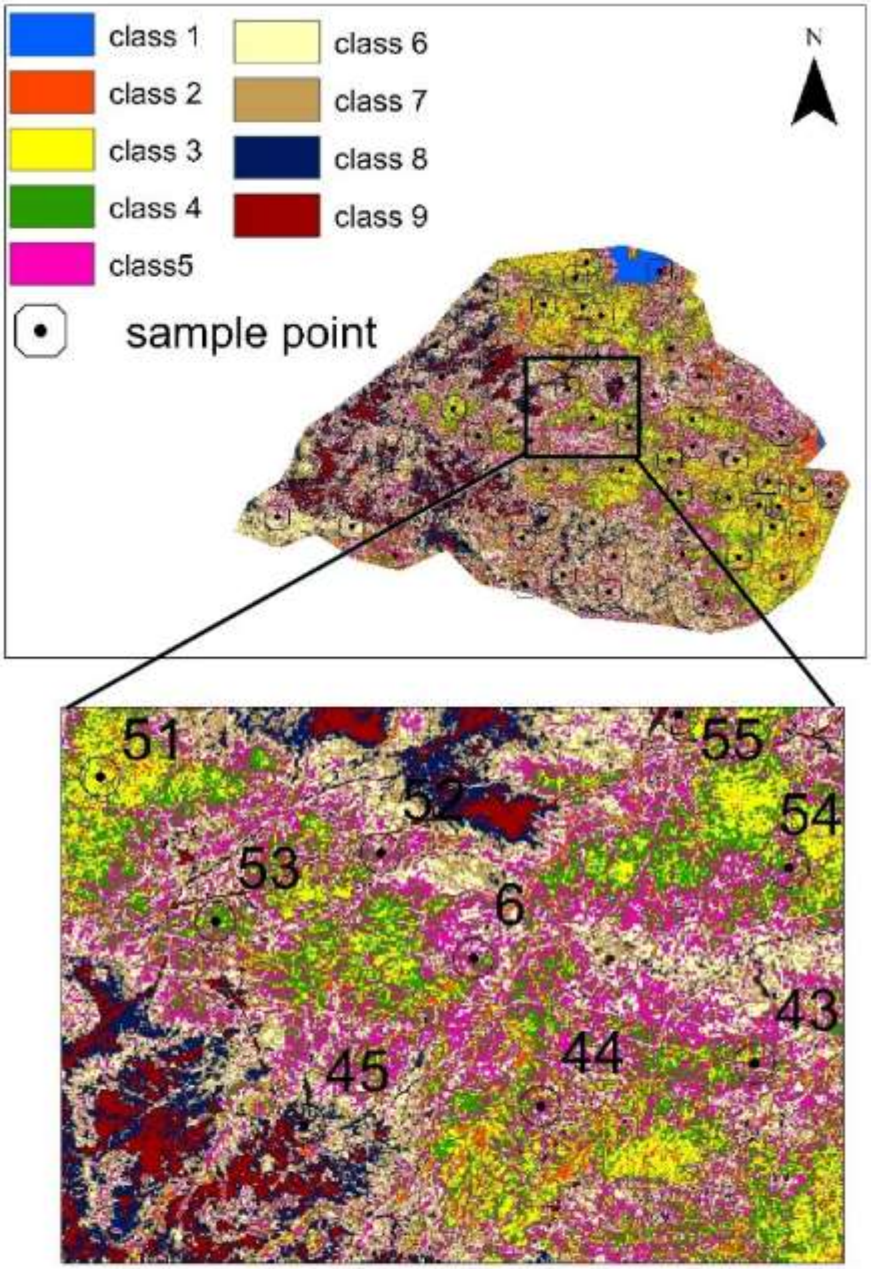

Figure 3.11 Unsupervised classification of the study area with samples location

This categorization was done in order to collect the most important data required to attain the aims of the present research. This involves the process required to categorize pixels into a restricted number of data sets based on the importance of the data collected (Al-Ruzouq, R et al., 2019). Each pixel has been rated in the various wavelength bands by its comparative reflectance. This process was conducted using ArcGIS software to detect and verify the foremost classes of soil texture in the field of study. Nonetheless, unsupervised classification can be used as pre-processing prior to acquire an impression of main classes (Maidment, D. R., 1992). When field data is lacking and the research area is exceptionally large, this approach is preferred. It is also acknowledged, however, that the unsupervised classification can be beneficial in the elaboration of the embryonic map for reconnaissance and soil survey, to identify places for soil samples. The findings of this process offer a good representation of certain classes and classified these classes based on the ranges of the image value, and also for surveying soil with a view to reducing the time and cost consumption.

Second step, sampling locations are selected in this step (120) based on the previous step. Where the places to cover the whole field of study area chosen and where all groups are included in the map. Sample point in this study was located using GPS. Whereas in the topsoil, the samples obtained by auger and depths were 20-40 cm. Subsequently, laboratory testing is used to predict the texture of the soil for each sample using sieve analysis and hydrometer test (Appendix A: A1 and A2).

Sieve analysis steps (Head. K., 2006):

- Determine minimum quantities of soil sample for particle size tests according to Table 3.2.
- Use a 0.05 mm sieve to separate the coarse soil (sand) from the fine soil (silt and clay). This is done by washing the sample where the fine particles pass with the water from the sieve and the sand particles remain only. Thus, the percentage of sand to each sample is calculated.
- Using Hydrometer test to separate the clay from the silt particles.

Table 3.2 Minimum quantities for particle size tests. Information based on BS 1377: part 2: 1990: 9.2.3, Table 3

Maximum size of material present retained on BS sieve (mm)	Minimum mass of sample to be taken for sieving
Pass 2 mm or smaller	100 g
3.35	150 g
5	200 g
6.3	200 g
10	500 g
14	1 kg
20	2 kg
28	6 kg

Hydrometer test steps:

- Take 50 g of the sample passed from 0.05 mm sieve.
- Mix 1-liter distilled water and 35 g sodium hydroxide to make the dispersion solution.
- Add 100 mm of dispersion solution to the soil and leave for 24 hours.
- After 24 hours, the sample is mixed with an electric mixer for a few minutes.
- The sample is emptied of a 1000 mm tube and readings are made with the hydrometer as required.

Third step, using a Landsat 8 satellite image to evaluate each location's spectral reflection, these images are represented by nine bands (Appendix B), using ArcGIS 10.7., while two thermal bands have been reduced.

Fourth step, a sensitivity analysis is performed to define the complicity of the band-to-soil texture relationship as (clay%, silt%, sand%). Using the RBFNN model, the spectral reflection and the percentages of soil textures were used as a database to create a mathematical model. There are three layers in this model that are input layer which is used for the network feeding feature matrix, the hidden layer where the base function result calculation is processed, and the linear output layer for the basic functions combined. The layer of input binds inputs to network. A nonlinear transition from input space to hidden space is implemented by the hidden layer. A linear transition from hidden space to output space is implemented by the output layer.

This model is relying on the process of interpolation of a multivariate function and one of its characteristics is that the number of radial base functions within the hidden layer depends not on the size of the data collection but on the complexity of the data. Thus, as for the finding, the results of the neural network are incorporated into GIS to provide a soil map for the catchment. The results of this model have been evaluated using Root mean square error (RMSE), Normalized root mean square error (NRMSE), Mean absolute error (MAE), Normalized mean absolute error (NMAE), Minimum absolute error, Maximum absolute error, Correlation coefficient (r) (Eq. a-e).

A brief description of the performance indices used to evaluate the performance of this model as below:

i. Root Mean Square Error

Root Mean Square Error (RMSE) measures how many errors exist between the two data sets. In other words, the estimated value is compared with the observed value. RMSE can be expressed as Equation a :

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (y_i - \hat{y_i}}\,)^2 \qquad \text{(a)}$$

Where n is the number of samples, y_i are the measured values, $\hat{y}$ is the estimated values.

ii. Mean Absolute Error

The Mean Absolute Error (MAE) of the developed model is related to the average value of the absolute value of each prediction error for all test data set. MAE values were calculated using Equation (b)

$$MAE = \frac{1}{n}\sum_{i=1}^{n}|y_i - \widehat{y_i}| \qquad (b)$$

Where n is the number of samples, y_i are the measured values, $\hat{y}$ is the estimated values.

iii. Mean Absolute Percentage Error

The Mean Absolute Percentage Error (MAPE) is the average absolute percentage error of prediction values. MAPE is expressed in Equation (c).

$$MABE = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{|y_i - \hat{y}_i|}{yi}\right) \qquad \text{(c)}$$

Where n is the number of samples, yi is the measured values, $\hat{y}_i$ is the estimated values.

iv. Nash-Sutcliffe efficiency

The efficiency of the Nash-Sutcliffe (NSE) efficiency (also called model efficiency) (ME) model is used to estimate the strength of the predicted hydrological model[M12]. Defined as Equation (d):

$$NSE = 1 - \frac{\sum_{i=1}^{n}(\hat{y}_i - y_i)^2}{\sum_{i=1}^{n}(\bar{y}_i - y_i)^2} \qquad (d)$$

Where n is the number of samples, $\mathrm{y_i}$ are the measured values, $\hat{y}$ is the estimated values and $\bar{y}_i$ is the mean of measured values.

v. Relative Error

Relative Error (ER) has been used to checking the accuracy of the prediction model during the testing period. RE is defined as Equation (e) :

$$RE = \frac{y-\hat{y}}{\hat{y}} \text{ x } 100\% \qquad \text{(e)}$$

Where y_i are the measured values, $\hat{y}$ is the estimated values and $\bar{y}_i$ is the mean of measured values.

Final step, inside ArcGIS 10.7, the results of the model were modified with the spatial analyst model as a tool for producing a digital map for the study are of the hydrological soil group.

3.4.1.2 Land use (LU)

Land use defines the purpose of the land, the land cover contains the natural aspect. The form of land use land cover provides significant information for runoff distribution. LULC such as bare ground and built up support development of high runoff against soil infiltration (Fagbohun B. J, 2018). Vegetation cover is associated with higher absorption and infiltration rates, and therefore lower runoff. Land use/cover is derived from satellite image Landsat 8 in Jun 2019. The LU, as the result of supervised classification which included creating a signature file for supervised classifications by taken training sample and perform maximum likelihood classification, categorized the study area into four main categories of land cover: grass and agricultural (35%), residential (10%), barren land (50%), and water (5%) as shown in Figure 3.12**.** Assessing or validating accuracy is an important phase in the processing of remote sensing techniques. It sets a user the details value of the resulting data. Only when the consistency of the data is established can geodata be efficient in use. An overall accuracy of a classification model measures how each pixel is categorized as opposed to the definite conditions of land cover derived from their specific field data. A number of 160 locations (points) have been generated within the study area's classified image. The results of the accuracy evaluation showed an overall accuracy of 87 % of the data captured from the random sampling process.

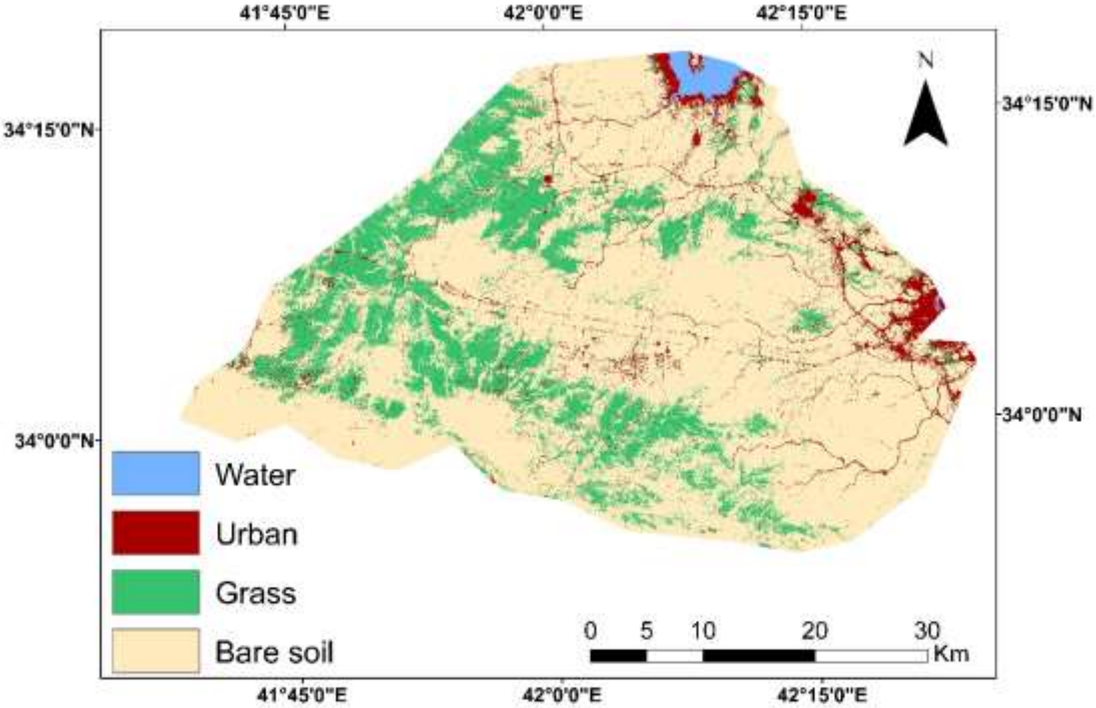

Figure 3.12 Land use map of the study area

3.4.1.3 Runoff depth

In fact, as the beginning of rainfall occurs, water flows into the soil until saturation retains its absolute retention. And the rate of runoff increases as upsurges of rainfall. It explains the presence of a large variation in the volume of the runoff from the same rainfall magnitude.

The SCS-CN approach estimates the Q based on the fallowing equation (Munyao, 2010):

$$Q = \frac{(p - 0.2s)^2}{p + 0.8s} \qquad p \geqslant 0.2s \qquad (1)$$

Q representing Runoff depth (mm)

P representing Rainfall depth (mm)

S representing potential maximum retention (mm)

Because S is highly varied, it can be extracted from equation 2 after determining CN.

$$S = \frac{25400}{CN} - 254 \qquad (2)$$

CN: the curve number of a hydrologic soil cover

$$I_a = 0.2S \qquad (3)$$

I_a: the initial abstraction (mm)

Al-Jabari et al., (2009) showed that the SCS-CN approach is utilized in rural areas. CN value and Rainfall data are the main data for current approach. The SCS approach relies on the simplified relationship between runoff depth (Q) and (p) rainfall depth within a definition of CN (Shadeed and Al Masri, 2010). CN can be defined as 0≤ CN ≤100.

The CN can be used to describe the runoff characteristics of certain soil land cover. The CN for the research area is calculated for each pixel, through the soil maps and LULC, after reclassifying soil map into HSG. Table 3.3 shows the CN values based on the USGS classification scheme (D, C, B and A). The primary soil map is inserted in the ArcGIS 10.7 database. Allotted to an acceptable hydrological category of soil were added the various soil groups within that region.

A weighted curve number CN_w can then be determined via equation 4.

$$CN_w = \frac{CN_i A_i + \cdots + CN_n A_n}{\sum_{i=1}^{n} A_i} \qquad (4)$$

CN_w: The Weighted CN

CN_i: CN of sub-areas

A_i : area of sub basin

n: the whole numeral of sub-basin

Table 3.3 CN values based on HSG and Land use (Munyao, 2010)

Land use / land cover	**Class A**	**Class B**	**Class C**	**Class D**
Bare soil	77	86	91	94
Urban	61	75	83	87
Water	100	100	100	100
Grass	43	65	76	82

The runoff volume is computed via multiplying the surface runoff depth calculated from Eq.1 by the area of that watershed as equation Equation (5)

$$Runoff\ volume\ = runoff\ depth\ \times area \qquad (5)$$

Runoff volume (m^3)

Runoff depth (m)

Area (m^2)

3.4.1.4 Slope

The slope map is a prime map in runoff appropriateness analysis for any catchment area. Slope take part in the inception of runoff and thus effectiveness the velocity of water current, the quantities of sedimentation, and the quantity of material desired to structure the dam (Adham et al., 2016). Siting of RWH structures on the very steep territory will lately lead to structural failure. Critchley et al. (1991) revealed that RWH did not recommend for regions with slope >5% due to unequal distribution of runoff and large amount of earthwork being requisite. The slope with less than 3% offers better storage qualification with economical earthwork that is desired (Critchley, W, 1991; Al-Adamat, 2008). The slope map is obtained from the DEM of the study area. Flats area and sinks were removed to preserve the volume of water flow. As shown in Figure 3.13, the slope map was categorized into four categories, first category < 2.5%, represents 70%, the second category (2.5-4.5) % represents

15%, the third category (4.5-6) % represents 11%, while the final category >6% represents 4% of the entire area.

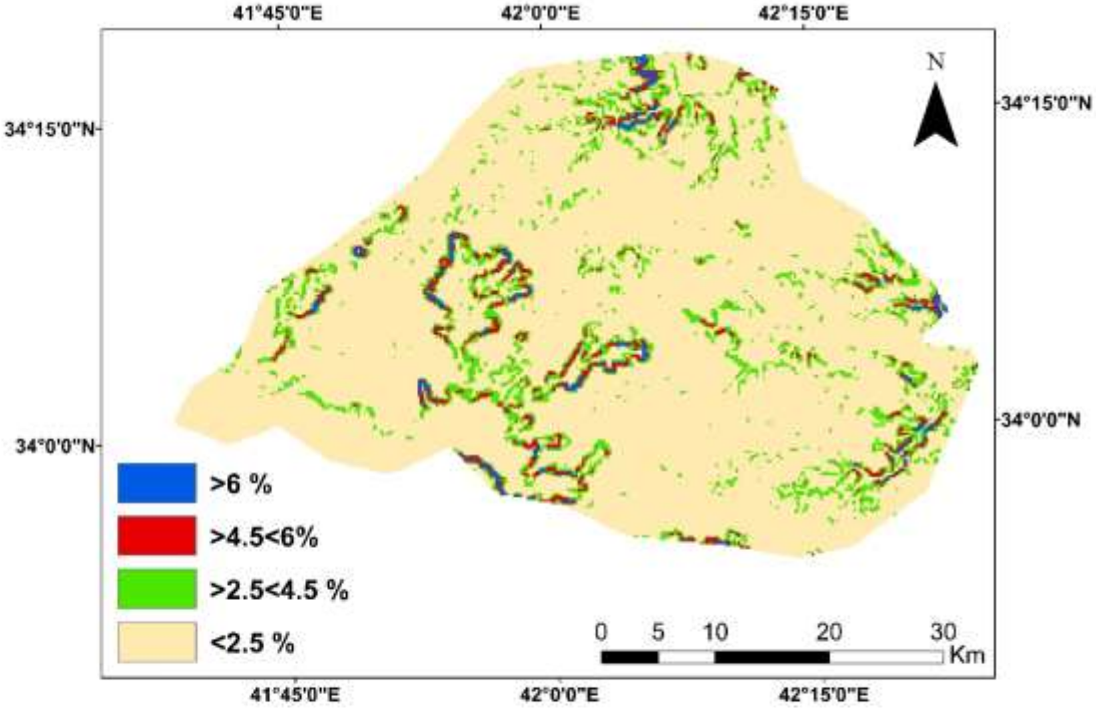

Figure 3.13 Slope map of the study area

3.4.1.5 Distance from irrigated lands

In order to take advantage of the harvested water, agricultural irrigation for instance, it is important that the water harvesting sites be near to the planted or cultivable area (Sayl, K. N., 2020) Thus, distance from irrigated lands were adopted in this study. The green areas were identified with the benefit of the Normalized Vegetation Difference Index (NDVI). This indicator plays a significant part to identify and determine the lushness of land surface. Vegetation cover map is derived from satellite image Landsat 8 in April 2019 (Appendix C). The vegetated cover represents 38% of the entire study area as shown in Figure 3.14.

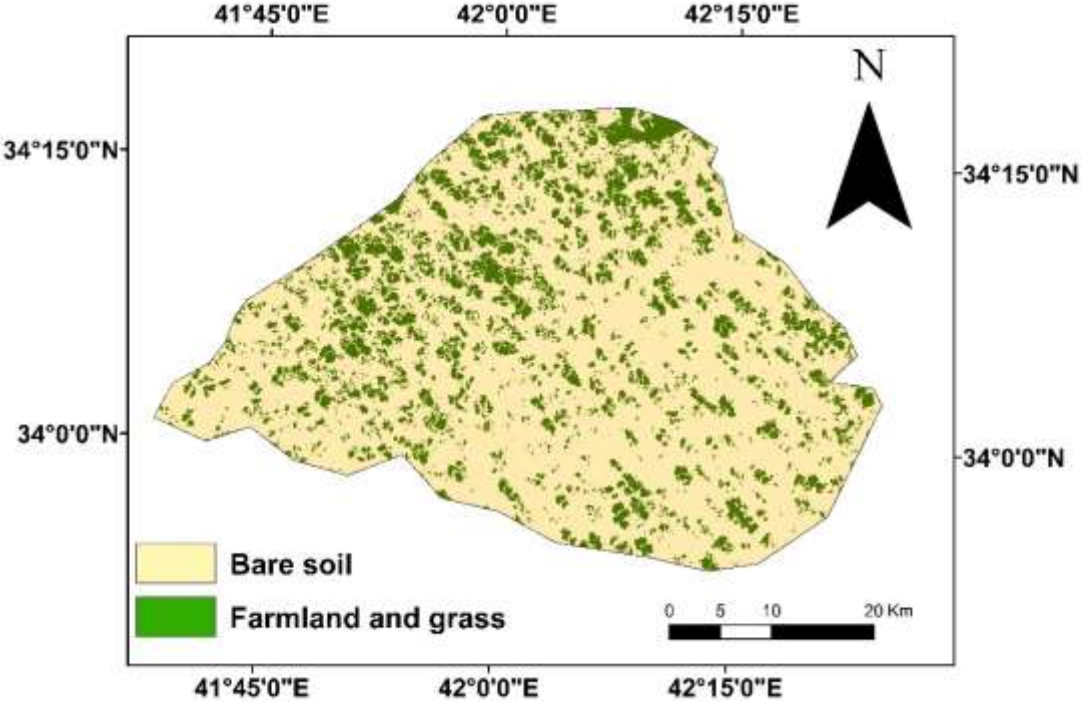

Figure 3.14 Irrigated areas map of the study area

3.4.1.6 Distance from residential area

This research focused on the local community, which represents the target of this study, the distance of chosen water harvesting sites to residential areas is considered a significant factor in the selection of the best RWH sites (Al-Adamat, 2008). The distance from resident area were classified into four classes 250-500 m, 500-1000 m, 1000-2000 m and > 2000 m, as shown in Figure 3.15. While less than 250 m must be excluded for safety reasons (Baban, S., Wan-Yusof, K., 2003; Al-Adamat et al., 2012). The map of this parameter was obtained, based on buffer areas adopted in Table 3.1, from Landsat 8 image taken in June 2019.

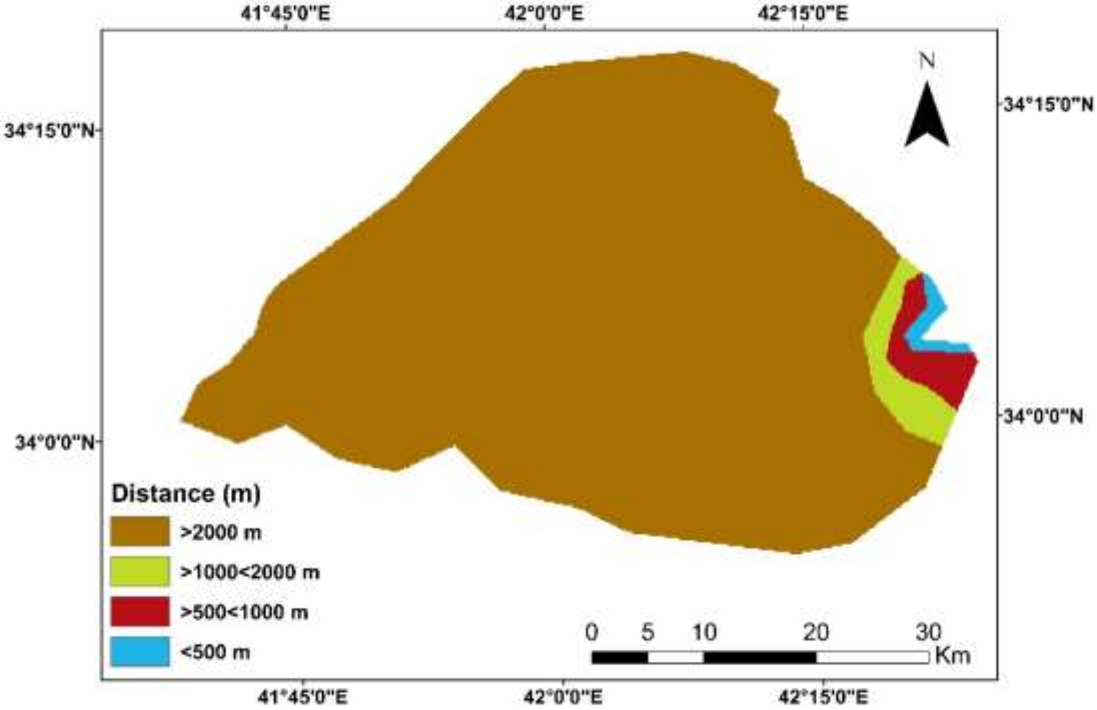

Figure 3.15 Distance from residential areas of the study area

3.4.1.7 Distance from roads

Roads have significant socio-economic importance for the regional population in the case study region by driving about in search of grass and water with their livestock (Al-adamat, 2008). The existing roads near proposed site contribute to reduce transportation cost. People there may drive their trucks and tankers across these roads from one location to another. As shown in Figure 3.16, the distance from road were classified into four classes 250-500 m, 500-1000 m, 1000-2000 m and > 2000 m. While less than 250 m is not recommend to prohibit any future inconsistency between RWH structure and roads (Al-adamat et al., 2012). The map of this parameter was obtained, based on buffer areas adopted in Table1, from Landsat 8 image taken in June 2019.

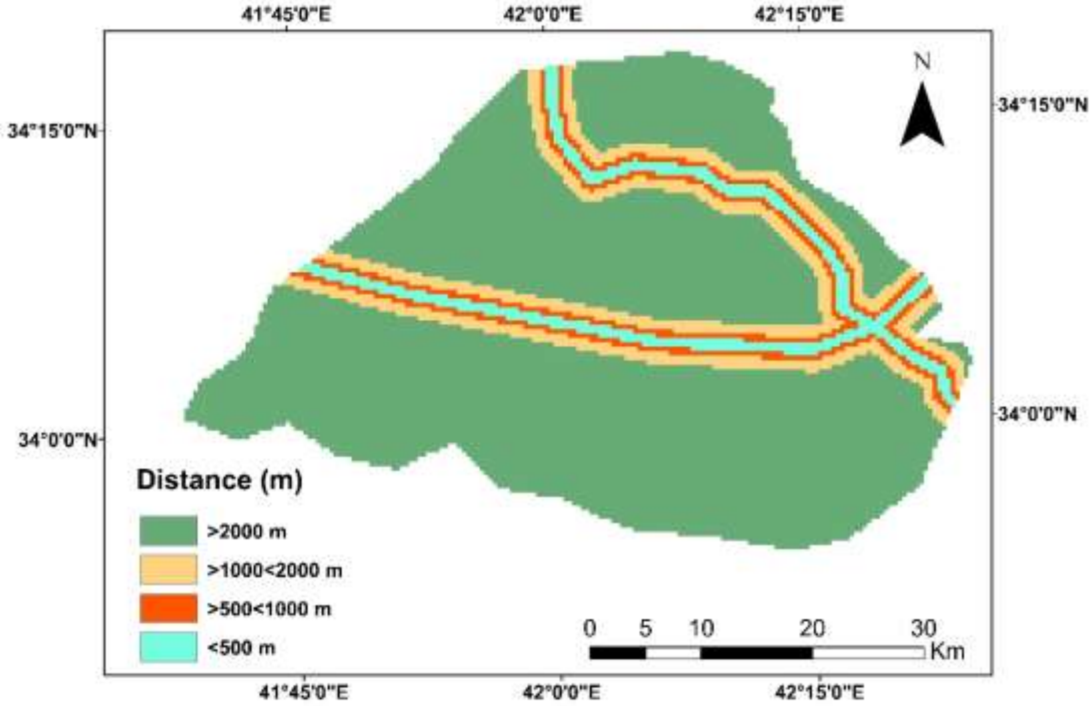

Figure 3.16 Distance from roads of the study area

3.4.2 Weights and rating of WLC criteria

WLC criteria were given weights, rates and justification based on the methodologies applied in previous that have similar environmental and physical condition to the western desert of Iraq (Jabr and El-Awar, 2005; Ould Cherif Ahmed et al., 2007; Munyao, J. N. , 2010; Ahmad, I., 2013; Hameed, H, 2013; Adham et al., 2018; Al-Ruzouq, R et al., 2019; Mbilinyi et al., 2007; Krois, J. and Schulte, A, 2014; Al-Adamat et al., 2010). Table 3.4 illustrates the weights and ratings given to seven criteria adopted in the current study.

Table 3.4 Weights and rating of seven criteria adopted in the WLC method

Criterion	**Weight**	**Rates**	**Score**	**Criterion**	**Weight**	**Rates**	**Score**
Runoff depth	9	31-23 mm 23-15 mm3 15-7 mm 2	4 3 2	**LU**	6	Grass Bair soil Water body Built up	4 3 0 0
Slope (%)	8	≤ 2.5 > 2.5 < 4.5 > 4.5 < 6 ≥ 6	4 3 2 1	**Distance from irrigated lands**	5	vegetation arid	2 1
				Distance from residential areas	4	≤ 500 m >500 ≤1000 m >1000≤2000 m >2000 m	4 3 2 1
Soil texture	7	Clay loam Silty loam Loam Sandy loam	4 3 2 1	**Distance from roads**	3	≤ 500 m >500 ≤1000 m >1000≤2000 m >2000 m	4 3 2 1

3.4.3 Weighted Linear Combination (WLC) method

One of the processes of multi-criteria evaluation is the method of WLC. It has been done in two steps:

i. multiplying the weight of each parameter as shown in Table 3.4 by rates of the category of the same parameter
ii. adding all the criteria layers in the raster calculator, as shown in equation (6) (Ibrahim, G.R. et al, 2019).

$$S = \sum W_i * X_i \qquad (6)$$

Where S represents suitable site, W represents weight of parameter i, and X represents value of raster for parameter i.

3.4.4 Boolean criteria preparation

The criteria in the Boolean overlay approach crisp (true or false) and it is limited to a small discrete location. This approach has been applied in several studies (such as Chang et al., 2008; Shatnawi, 2006; Al-Adamat et al., 2010; Sayl et al., 2017). The stream order and distance from faults are adopted in this method. The details of the two criteria will be discussed in the following sections.

3.4.4.1 Stream order

Stream order analysis for suitability mapping is important for suitability areas for RWH. The higher stream order indicates more tributaries are flowing drainage which gives a higher possibility to harvest more water (Adham et al., 2018; Sayl et al., 2019). The greater the flow accumulation of a stream, the higher the drainage order to this stream. The small number of stream order results in a higher infiltration and permeability and vice versa. In addition, the configuration of dendritic drainage displays the homogeneity in texture and shortage of tectonic control. As mentioned by Sayl, et al., (2019) stream order larger than third order is given the value 1, while less than third is given 0 for this study. The stream order map is derived from DEM by using ArcGIS 10.7 (Figure 3.17). The following procedures were performed to extract the drainage pattern and flow accumulation:

i. Flow direction determines the direction of each cell to which water flows

ii. From of the flow direction map, flow accumulation is calculated, showing how many upstream cells give water to each cell. For the concept of drainage, the flow accumulation feature is required.

iii. Identifying a threshold for accumulation of drainage flow by cell determination, with values greater than the threshold, was used to classify streams in the research area.

iv. Using Strahler classification, a numerical order is assigned to connect a drainage network. If the network drainage has been defined it can be translated into a vector layer.

The study area includes sixth stream order. The total length of the highest stream order sixth order is 8.0 km; the total length of fifth order is 3 km; the total length of fourth order is 70 km.

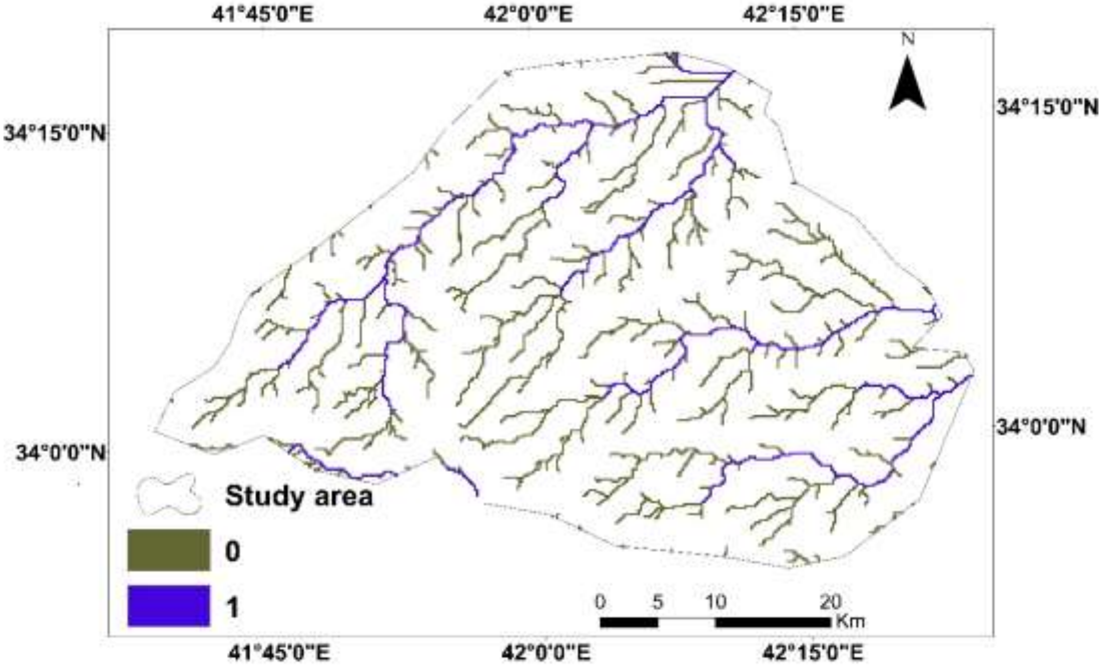

Figure 3.17 Stream order of the study area

3.4.4.2 Distance from faults

The fault is among the original geological tectonic structures, which is a combination of fractures and cracks in rock masses followed by a change or difference (movement) or displacement in the depth of the rock layers on the both sides of the fracture level. In the Western Desert, four sets of faults are identified by analyzing Landsat images. The fault systems are NE – SW, N – S, NW – SE and E – W.

Faults are a big impediment when determining to have RWH system. The localization of the faults is gained via the use of the available geological map of the study area. The exclusion of the fault area from the selecting sites is critical when identifying a site for RWH (Shatnawi, 2006). Thus, a value of zero is given to areas that are at a distance of 1000 m or less from the fault area, the value 1 is given to areas more than 1000 m away Figure 3.18.

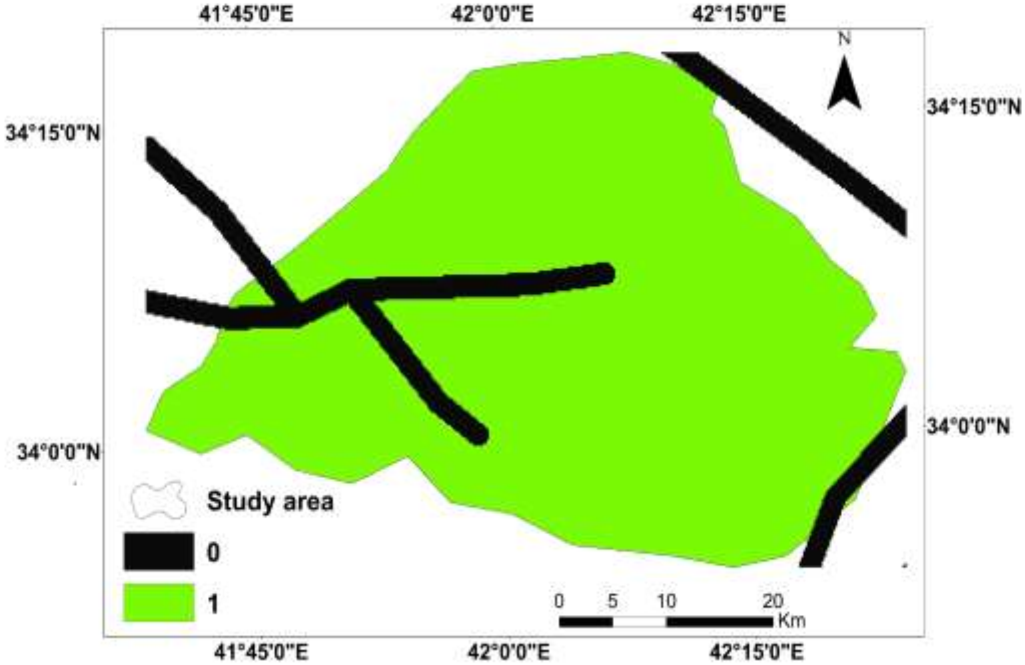

Figure 3.18 Distance from faults

3.5 Boolean overlay method

The Boolean overlay approach provides site selection of RWH relied on using either (the OR) or (the AND) operations, it is crisp (true or false), and it is restricted to small separated locations when using (the AND) operation. This method is significant for excluding a certain area identifies by the WLC method. Spatial analyst tools and Raster calculators were used in the ArcGIS platform. The two Boolean criteria were multiplied to obtain the sites with value 1 which is suitable for RWH.

3.6 Proposed water storage sites

The first significant characteristic to localize the appropriate site is set up by decreasing the cross-section of the wadi. These characteristics permit using the natural features as support site structure. This process permits the reduction of earth dam dimensions and performance costs (Nilsson et al., 1988). The cross-section graph generated from DEM and Triangulated Irregular Network (TIN) was subsequently proposed.

The Watershed modeling system (WMS 11.0) software with DEM was used to determine the morphometric criteria and delineate the watershed for each site. This analysis is significant to recognize a total land area bounded by basin border. One of the most important morphometric criteria is the basin area, where the quantities of surface runoff to be harvested in the reservoir depending on the basin area. Then, the influence area corresponds to the upstream narrows surface, which after realization of the dam, is very important to the analyze the potential hazards from the extents of floods on the surrounding area.

3.7 Area Volume Elevation Curve Analysis

The highlight of the proposed technique is to combine the geospatial data with GIS to develop area-volume-elevation (AVE) curve for each site which plays an important role in sustainable water and avoids extravagant evaporation losses. The analysis based on the AVE curve is a vital part of this study where ranking and the analyses of the possible sites are generated. The prime restriction in planning RWH is the absence of information of storage quantity and surface area at any deepness of the dam reservoir. Therefore, the AVE curve plays an important role in determining the highest volume quantity, optimal surface area, and the ultimate appropriate. This relationship is key in the arid region that has a high evaporation rate. The DEM generated from ASTER data was imported in ArcGIS 10.7 with a 3D Analyst to develop the AVE curve data for each site. The surface area and volume for every 2 m were calculated. The intersection of AVE curve exemplifies the typical crest for the proposed dam. The comparison among sites suggested has been adopted. This comparison can be vision instantly and it is comparatively supportive in analyzing and selecting the suitable site to minimize extravagant evaporation losses.

3.8 Summary

This chapter illustrates the use of different data and criteria created in which can be utilized in open source Geographic Information Systems. These data are utilized as the base data source for the tools and models to develop methods and methodology for detecting of suitable sites for RWH planning. This chapter exemplifies the use of spectral reflectance variation as the foundation for the soil texture type recognition with the aid of the Radial Basis Neural Network model. That model serves to establish the study area’s digital soil map. Its incorporation with GIS helps attain complete coverage of the region. In addition, this chapter provides the use of incorporating GIS technique and SCS-CN approach for runoff estimation in the ungauged watershed. However, chapter 3 illustrates the use of ArcGIS in creating data products depending on multiple remote sensing data. The advancement of the current study is to estimate the AVE curve based on the of DEM generated from (ASTER), which would be the foundation principle for ranking the suitable sites for RWH. The methodology suggested is particularly beneficial for large areas, which data is limited and scarce.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Overview

This chapter explores the outcome of the methods and models built in this research, enabling decision-makers to control and model a particular dataset. The methods and models demonstrated in this chapter provide an effective means for generating new filtered/optimized outcomes from existing data. It provides policy makers with the opportunity to perform large-scale, high-level evaluations as well as address fundamental questions relevant to the planning process for RWH.

4.2 Soil Texture

One of the most important objectives of this study is to obtain a soil texture map for the study area. It was found that the unsupervised classification offers an appropriate and detailed description of certain sets. Therefore, these sets are graded depending only on the image value. Using the unsupervised classification can be a suitable method for constructing an embryonic map to assemble soil samples. This method would diminish task expenses and time. The selection of the soil sample position is carried out based on certain criteria in order to avoid the errors associated with spectral reflectance and to perform accurate estimation of soil type.

4.2.1 Laboratory tests

Soil tests were conducted for 120 samples taken from the study area, which included sieve analysis and hydrometer testing for finding the percentage of sand, silt and clay for each sample, where the results are listed in Appendix B. This appendix shows the geographical coordinates of the location of each sample, the spectral reflectance values for all bands from 1 to 9, and the type of soil texture depending on the percentages obtained from the tests. It was observed that 74 % of the samples had percentages of loam soil, 2 % sand soil, 13 % silty loam soil, and 11% sandy loam soil.

4.2.2 Sensitivity analysis

Sensitivity analysis is used to ensure the relationship of complexity between output as (sand%, silt%, clay%) and input data as spectral reflection. Figure 4.1 indicates the sensitivity of the clay, sand and silt to the bands. Clearly, Figure 4.1 shows that band 8, band 4, and band 7 comprise the highest degree of sensitivity to soil types, especially sand and silt, whereas band 2, band 3 and band 1 show a higher degree of the sensitivity of the clay. Additionally, the soil type and spectral reflection is complicated where all bands contribute to the sense of soil type but in different weights. Hence, including all the bands in the Artificial Neural Network (ANN) model is important.

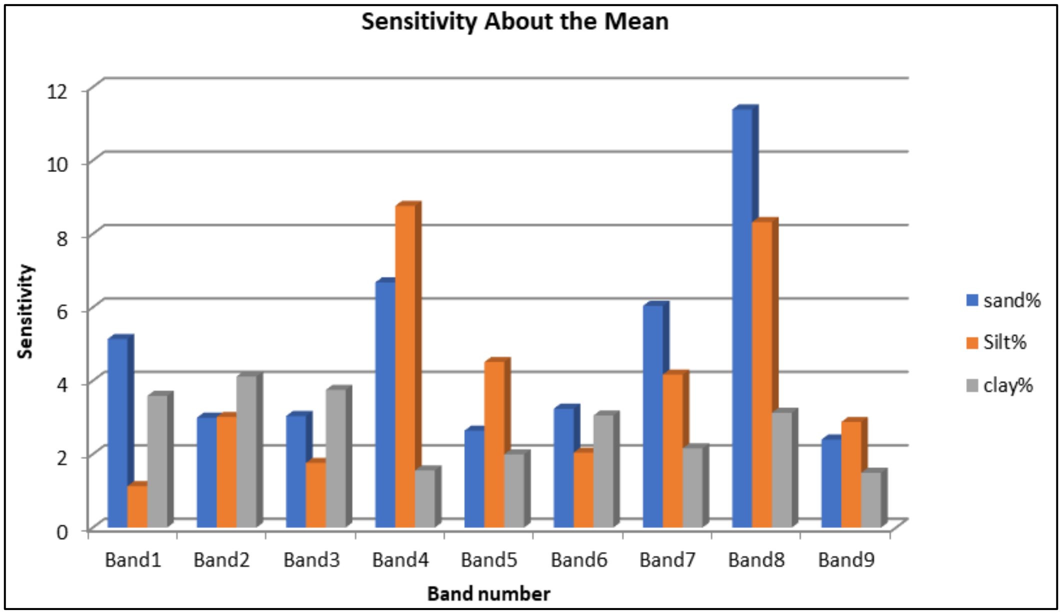

Figure 4.1 Sensitivity of bands for clay, silt, sand of the study area

4.2.3 Performance of ANN model

The spectral reflection and the percentages of soil textures obtained from laboratory tests for 120 samples were used as a database to develop ANN model. This model was evaluated based on the difference between estimated and actual values.

Estimated and actual ANN model values for 25 samples are shown in Figure 4.2. This figure indicates that the predicted clay values are more reliable than sand and silt because there is a significant fluctuation between the actual and estimated value for sandy and silt soil. Indeed, due to the constant comprehensive performance of this model, the total expected value of the ANN production is 100%.

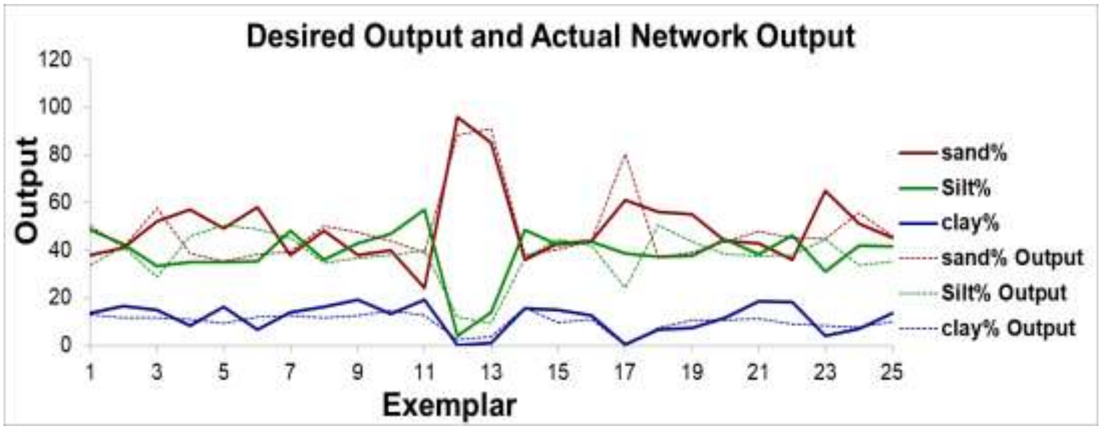

Figure 4.2 Estimated and actual values of sand, silt and clay for the tested samples

To determine the modeling performance where Table 4.1 presents ANN performance for each soil type. Obviously, it can be assumed that there is a significant difference in the precision of the three types of soil estimation values. Among other types, the clay predictor has higher results in all output criteria where the lowest RMSE, NRMSE, MAE, NMAE and minimum, maximum Abs error are (4.237, 0.2047, 3.489, 0.1685, 0.47866 and 8.9533 respectively) while the highest correlation coefficient is (r = 0.749). The results indicated that the RMSE of sand, silt, and clay were 11.08, 9.50, and 4.23, respectively. As seen in Figure 4.3, some fluctuation in outcomes can be shown by comparing sand and silt accuracies. Based on NRMSE and NMAE, estimating the silt works more efficiently than estimating the sand.

The results of estimated values of 25 samples obtained from the proposed model were also evaluated by the USDA-developed hydrological soil groups, as is apparent in Figure 4.3. Nevertheless, the importance of this statistic in terms of soil texture indicates the real and expected values of the soil samples. Here we can analyze the model's actual overall performance in terms of hydrological soil group. The red (estimated) and blue (actual) numbers in the soil triangle provide the location of the test. Out of 25 samples in general, only 4 samples show minor differences in the estimated and calculated soil texture group. Although the error in estimating soil texture of these samples but still in the same hydrological group that is the main target of this analysis. Ultimately, ANN's overall performance is quite superior to what was previously portrayed.

Table 4.1 Neural network models performance criteria for clay, silt and sand

Performance	Sand%	Silt%	Clay%
RMSE	11.08087	9.503868	4.237794
NRMSE	0.160592	0.140175	0.204724
MAE	8.579605	8.07004	3.489235
NMAE	0.124342	0.119027	0.168562
Min Abs Error	0.068127	0.852735	0.47866
Max Abs Error	20.11589	17.07785	8.953379
r	0.732294	0.588528	0.749586

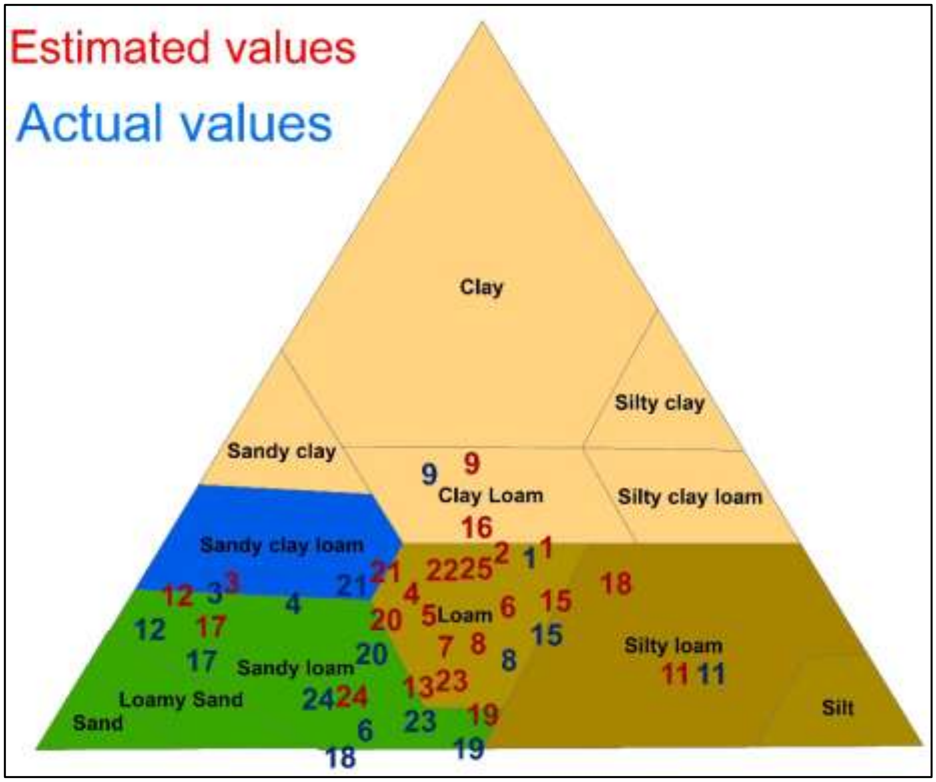

Figure 4.3 Estimated and actual points on the triangle of soil texture

4.2.4 Digital soil texture map

The map of the estimated soil texture was developed for the study region by simulating the spectral reflectance of 1200 points at various locations in the ANN model (Figure 4.4). The soil map was categorized into four categories first category (loam) represents 63%, the second category (clay loam) represents 23%, the third category (silty loam) represents 13%, while the final category (sandy loam) represents 1% of the entire area.

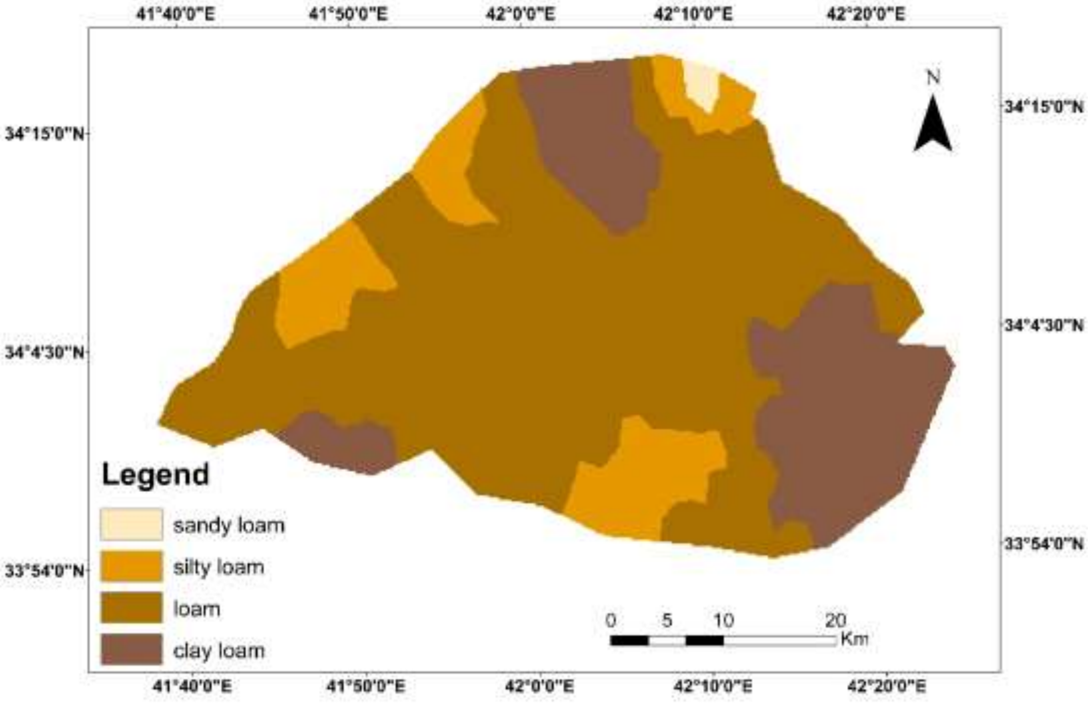

Figure 4.4 Soil texture map of the study area

4.2.5 Hydrological soil group map

The percentage of soil types are listed according to the USDA hydrological soil classification. The results of the categorization calculated using GIS as a means of creating a digital map of the hydrological soil group by the spatial analyst model, as shown in Figure 4.5. This map shows the distribution of hydrological soil group over the study area which is a vital factor for investigation types of diversity. HSG map was categorized into three categories first category (A) represents7 %, the second category (B) represents 65 %, the third category (D) represents 28 % of the entire area.

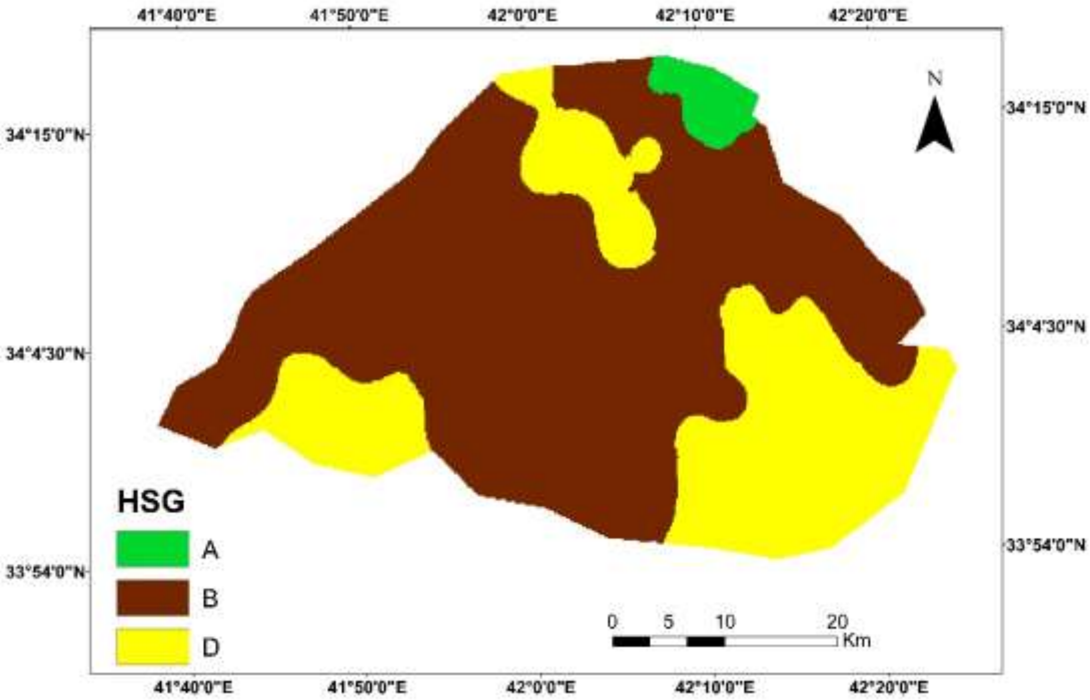

Figure 4.5 Hydrological soil group map

4.3 Runoff Estimation Using Soil Conservation Service-Curve Number Approach

For the soil, the SCS ordered four hydrological classes, depending on the capacity for soil runoff (USDA, 1986). These classes are denoted as (D, C, B, and A), where class A takes the lowest potential runoff, while class D has the largest. According to the soil texture map, the study area is classified into three HSG as shown in Figure 4.6. Table 4.2 illustrate the HSG based on infiltration rate.

Table 4.2 Properties of Hydrological soil group (Maidment, 1992)

HSG	**Soil type**	**Direct runoff**	**Infiltration rate (mm/h)**
A	loamy sand or Sandy loam, sand	Low	25.0
B	Silty loam, loam	Medium	13.0
C	Sandy clay loam	High	6.0
D	Silty clay loam, clay loam	Very high	3.0

In ArcGIS 10.7, the CN map procedure created the land use/cover map and soil map for each sub-watershed of different types. Figure 4.6 illustrates the curve number for each pixel of the study area. Based on equation 4 and the data of Table 4.3, for the three wadis included in the study area the weighted curve number CN_w was determined to be: Al-Fahamy 79.9, Hijlan 83.6 and Zgadan 86.6.

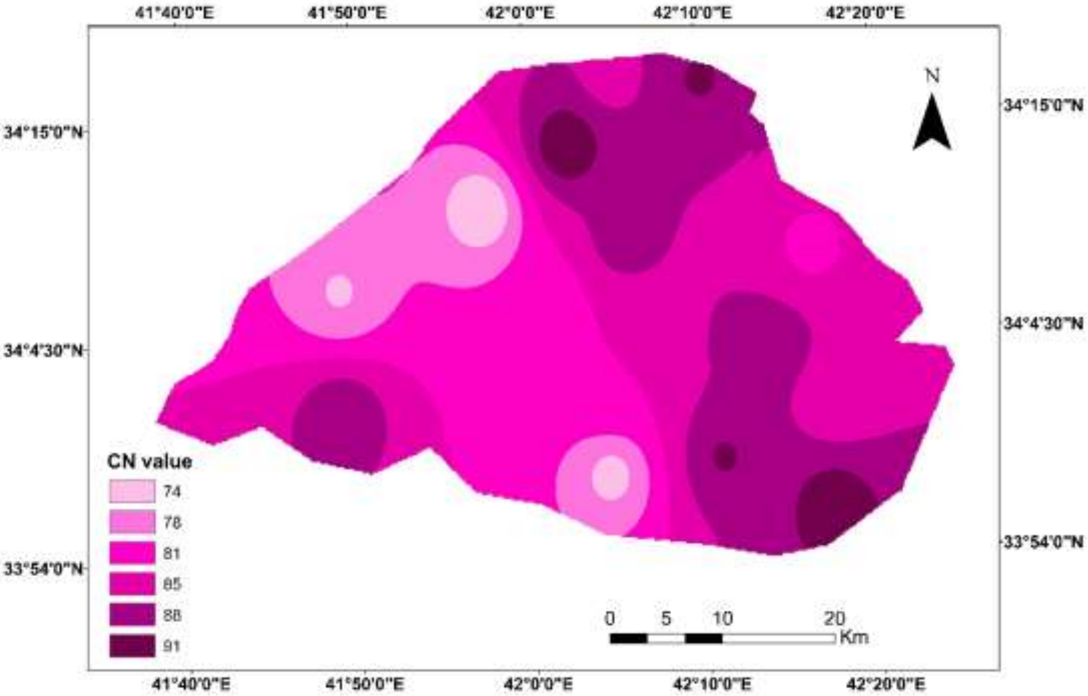

Figure 4.6 CN value map of the study area

To obtain the runoff depth (Q) for the whole study area, Q was estimated for each sub-watershed depending rainfall data and CN value in the same sub-watershed based on equation 1, equation 2 was used to calculate the potential maximum retention (S). The initial abstraction I_a was obtained for each watershed according to equation 3 as shown in Table 4.4. This table illustrates all variables of the SCS-CN method. Figure 4.7 shows the runoff depths distributed for the whole study area based on the maximum rainfall that occurred during (2018). The values of the runoff depths range between (12.5 to 20.3) mm.

It is not all rainfall that can be transformed into runoff. Rainfall parts are evaporated, captured on land and some permeated through the soil. Finally, the un-captured rainfall part causes runoff event. The analysis indicated that only 32 % of rainfall donates to runoff, whereas the residual 68 % donates to losses and interceptions.

The direct depth of runoff over the watershed of the study determined via equation 1. The amounts of water flow over the entire study area, are determined based on the runoff depths and the area of the same sub-watershed area (equation 5). Figure 4.8 shows the surface runoff volume for each wadi of the study area: Al-Fahamy, Hijlan and Zgadan 12.75, 7.3887, and 9.85159 million m^3, respectively.

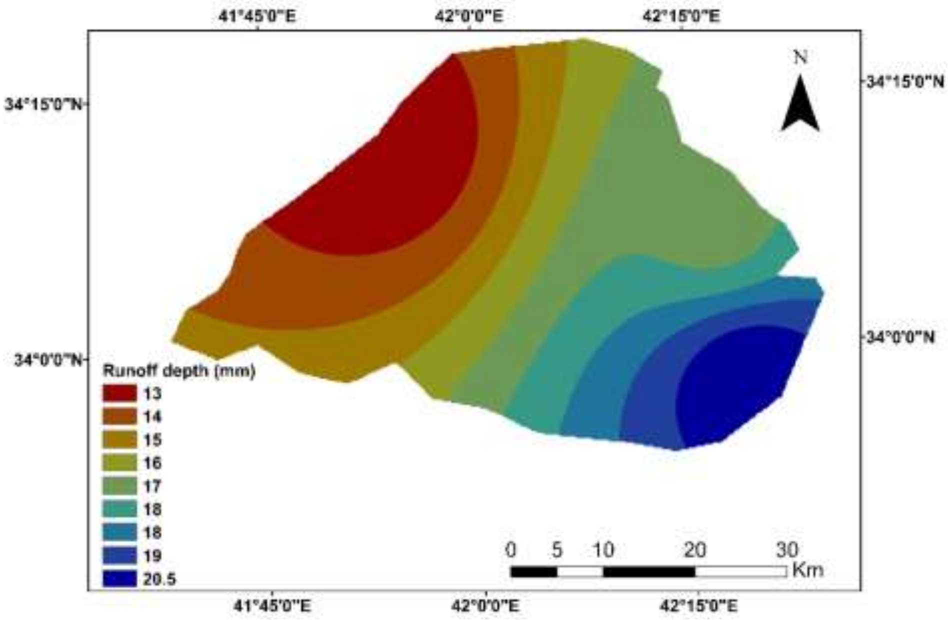

Figure 4.7 Runoff depth map

Table 4.3 The CN values for each sub-area

Sub-watershed	**Sub-area no.**	**Area (km^2)**	**CN value**	**CN*Area**
Al-Fahamy	**1**	217	82	17794
	2	234	76	17784
	3	90	75	6750
	4	167	92	15364
	5	101	83	8383
	6	211	73	15403
		$\sum = \mathbf{1020}$		$\sum = \mathbf{81478}$
Hijlan	**1**	271	80	21680
	2	110	89	9790
	3	28	88	2464
	4	38.8	90	3492
		$\sum = \mathbf{447.8}$		$\sum = \mathbf{37426}$
Zgadan	**1**	218	83	18094
	2	61	85	5185
	3	86.6	93	8053.8
	4	51	90	4590
	5	68.7	89	6114.3
		$\sum = \mathbf{485.3}$		$\sum = \mathbf{42037.1}$

Table 4.4 Values of SCS-CN variables in study area

Sub-watershed	**CN_w**	**S (mm)**	**I_a (mm)**	**Rainfall depth (mm)**	**Runoff depth Q (mm)**	**Area (km^2)**	**Runoff (Million m^3)**
Al-Fahamy	79.9	63.9	12.78	48	12.5	1020	12.75
Hijlan	83.6	49.8	9.96	48	16.5	447.8	7.3
Zgadan	86.6	39.3	7.86	48	20.3	485.3	9.8

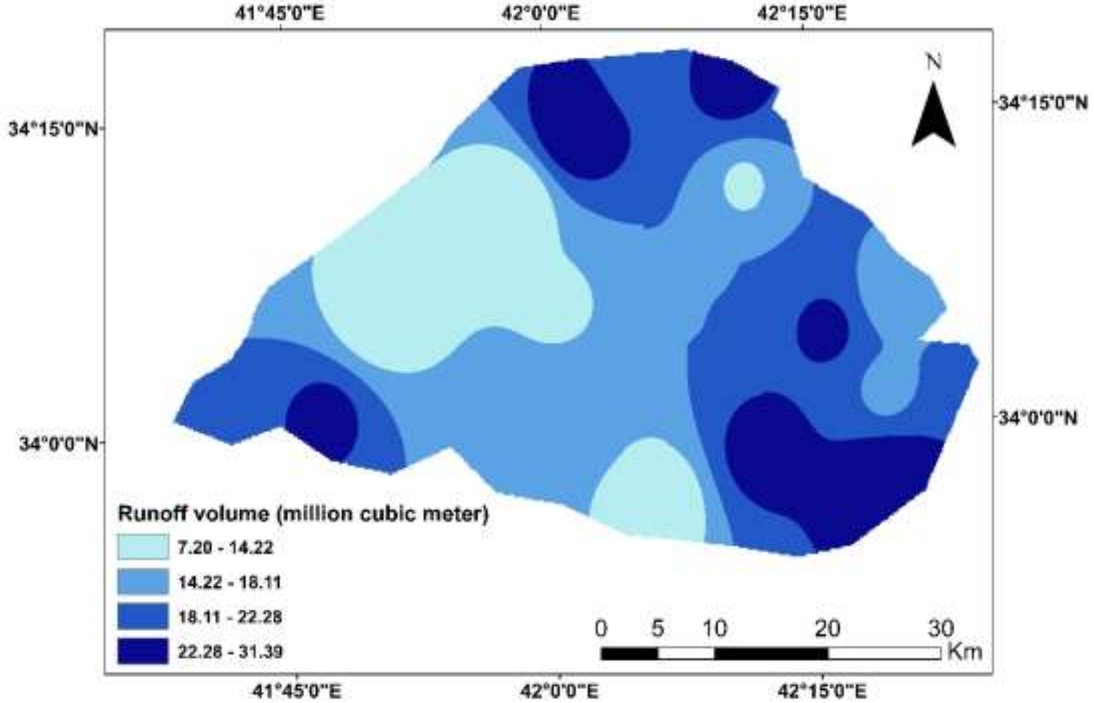

Figure 4.8 Runoff volume map of the study area

4.4 Suitable Rainwater Harvesting Zone

Adopting appropriate locations using GIS method is a sophisticated detail because of many criteria that impact the place of dams. Thus, this study aims to simplify the sieving mapping.

4.4.1 Weighted linear combination method

According to seventh criteria adopted in WLC step i.e., runoff depth, slope, soil texture, land use (LU), distance from irrigated lands, distance from residential areas and distance from roads, the suitability sites for the RWH were calculated using Multi-criteria evaluation. The WLC criteria set out in Table 3.4 has been implemented using ArcGIS 10.7 packages. Figure 4.9 displays the raster values for all criteria maps resulting from the multiplication of weights based on Table 3.2 for each parameter.

Based on equation 3, all layers of the criteria are added to the raster calculator to obtain the final map of the WLC criteria method as shown in Figure 4.10. The maximum value of WLC parameter is (141) while the minimum value is (61). According to differences between maximum and minimum value of the WLC parameters, the findings map of the WLC criteria included three comparable units that have been used as markers for possible rainwater harvesting sites due to their suitability: more suitable, moderate, and unsuitable. It was found that a suitable area represents 16%, moderate suitable represents 60%, and the unsuitable represents 24% of the entire study area. The results map of WLC criteria shows that the most downstream zone of three valleys was suitable for RWH. The major soil texture in the regions with suitable was clay loam, and the runoff depth diverse between 23 mm and 30 mm. The main regions with suitable for RWH had slopes varied between 1.5% to 4.5%., and intensively cultivated. The findings of the WLC criteria are in agreement with the studies of (Mbilinyi et al., 2007; Adham et al., 2018). These studies showed that the regions having fine to moderate slopes integrated with clay loam were appropriate for RWH.

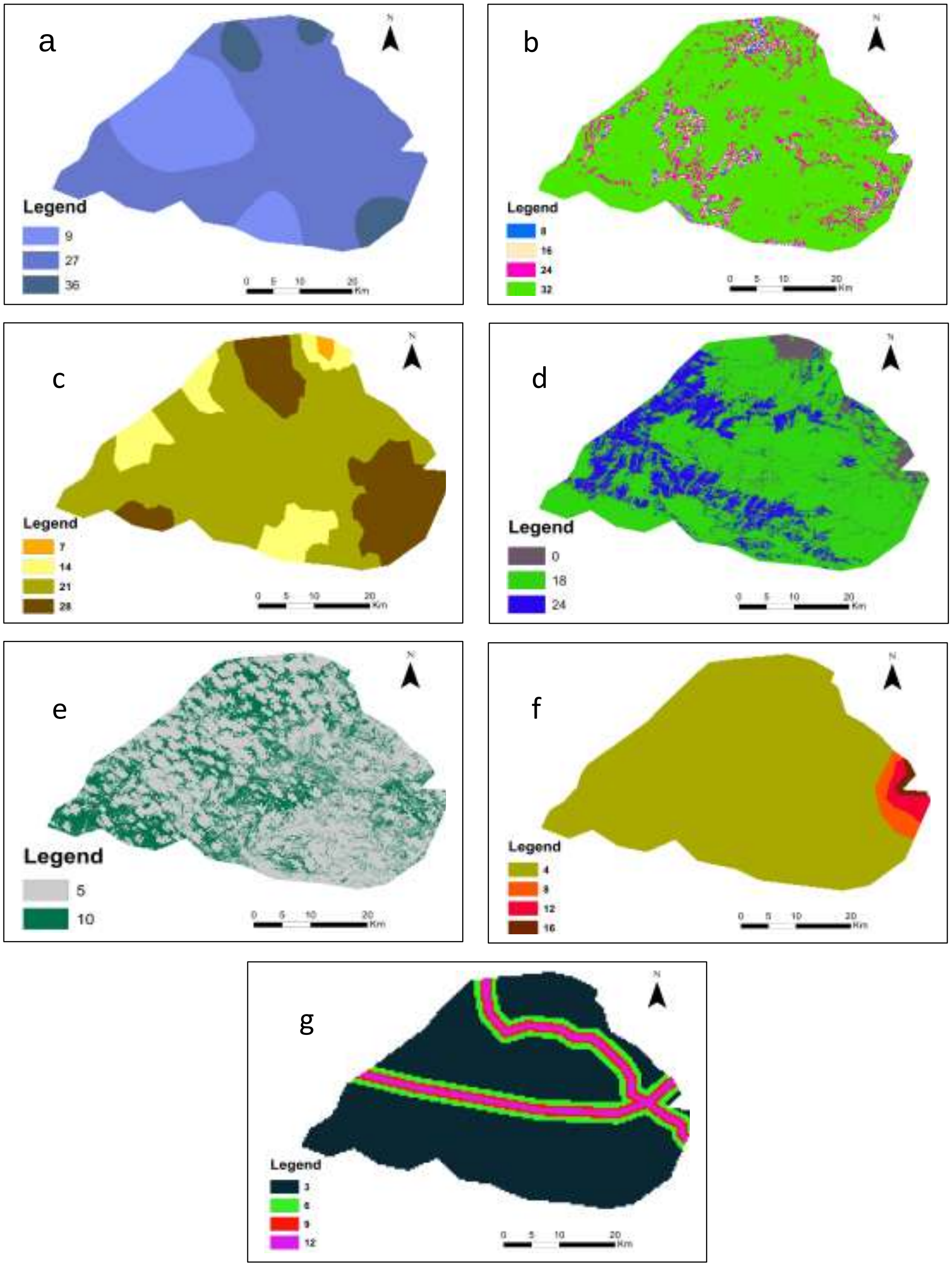

Figure 4.9 Analyzing the WLC parameters: a) Runoff depth; b) Slope; c) Soil texture; d) Land use; e) Irrigated area map; f) Distance from resident; g) Distance from roads

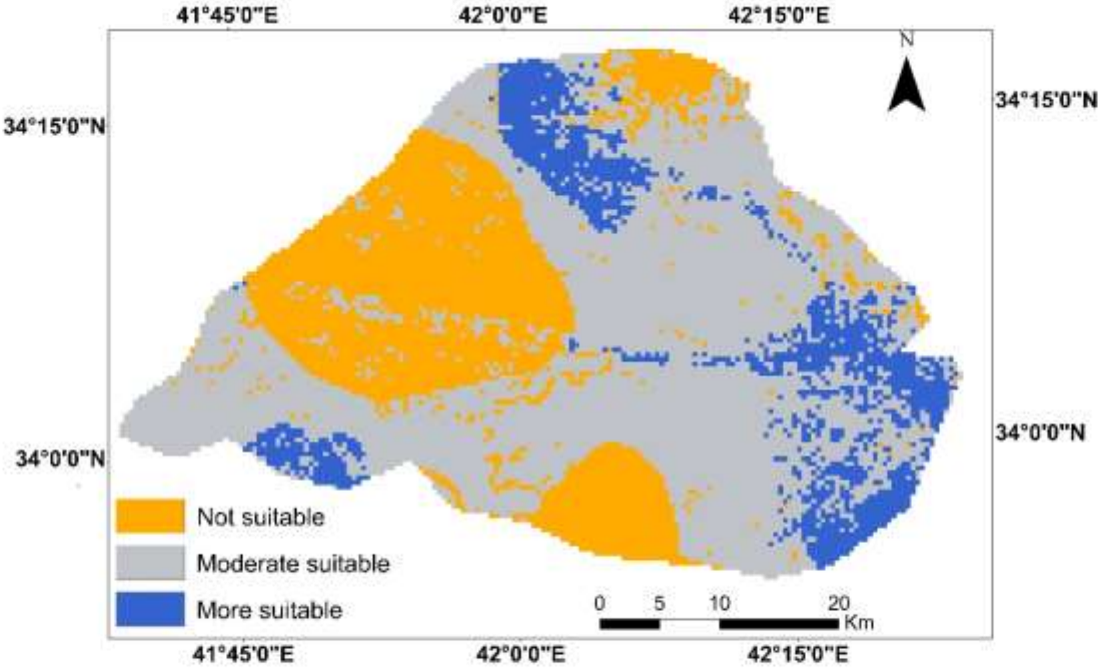

Figure 4.10 Outcome of WLC criteria analyzing

4.4.2 Boolean overlay method

This method is significant for excluding a certain area identifies by the WLC method. According to the financial resources, earth dams were the most common and suitable RWH structure in study area. In this context, the potential sites for RWH are limited throughout the seasonal drainage network. Thus, The Boolean overlay method used to limit the selection for RWH in small separated locations. The selection process in this method is qualitative and the negative restraint at any one of these criteria removes a certain area from further consideration. The findings map of the Boolean overlay step were generated based on distance from fault and stream order as shown in Figure 4.11. This step is a significant method to exclude a certain area identify by the WLC process. The results map show that the remarkably high potential for RWH sites represents the highest stream (sixth order), which was observed in the outlet of the catchment of the study area.

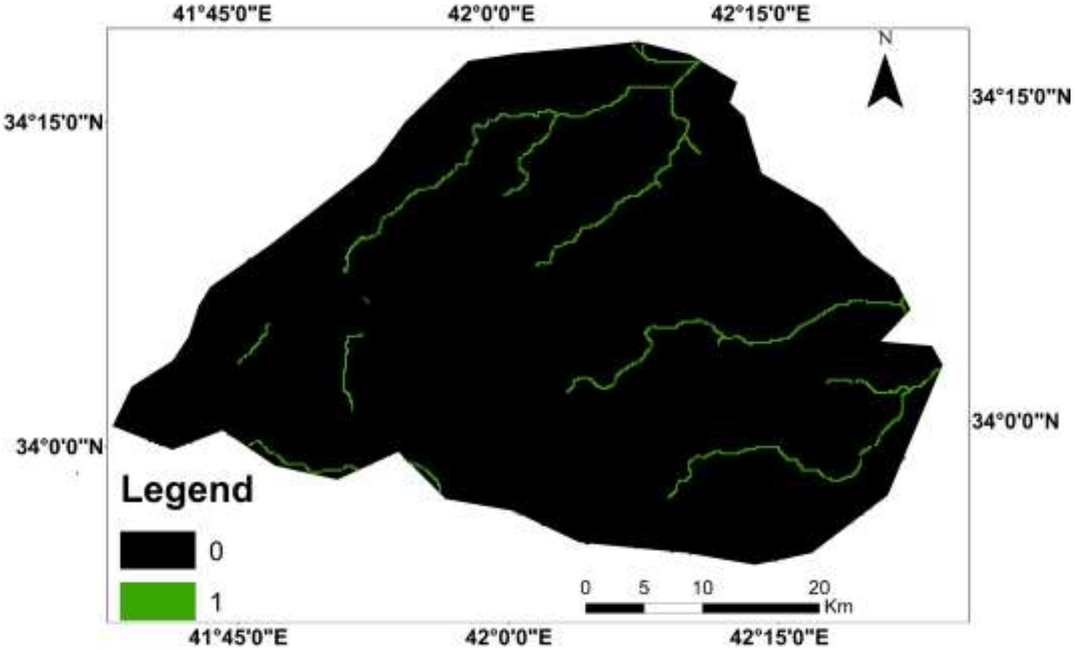

Figure 4.11 Outcome of Boolean criteria for the study area

4.4.3 Combination of WLC method and Boolean overlay

The resulting maps from both WLC step and Boolean overlay step are multiplied to create the final map of a raster as in Figure 4.12. The least pixel value defined by the WLC and Boolean method was determined to be 0, while the highest pixel value would be 135. This map included three comparable units that have been used as markers for possible RWH sites due to their suitability: suitable, moderate, and unsuitable. The variance between the pixels value was broken down into three classes: high suitable (135-106), moderate suitable (106-0), and the unsuitable (0). The results indicated that 6% (117 $\mathrm{k}m^2$) of the basin area is suitable, 4% (78 $\mathrm{k}m^2$) of the basin area is moderately, and 90% (1758 $\mathrm{k}m^2$) of the basin area is not suitable. It is obvious that places with a large amount of runoff and clay soil texture would rank highly appropriate for RWH. The stream order is a key restricting factor to rainwater harvesting sites since the dams are the structures suggested to harvested rainwater.

The high stream order areas were therefore highly ideal for rainwater harvesting sites. The eastern part of the study area listed as highly suitable RWH areas because such areas have been shown to be downstream of watersheds included in the study area as well as of the slopes below 5%.

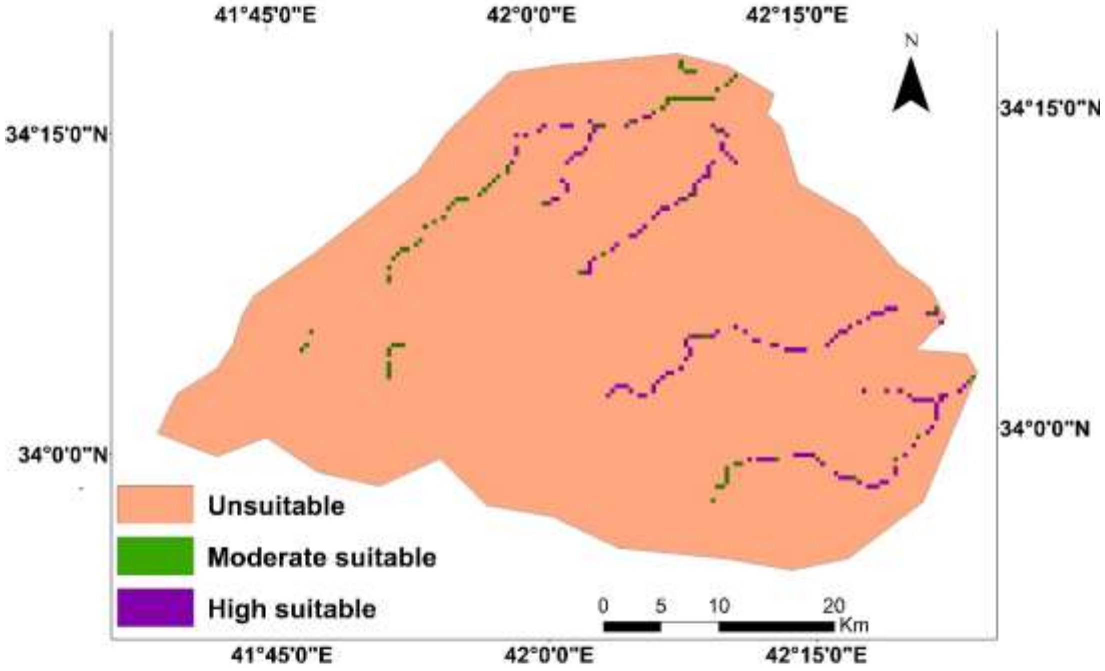

Figure 4.12 Final map of Boolean and WLC of the study area

4.5 Proposed Water Storage Sites

After locating the potential sites for RWH throughout the seasonal drainage network, the first significant characteristic to localize the appropriate site is constituted by reducing the cross-section of the valley. These sites along the drainage network were selected on the basis of substantial features to consider a proper location of a small earth dam. As shown in Figure 4.13 six potential locations were selected on the suitable zone characterized by the reduction in the cross-section of the valley. All cross-section lengths did not exceed 500 m as shown in Figures (4.14 - 4.19).

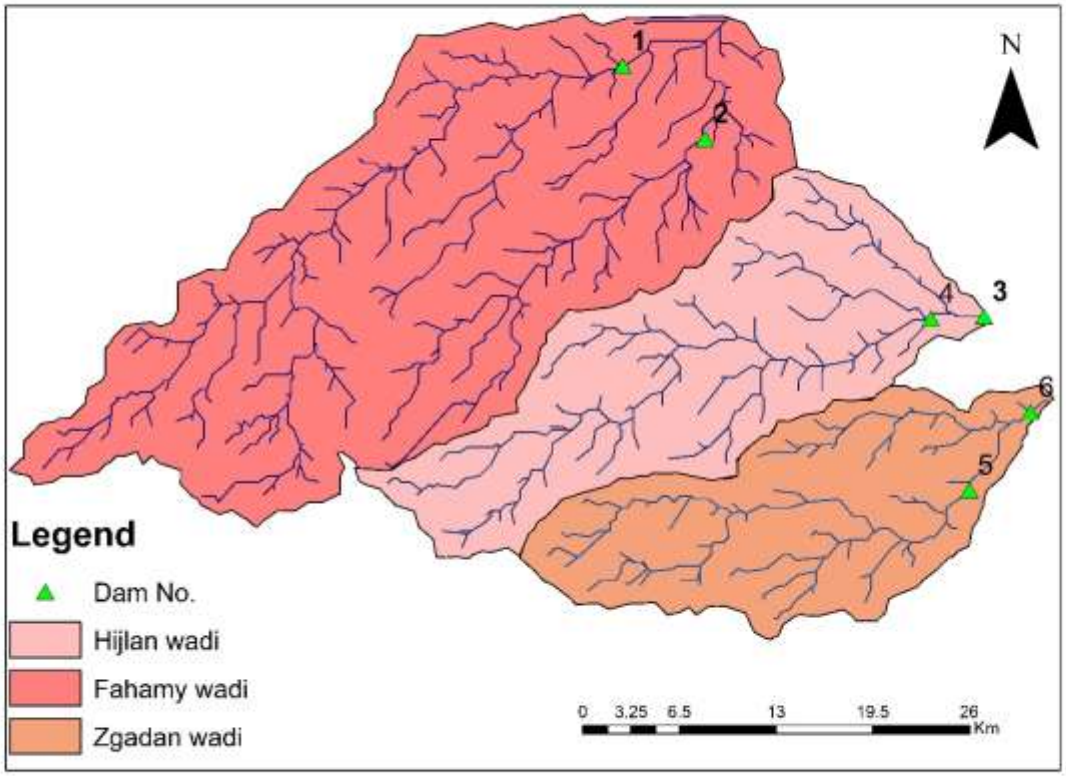

Figure 4.13 All proposed dams’ locations for the study area

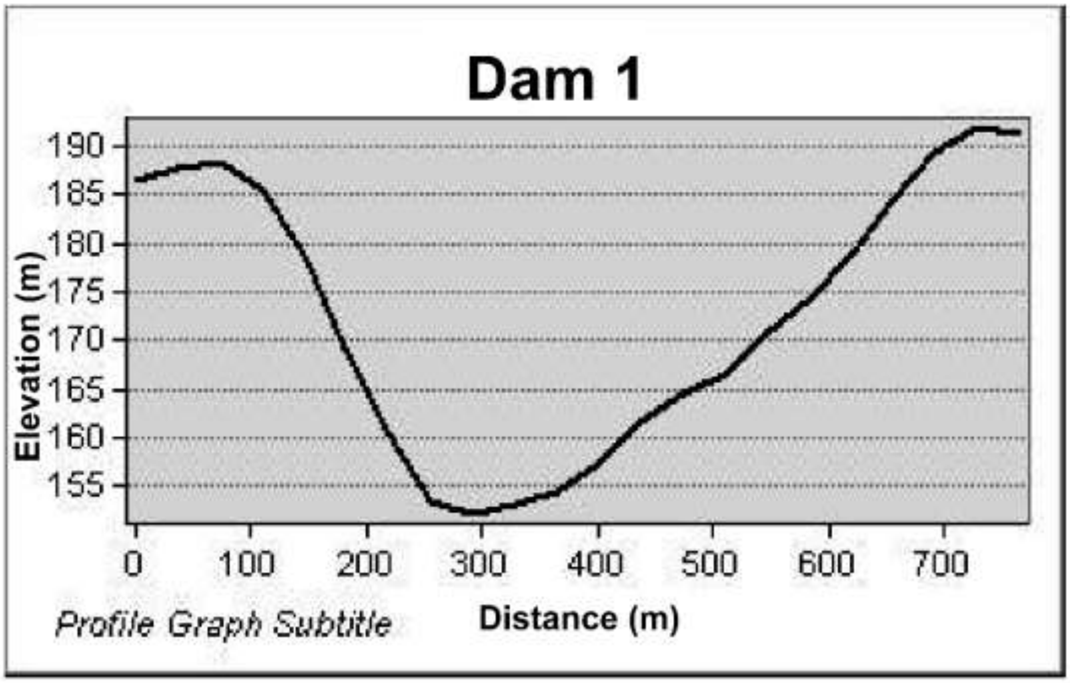

Figure 4.14 Profile for Dam 1

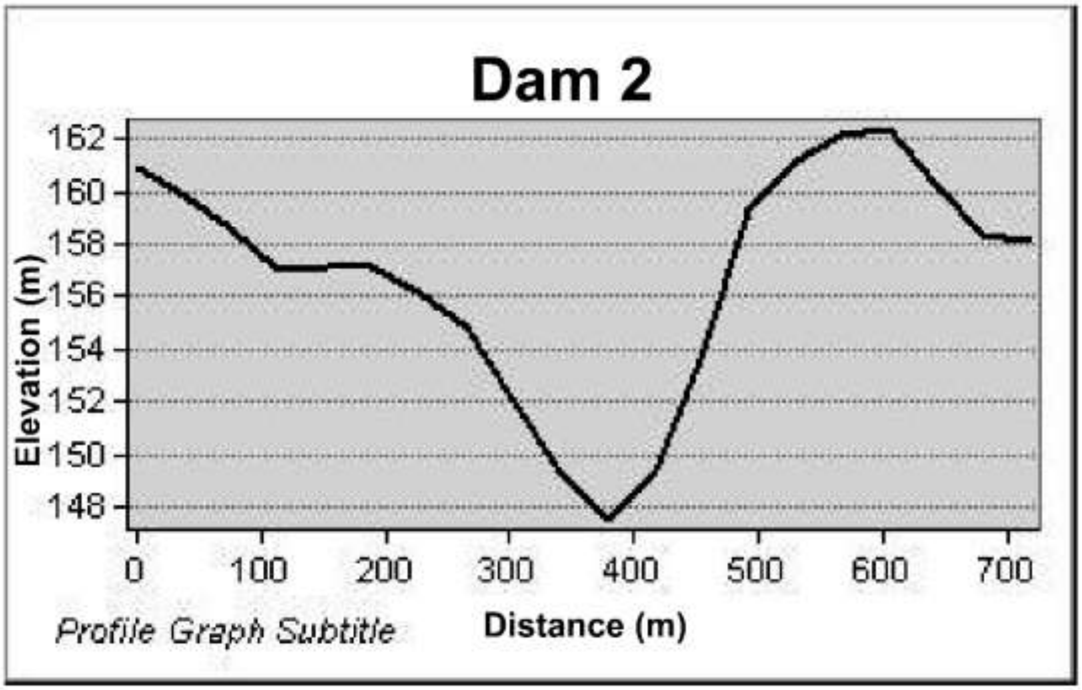

Figure 4.15 Profile for Dam 2

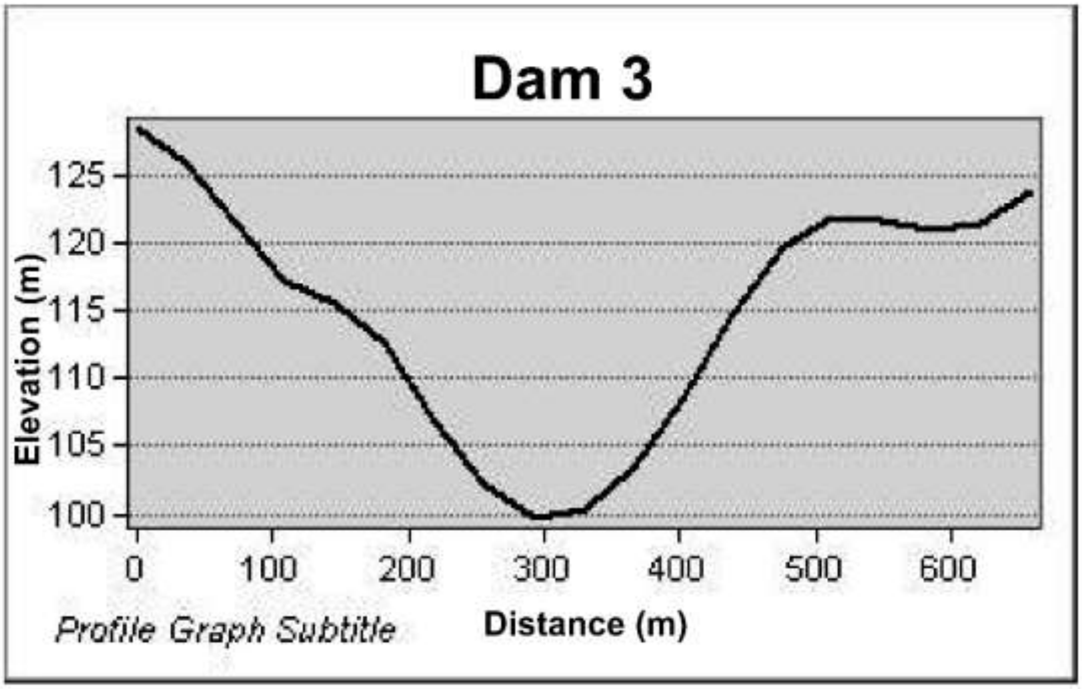

Figure 4.16 Profile for Dam 3

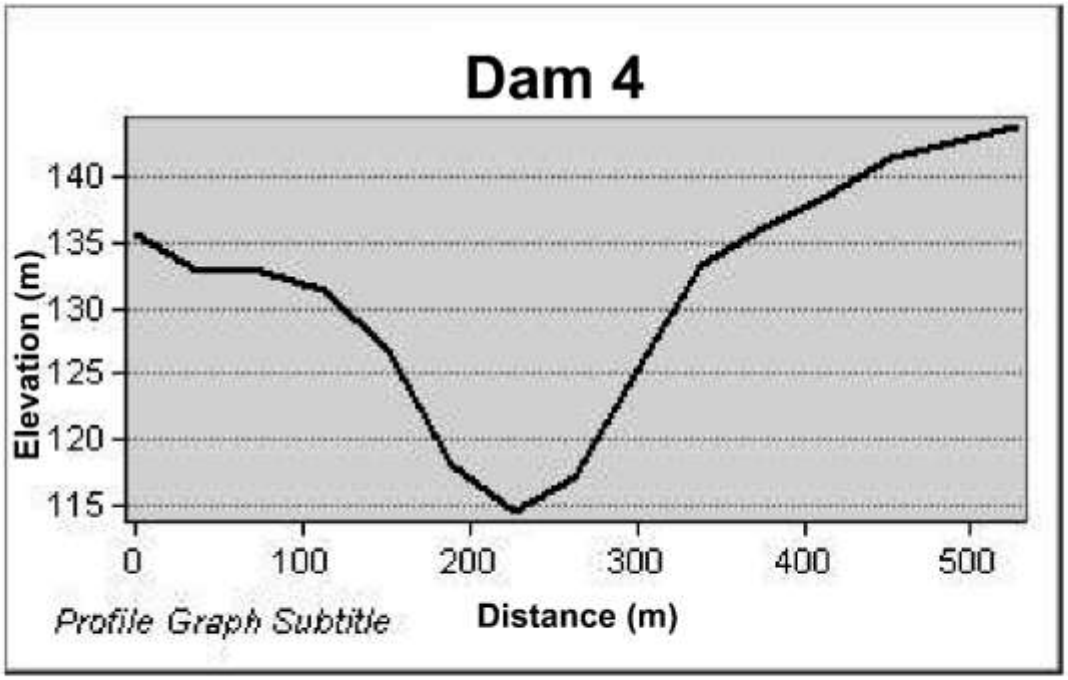

Figure 4.17 Profile for Dam 4

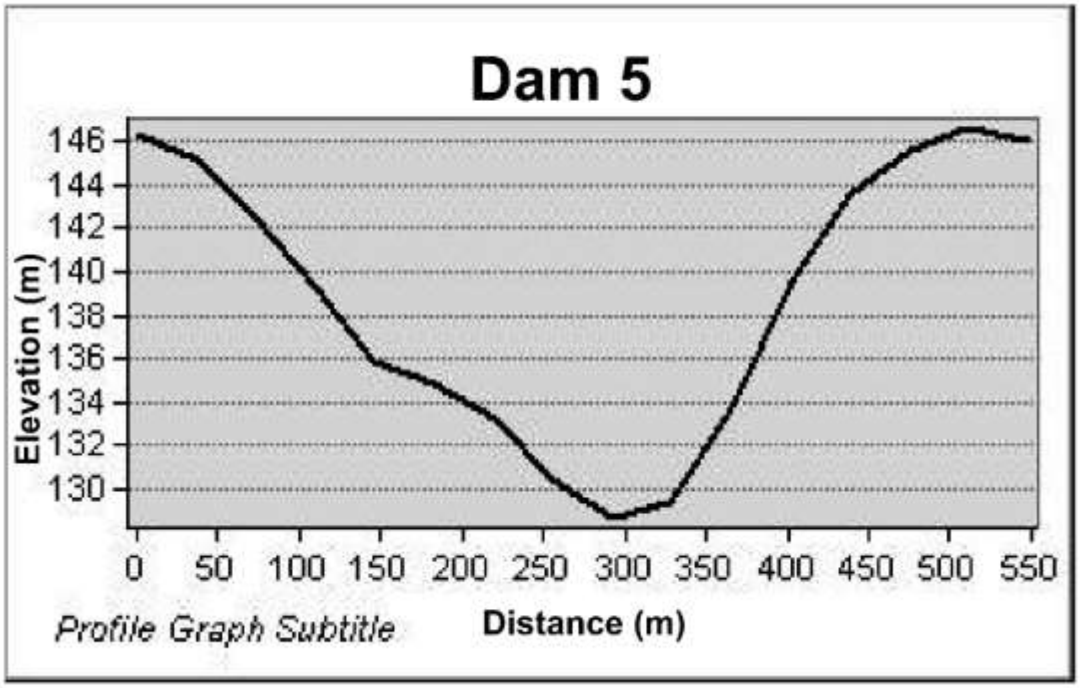

Figure 4.18 Profile for Dam 5

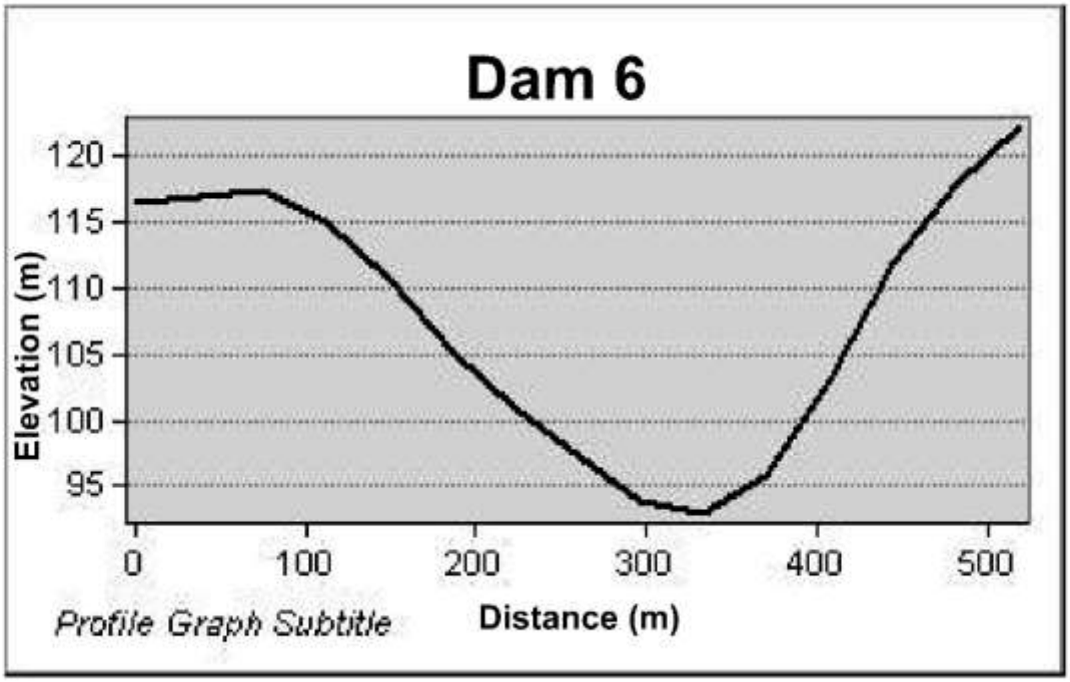

Figure 4.19 Profile for Dam 6

The Watershed modeling system (WMS 11.0) software was used to determine the morphometric criteria and delineate the watershed for each site. One of the most important morphometric criteria is the basin area. It is considered as a vital hydro-morphometric feature for driving watershed runoff patterns and is closely related to other morphometric features that impact surface runoff (i.e. basin length and maximum flow distance). This analysis is significant to fill the reservoir.

The analysis of the influence area corresponding to the upstream surface after realization of the earth dam is highly important to the analysis of potential hazards from the extents of floods on the surrounding area. This analysis is significant to study the socio-economic impact on the influence area. As shown in Figures (4.20 - 4.25), different layers represent water levels at different depths for each potential site.

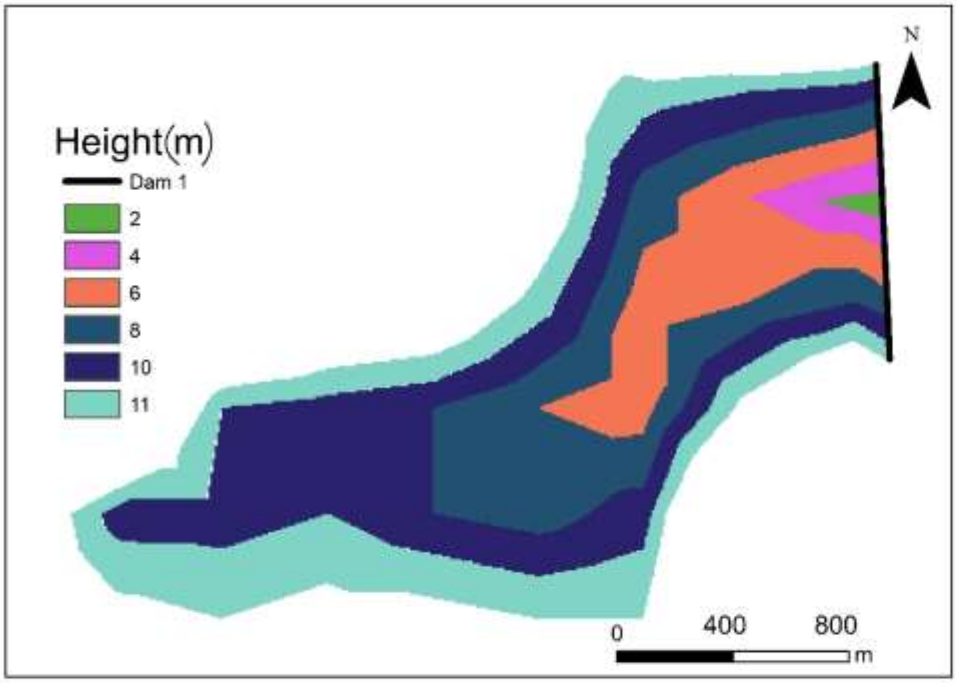

Figure 4.20 Water levels at different depths for Dam 1

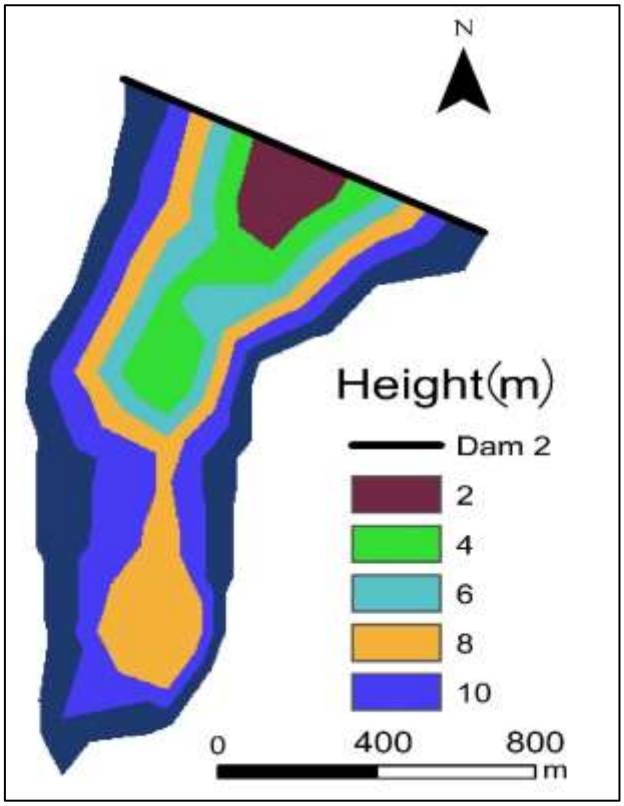

Figure 4.21 Water levels at different depths for Dam 2

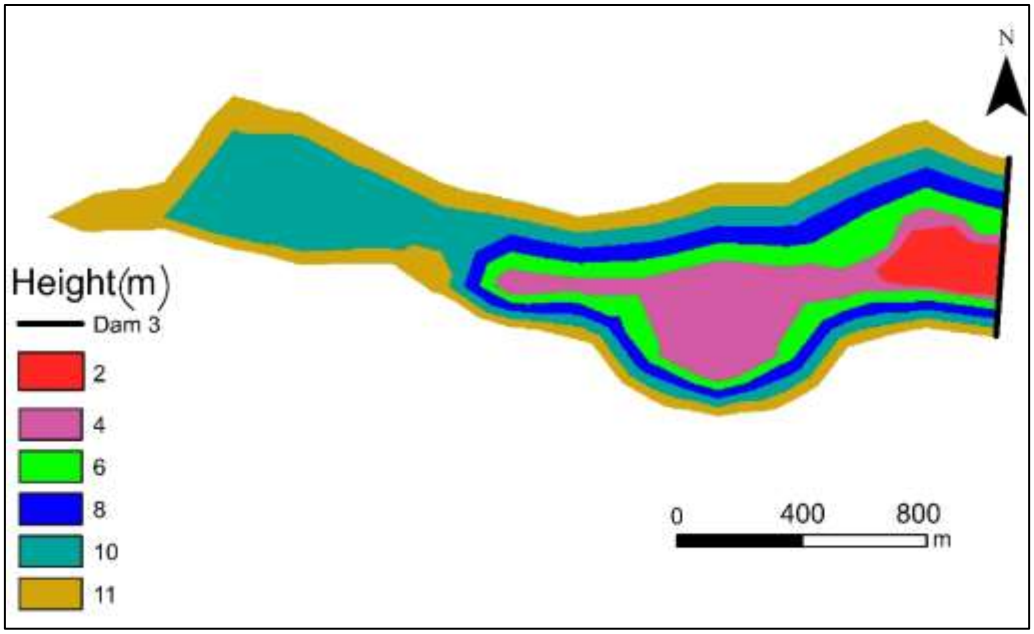

Figure 4.22 Water levels at different depths for Dam 3

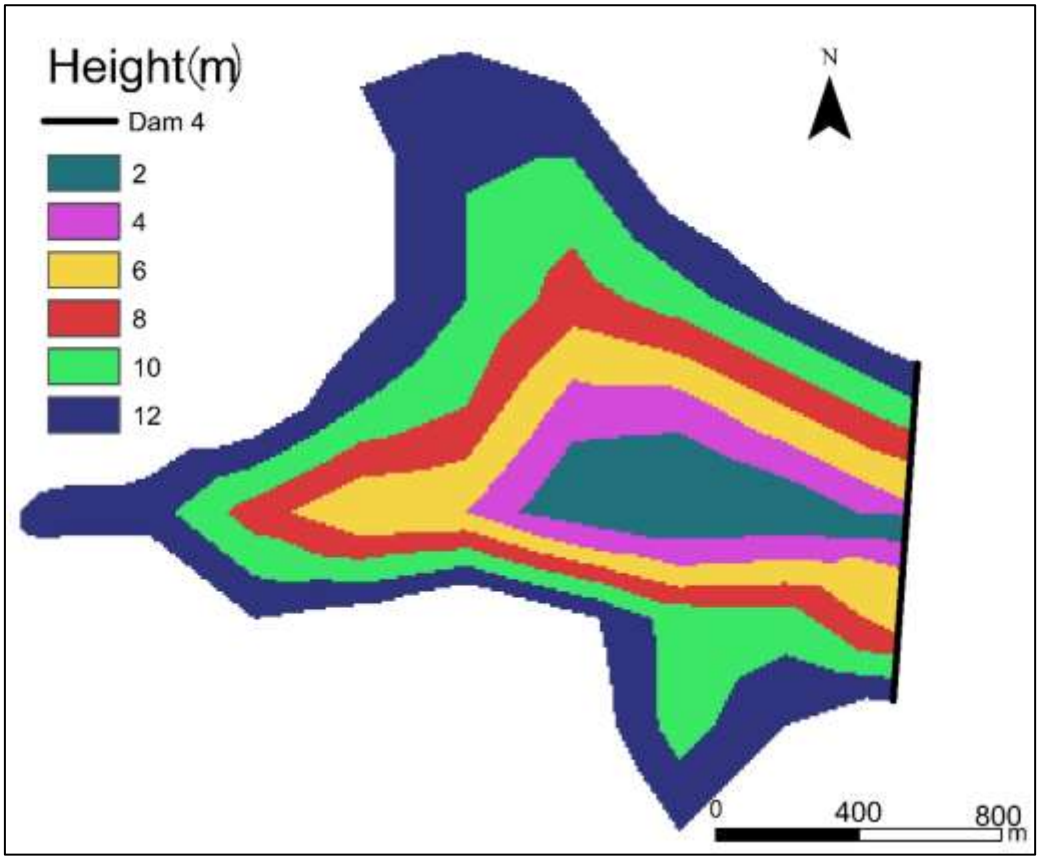

Figure 4.23 Water levels at different depths for Dam 4

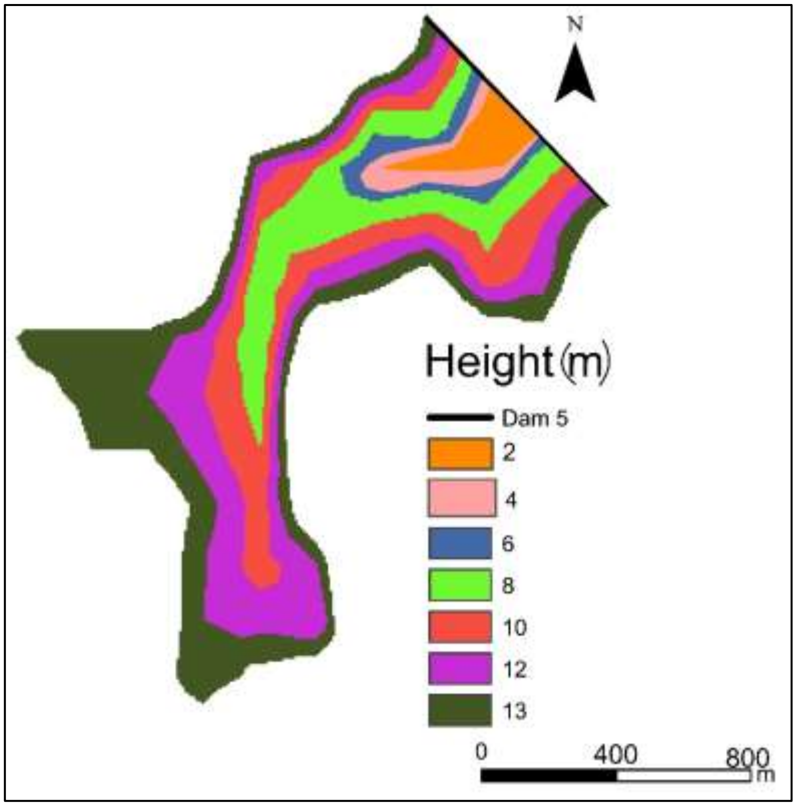

Figure 4.24 Water levels at different depths for Dam 5

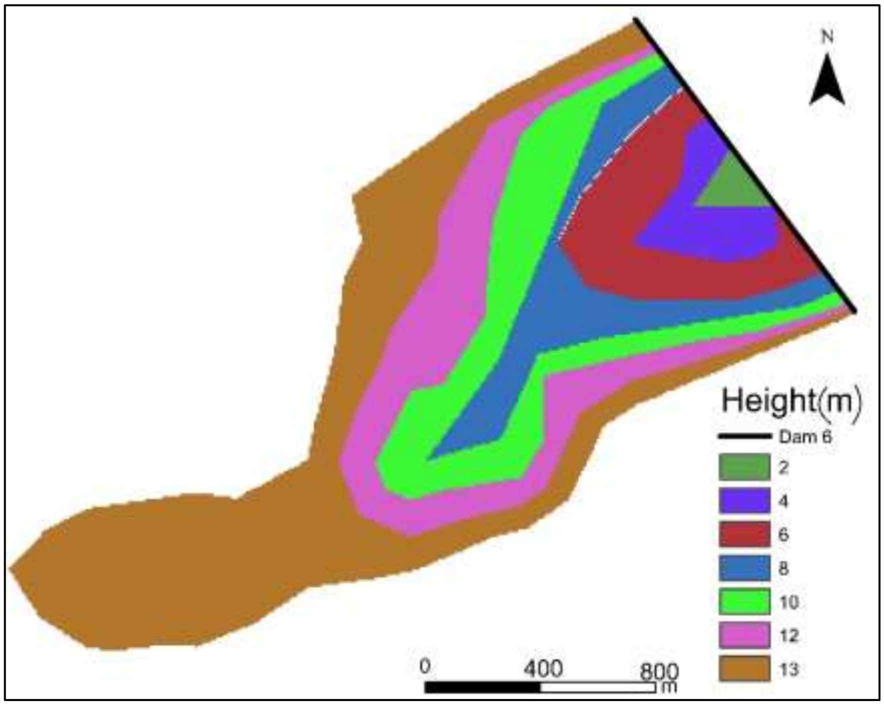

Figure 4.25 Water levels at different depths for Dam 6

4.6 Area Volume Elevation curve analysis

The accessibility of water in most arid areas is scarcely sufficient, particularly during drought seasons. Quantifying the obtainable water harvested in these areas could aid planners in meeting consumers' demand. Thus, the current study is pioneering the analysis based on the AVE curve as shown in Figures (4.26 – 4.31). The key advantage of this analysis indicates the form of the barrage body. This form has an influence on the process of evaporation rate which is increasing with the excess of the surface extent of the harvested water. The primary hypothesis of this analysis is the volume of the reservoir points out the volume of the pyramid at each level, which basis represents the surface of the water (Sawunyama, 2006). According to the environmental conditions of the research study, it is proposed that the barrage be narrow and deep to minimize evaporation rate losses. Climatic conditions, such as temperature, wind speed, sunshine, and relative humidity have a direct effect on the evaporation operation (Sayl et al., 2016). These conditions have relatively similar degree of influence on the evaporation rate, with only trivial variation over the research study Therefore, the shape index which represents the average proportion of the storage quantity to the surface area at each level for each site suggested in the study area is considered. The six suggested dams, (1, 2, 3, 4, 5, and 6) have a shape index of (2.99, 1.7, 2.4, 2.5, 2.2, and 2.1) respectively. The highest value represents maximum storage volume, while minimum surface area led to minimum evaporation rate losses. The results of this index indicate that site no. 1 turned out to be better because it has a more suitable shape than site no. 2 for Fahamy valley, while site no. 4 is better than site no. 3 for Hijlan valley, and site no. 5 is better than site no. 6 for the Zgadan valley.

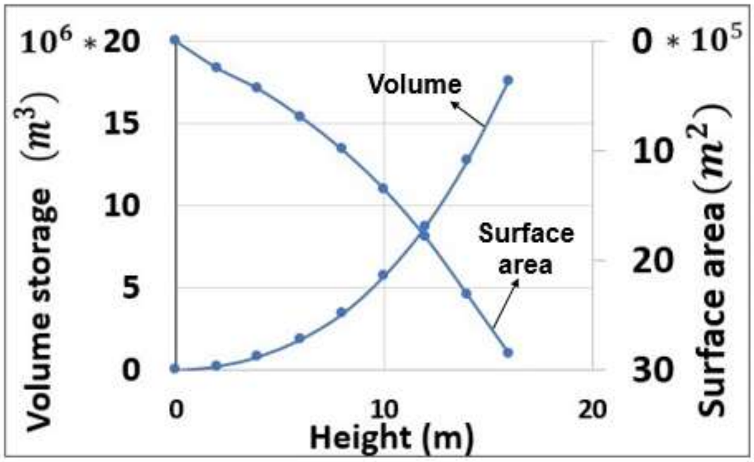

Figure 4.26 Area volume elevation curve for Dam 1

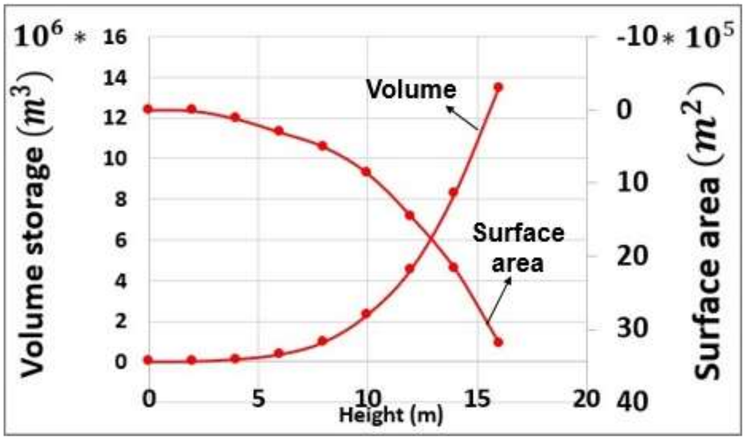

Figure 4.27 Area volume elevation curve for Dam 2

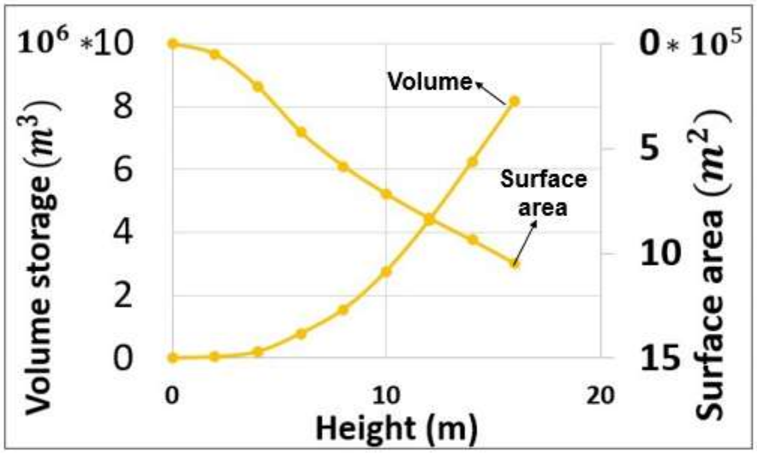

Figure 4.28 Area volume elevation curve for Dam 3

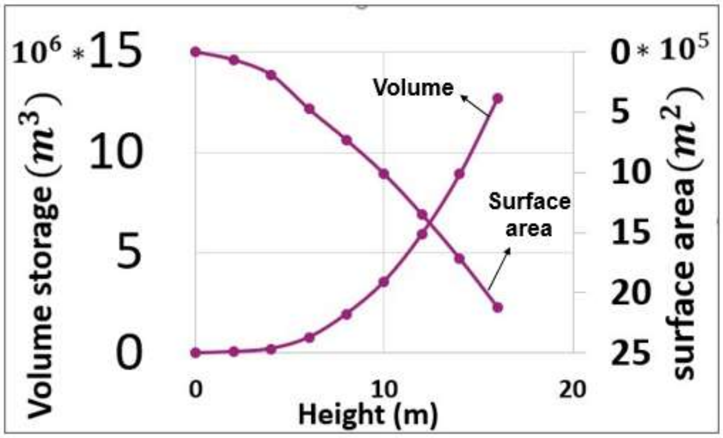

Figure 4.29 Area volume elevation curve for Dam 4

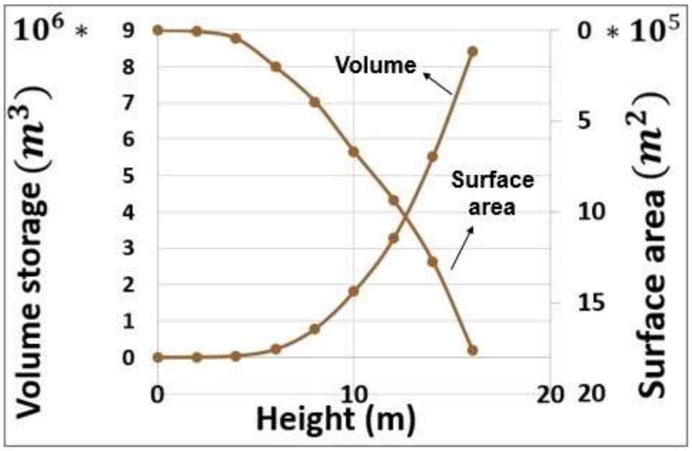

Figure 4.30 Area volume elevation curve for Dam 5

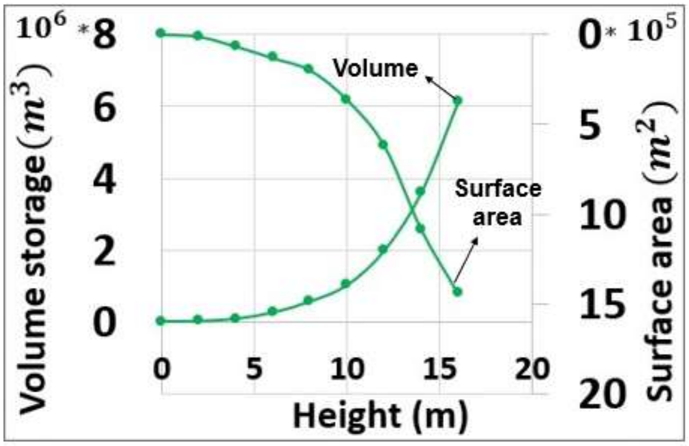

Figure 4.31 Area volume elevation curve for Dam 6

According to the highest rainfall storm (48 mm) recorded at Haditha station through 2018, the surface runoff generation provided between 3 and 9 million m^3. The evaporation rate seems to be the major issue in an arid and semi-arid region. Hence, the evaporation losses were calculated based on mean monthly evaporation rate recorded during dry seasons: May (227 mm), June (350 mm), July (391 mm), August (373 mm), and September (260 mm), and the data extracted from AVE curve. The comparison among six sites suggested has been adopted based on basin area, storage, surface area, the height of the dam, and the storage quantity after the dry season, as shown in Table 4.5. The results of this comparison indicate that site no. 1 turned out to be better because it provides a large storage volume than site no. 2 despite the fact that both have the same surface area for Fahamy valley while site no. 4 is better than site no. 3 for Hijlan valley, and site no. 6 better than site no. 5 for Zgadan valley. Sites no. 1,4, and 5 appeared as more suitable for earth dam location because they have large reservoir storage during the dry season. In addition, the results of this comparison indicate that site no. 1 has the priority for implementation than site no. 4 and site no. 5 because of its large reservoir capacity, the highest value of shape index, minimum cross-section, and basin area results in proper surface runoff.

Table 4.5 The resulting of the phases in selecting RWH dams

Phase	Property	Fahamy		Hijlan		Zgadan	
		Basin 1	Basin 2	Basin 3	Basin 4	Basin 5	Basin 6
WMS 11.0	Basin area (km^2)	708	225	447	317	237	331
AVE curve	Storage (million m^3)	8.1	6	3.25	6.1	3.9	2.75
	Surface area (million m^2)	1.75	1.75	0.8	1.5	1.05	0.9
	Dam height (m)	11	12	11	12	13	13
Evap. losses	Storage after dry season (million m^3)	5.9	3.5	2.1	4	2.6	1.65

4.7 Summary

This chapter shows the results reached through the proposed methodology, as these results achieve the objectives set forth in this study such as developing soil texture map, developing hydrological soil group map for the study area, estimating the runoff amount for ungauged watersheds, and finally detecting suitable sites for RWH in the study area. This research serves as the basis for further studies to devise a decision support framework, which may include a multi-criteria research method for decision making. In addition, the reliability of the provided knowledge is also compared with the conventional methods and past studies.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

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CONCLUSIONS AND RECOMMENDATIONS

5.1 Overview

This chapter is a summary of the work in the thesis and a guide to the most important findings and scientific facts related to the selection of suitable sites for harvesting water using remote sensing data, GIS and field survey.

The findings of this study are crucial to demonstrating the RWH planning methods or resources, which use the accessibility of remotely sensed data to change the conventional planning process.

5.2 Conclusion

This section focuses on the findings of the study and net benefit as following:

1. The method used to predict soil texture by using GIS and remote sensing data has proven effective in terms of accuracy of the results and cost. The results indicate that the RMSE for clay, silt, and sand content are 4.2, 9.5, and 11.0, respectively. The highest correlation coefficient (0.749) was produced by the clay soils. Furthermore, only four samples out of 25 have minor variations in the estimated and measured soil texture category defined by the USGS. However, all samples were located in the same hydrological soil group.
2. The results of incorporating the SCS-CN approach with the GIS technique offer a good estimation of the amount of runoff for the ungauged valleys. It would be reasonable to apply this approach for planning purposes at other sites in the Western Desert of Iraq. The results of the incorporation approach revealed that the runoff depth ranged from 12.5 mm to 20.3 mm for (48mm) for the maximum storm of rainfall recorded at Haditha station in 2018, while the amount of runoff of the maximum storm amount of runoff was 7388700 m^3, 12750000 m^3 and 9851590 m^3 for Hijlan, Fahami and Zgadan, respectively.

3. This study presented a cost-effective method to detect suitable sites for RWH planning in the arid region with limited data.
4. The study area can be classified into three classes of suitability, i.e.: (i) Highly suitable with 6% coverage (117 km2), (ii) Moderately suitable with 4% coverage (78 km2), and (iii) Least suitable with 90% coverage (1758 km2) of the basin area according to the results of the combination of WLC method and Boolean overlay method in a GIS platform.
5. Only one site for each valley could be implemented in the highly suitable category of the whole study area according to the results of the AVE analysis.
6. The combination of geospatial data and GIS with multi-criteria decision approach demonstrated to be appropriate for site selection process in arid region with limited data.

5.3 Recommendations

The general proposed suggestions for future studies are set out below, based on the work outlined in this research:

1. The method used for estimating the soil texture map represented by use RBNN model with GIS in this study can be generalized for the whole Western Desert region of Iraq.
2. The method used for developing the HSG map in this study can be generalized for the whole Western Desert region of Iraq.
3. Verifying the actual measurements runoff during rainy season in the valleys studied in this research and comparison with SCS-CN results.
4. Verifying suitable sites using sensitivity analysis method.
5. Recommending the responsible authorities, the necessity of establishing stations to measure the depth of surface runoff in the valleys of the Western Desert.
6. Recommending the use of more socio-economic criteria for selecting suitable sites for RWH.

7. It is recommended to use a more accurate DEM Digital Elevation Model for the western region to give more accurate results when dealing with the GIS platform.
8. Applying supervised classification as the base for choosing the samples locations can be suggested for future research.

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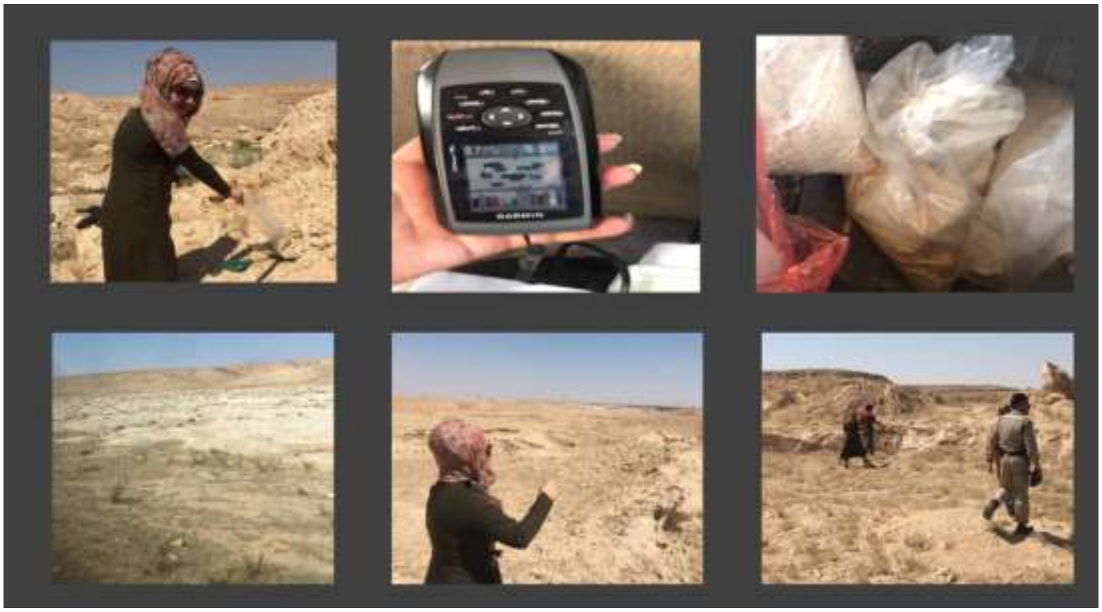
Appendix A

A1: Soil sampling from the field



A2: Laboratory work for soil tests (sieve analysis and Hydrometer)

Appendix B

Spectral reflectance of nine bands and soil texture for 120 soil samples

S. No.	**X (Decimal Degree)**	**Y (Decimal Degree**	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	**B8**	**B9**	**sand%**	**Silt%**	**clay%**	**soil type**
0	42.3	34.1	15235	15670	18031	21379	25367	28166	23543	18169	5068	54	33.442	12.558	loam
1	42.3	34.1	15410	15918	18354	22123	26512	28798	24259	20012	5073	64	36	0	loam
2	42.3	34.1	13691	13729	15216	18072	22133	25704	21643	16037	5064	56	37.4	6.6	loam
3	42.3	34.1	15269	15525	17696	21311	25813	27604	22535	18427	5066	59	39.032	1.968	loam
4	42.3	34.1	15576	16189	18884	22538	26337	28390	23909	20627	5072	94	6	0	sand
5	42.2	34.0	13663	13785	15447	18591	22592	25901	21763	15970	5075	36.6	62.3856	1.0144	silty loam
6	42.3	34.1	16581	17219	19736	23032	27155	30504	25036	20926	5070	88	11.0364	0.9636	sand
7	42.3	34.1	15657	16254	18867	22670	26923	29457	24167	19611	5071	77.35	22.2876	0.3624	loam
8	42.3	34.1	13771	13803	15349	18331	22148	25756	21670	16244	5067	44	55.1	0.9	silty loam
9	42.3	34.1	16597	17005	19174	22615	26882	30365	25026	21152	5073	96	3.936	0.064	sand
10	42.3	34.1	14279	14632	16660	20179	24871	26739	21411	18219	5074	55	45	0	loam
11	42.3	34.1	15410	15781	17829	20836	24966	28406	23704	17728	5065	55	38.5	6.5	loam
12	42.3	34.1	15281	15670	17845	21659	25757	28540	23890	18818	5073	31	63.46	5.54	silty loam
13	42.3	34.1	13947	13991	15556	18442	22339	25739	21635	17002	5075	58	39.3	2.7	loam
14	42.3	34.1	13884	13974	15644	18775	22717	26220	22236	16480	5073	25	73.8	1.2	silty loam
15	42.4	34.1	13242	12847	12709	11465	12657	11619	9392	13334	5063	85	14	1	sand
16	42.4	34.1	15377	15785	18051	20972	24962	26553	22078	21358	5046	64	34.5	1.5	loam
17	42.2	34.1	13696	13724	15322	18243	22143	25756	21627	14988	5073	60	34.88	5.12	loam
18	42.3	34.1	14077	14007	14448	16033	18569	20179	18483	16388	5064	61	38.7	0.3	loam

19	42.3	34.1	14280	14581	16592	19938	24112	27122	22790	17316	5072	65	31.066	3.934	loam
20	42.3	34.1	14532	14777	16973	20688	24694	27645	23846	18416	5063	73	22.2318	4.682	loam
21	42.3	34.1	15036	15409	17818	21517	25862	28917	24970	20288	5075	85	13.6	1.4	sand
22	42.3	34.1	13816	13884	15545	18613	22463	26277	22360	16545	5069	65.3	28.57	6.13	loam
23	42.3	34.1	14584	14847	17088	20847	25383	28777	24199	18221	5063	51	41.9195	7.0805	loam
24	42.3	34.1	14061	14231	16126	19475	23506	26927	22859	16934	5073	71	26.2	2.8	loam
25	42.2	34.2	13691	13933	16081	20256	24658	28051	23337	17223	5097	44	43.4	12.6	Loam
26	42.2	34.2	13446	13511	15350	19115	23360	26836	22147	16554	5076	33	48.1	18.9	Loam
27	42.3	34.1	14142	14389	16804	21532	26520	30102	24812	17917	5075	50	38.9	11.1	Loam
28	42.2	34.1	13598	13661	15409	18925	23344	26827	22189	16844	5088	39	44.7	16.3	Loam
29	42.2	34.2	13569	13680	15705	19643	23845	27176	22582	16889	5068	39	45.8	15.2	Loam
30	42.1	34.1	13510	13586	15528	19304	23668	27230	22325	16856	5087	44	42	14	Loam
31	42.1	34.1	13739	13927	16037	20177	24632	27833	23021	17648	5089	38	42.6	19.4	Loam
32	42.0	34.1	13927	14198	16612	21346	25984	29222	24669	18219	5090	48	35.8	16.2	Loam
33	42.0	34.1	13644	13746	15775	19665	23870	27279	22837	16733	5075	47	38.1	14.9	Loam
34	41.9	34.1	13507	13587	15387	19187	23429	27110	22635	16747	5097	46	36.4	17.6	Loam
35	41.9	34.1	14084	14398	16753	21159	25809	28728	24020	17895	5084	43	38.4	18.6	Loam
36	41.9	34.0	13469	13527	15421	19277	23565	27049	22302	16888	5080	49	35.8	15.2	Loam
37	42.0	34.1	13949	14144	16554	21493	26148	28964	23989	18233	5097	43	41.6	15.4	Loam
38	42.0	34.1	13978	14219	16596	21171	25602	28701	24106	18085	5077	47	43.2	9.8	Loam
39	42.1	34.1	13906	14174	16501	20872	25229	28381	23899	17868	5082	44	45.7	10.3	Loam
40	42.1	34.1	13516	13585	15491	19256	23402	26954	22517	16759	5076	49	41.6	9.4	Loam
41	42.1	34.1	13430	13453	15212	18783	22901	26556	22065	16495	5106	36	46	18	Loam
42	42.1	34.1	13467	13511	15399	19211	23217	26957	22652	16518	5084	41	42.4	16.6	Loam
43	42.2	34.1	13627	13636	15466	19023	22948	26452	22238	16721	5071	40	47.5	12.5	Loam
44	42.1	34.0	13524	13573	15359	19135	23113	26650	22409	16700	5077	48	41.2	10.8	Loam

45	42.1	34.0	13610	13665	15462	19073	22977	26480	22219	16584	5093	44	44.4	11.6	Loam
46	42.1	34.0	13402	13497	15410	19735	24629	28475	23233	17642	5083	40	46.9	13.1	Loam
47	42.0	34.0	13935	14160	16506	21203	25976	29322	24244	18552	5080	38	48.5	13.5	Loam
48	42.0	34.0	13666	13849	15988	20438	25106	28684	23847	17515	5084	39	47.7	13.3	Loam
49	42.0	34.0	13943	14158	16546	21101	25688	28803	24066	18006	5078	38	42.9	19.1	Loam
50	42.0	34.0	13315	13327	15030	19269	23890	27536	22800	16423	5087	48	37	15	Loam
51	42.0	34.0	13615	13654	15509	19165	23099	26567	22330	16582	5084	47	42.2	10.8	Loam
52	42.0	34.0	13816	13900	15631	18937	22851	26405	22101	16594	5086	44	44.6	11.4	Loam
53	42.0	34.0	13818	13950	15992	20060	24223	27211	22919	17463	5081	37	44.3	18.7	Loam
54	41.9	34.0	13461	13463	14976	18108	21854	25446	21462	16179	5079	42	40.1	17.9	Loam
55	41.9	34.0	13339	13237	14460	17179	20868	24912	20925	15403	5067	33	46.3	20.7	Loam
56	41.9	34.0	13878	14008	16137	20018	24127	27447	23120	17316	5077	45	38.3	16.7	Loam
57	41.9	34.0	13452	13381	15004	18404	22197	26177	22051	16165	5078	46	41.6	12.4	Loam
58	41.8	34.0	13565	13651	15429	18888	22931	26382	22098	16513	5073	40	46.2	13.8	Loam
59	41.8	34.0	13415	13302	14591	17340	21041	25090	20970	15348	5074	49	41.1	9.9	Loam
60	41.8	34.0	13302	13273	14828	18082	22012	26003	21667	15709	5105	43	40.6	16.4	Loam
61	41.7	34.0	13674	13811	15885	19842	24150	27456	22809	17138	5064	32	55.4	12.6	Silty Loam
62	41.8	34.1	14322	14636	16918	21248	25585	28586	24180	18604	5090	62	27.2	10.8	Sandy Loam
63	41.9	34.1	14118	14329	16637	20993	25378	28545	23817	17868	5067	53	33.7	13.3	Sandy Loam
64	41.9	34.1	13862	14019	16147	20236	24361	27221	22759	16825	5068	58	35.3	6.7	Sandy Loam
65	41.9	34.1	13438	13396	14749	17713	21643	25486	21225	15722	5072	52	40.7	7.3	Sandy Loam
66	41.9	34.2	14168	14389	16847	21547	25884	28652	24234	18341	5078	55	39.3	5.7	Sandy Loam
67	42.0	34.2	13615	13654	15509	19165	23099	26567	22330	16582	5084	47	42.2	10.8	Loam
68	42.0	34.2	13816	13900	15631	18937	22851	26405	22101	16594	5086	44	44.6	11.4	Loam
69	42.0	34.2	13818	13950	15992	20060	24223	27211	22919	17463	5081	37	44.3	18.7	Loam
70	42.0	34.2	13461	13463	14976	18108	21854	25446	21462	16179	5079	42	40.1	17.9	Loam

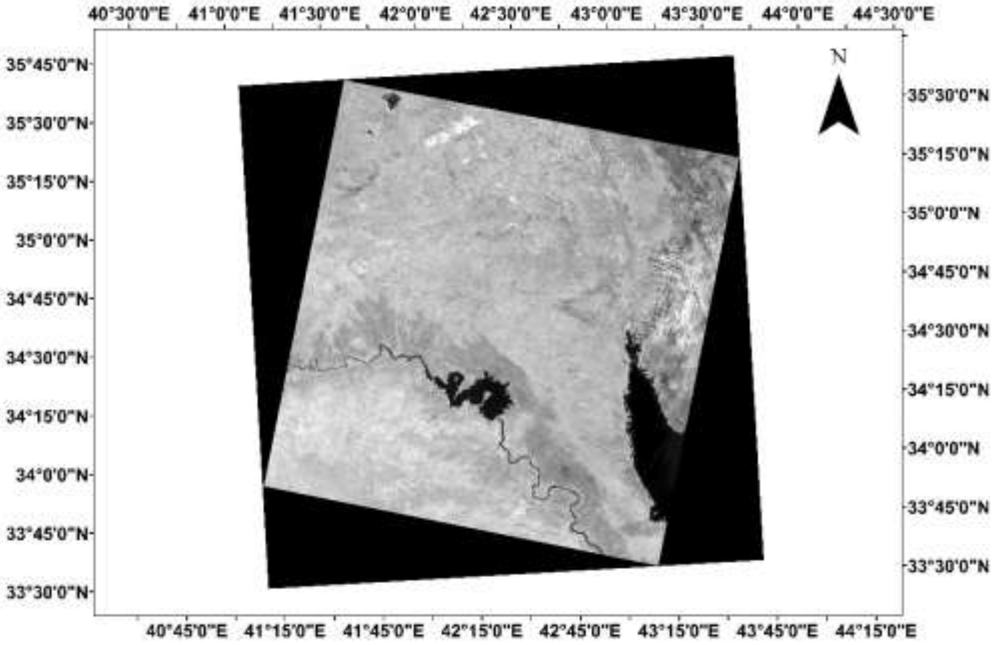
71	42.1	34.1	13339	13237	14460	17179	20868	24912	20925	15403	5067	33	46.3	20.7	Loam
72	42.1	34.2	13878	14008	16137	20018	24127	27447	23120	17316	5077	45	38.3	16.7	Loam
73	42.2	34.2	13452	13381	15004	18404	22197	26177	22051	16165	5078	46	41.6	12.4	Loam
74	42.2	34.2	13565	13651	15429	18888	22931	26382	22098	16513	5073	40	46.2	13.8	Loam
75	42.2	34.1	13588	13601	15397	19019	23220	26863	22350	16398	5076	57	34.8	8.2	Sandy Loam
76	42.2	34.1	13517	13496	14968	18061	21952	25834	21593	16180	5073	53	38.3	8.7	Sandy Loam
77	42.2	34.1	13415	13302	14591	17340	21041	25090	20970	15348	5074	49	41.1	9.9	Loam
78	42.2	34.0	13302	13273	14828	18082	22012	26003	21667	15709	5105	43	40.6	16.4	Loam
79	42.2	34.0	13470	13462	15158	18697	22602	26284	21955	16241	5087	55	35.6	9.4	Sandy Loam
80	42.2	33.9	13649	13693	15407	18931	22848	26197	22053	16882	5078	43	42.1	14.9	Loam
81	41.9	34.2	13764	13838	15747	19520	23546	26895	22653	16637	5073	45	48.8	6.2	Loam
82	41.9	34.2	13905	13952	15999	19730	23881	27335	23151	17150	5082	46	47.9	6.1	Loam
83	41.8	34.1	13098	12939	13985	16562	20536	24561	19974	14925	5077	36	48.6	15.4	Loam
84	41.8	34.1	13502	13504	15053	18325	22399	26100	21359	16092	5104	55	37.6	7.4	Sandy Loam
85	42.2	34.3	13342	13315	14738	17834	21935	25476	20939	15108	5094	24	57	19	Silty Loam
86	42.2	34.3	13691	13832	15919	19978	24330	27795	23127	17296	5067	31	53.5	15.5	Silty Loam
87	42.2	34.2	13478	13560	15427	19079	23176	26693	22243	16263	5060	30	50.3	19.7	Silty Loam
88	42.2	34.2	13502	13504	15053	18325	22399	26100	21359	16092	5104	55	37.6	7.4	Sandy Loam
89	42.2	34.3	13142	13035	14229	17032	21072	25019	20380	15071	5109	55	37.6	7.4	Sandy Loam
90	42.1	34.3	13646	13712	15443	18899	23145	26723	21970	16812	5080	53	36.6	10.4	Sandy Loam
91	42.1	34.3	13302	13273	14828	18082	22012	26003	21667	15709	5105	43	40.6	16.4	Loam
92	42.2	34.3	13470	13462	15158	18697	22602	26284	21955	16241	5087	55	35.6	9.4	Sandy Loam
93	42.2	34.3	13588	13601	15397	19019	23220	26863	22350	16398	5076	57	34.8	8.2	Sandy Loam
94	42.2	34.3	13517	13496	14968	18061	21952	25834	21593	16180	5073	53	38.3	8.7	Sandy Loam
95	42.2	34.3	13598	13661	15409	18925	23344	26827	22189	16844	5088	39	44.7	16.3	Loam
96	42.1	34.2	13569	13680	15705	19643	23845	27176	22582	16889	5068	39	45.8	15.2	Loam

97	42.1	34.3	13510	13586	15528	19304	23668	27230	22325	16856	5087	44	42	14	Loam
98	42.3	34.1	13739	13927	16037	20177	24632	27833	23021	17648	5089	38	42.6	19.4	Loam
99	42.4	34.1	13927	14198	16612	21346	25984	29222	24669	18219	5090	48	35.8	16.2	Loam
100	42.2	34.2	13588	13601	15397	19019	23220	26863	22350	16398	5076	57	34.8	8.2	Sandy Loam
101	42.2	34.2	13517	13496	14968	18061	21952	25834	21593	16180	5073	53	38.3	8.7	Sandy Loam
102	42.2	34.2	13666	13849	15988	20438	25106	28684	23847	17515	5084	39	47.7	13.3	Loam
103	42.1	34.2	13943	14158	16546	21101	25688	28803	24066	18006	5078	38	42.9	19.1	Loam
104	42.1	34.2	13315	13327	15030	19269	23890	27536	22800	16423	5087	48	37	15	Loam
105	42.1	34.0	13810	14029	16235	21050	26203	30106	24552	18305	5108	56	31.3	12.7	Sandy Loam
106	42.1	33.9	13294	13327	15104	19370	24242	28227	23016	16558	5089	51	35.8	13.2	Loam
107	42.0	34.1	14080	14355	16710	21457	26136	29201	24276	18358	5071	53	34.3	12.7	Sandy Loam
108	42.1	34.1	13949	14144	16554	21493	26148	28964	23989	18233	5097	43	41.6	15.4	Loam
109	42.1	34.1	13978	14219	16596	21171	25602	28701	24106	18085	5077	47	43.2	9.8	Loam
110	42.1	34.1	13906	14174	16501	20872	25229	28381	23899	17868	5082	44	45.7	10.3	Loam
111	42.1	34.1	13516	13585	15491	19256	23402	26954	22517	16759	5076	49	41.6	9.4	Loam
112	42.2	34.1	13674	13811	15885	19842	24150	27456	22809	17138	5064	32	55.4	12.6	Silty Loam
113	42.1	34.3	13498	13528	15197	18543	22535	26332	22023	16783	5098	45	41.6	13.4	Loam
114	42.0	34.3	13538	13620	15398	18949	23210	26833	22226	16693	5074	46	40.8	13.2	Loam
115	42.1	34.2	13466	13520	15320	19101	23356	26915	22212	16494	5067	47	46.6	6.4	Sandy Loam
116	42.0	34.2	13480	13550	15338	18964	23030	26699	22261	16506	5079	44	49.3	6.7	Sandy Loam
117	42.0	34.2	13694	13895	16141	21049	26377	29794	24681	17857	5106	55	35	10	Sandy Loam
118	42.0	34.1	14177	14441	16935	22168	27698	30856	25356	18570	5060	52	33.3	14.7	Sandy Loam
119	42.0	34.2	13592	13761	15910	20840	26197	30079	24662	17293	5071	60	27.7	12.3	Sandy Loam

Appendix C

A1: Landsat 8 image of July, 2019

A2: Landsat 8 image of April, 2019



جمهورية العراق

وزارة التعليم العالي والبحث العلمي

جامعة الانبار – كلية الهندسة

قسم هندسة السدود والموارد المائية

التحري عن المواقع المناسبة لتخطيط حصاد مياه الأمطار باستخدام نظم المعلومات الجغرافية وتقنيات الاستشعار عن بعد في الصحراء الغربية للعراق

رسالة

مقدمة الى قسم السدود والموارد المائية في جامعة الانبار كجزء من متطلبات نيل درجة الماجستير في علوم هندسة الموارد المائية

من قبل

هديل قيس هاشم

(بكالوريوس هندسة سدود وموارد مائية، ٢٠١٤)

إشراف

آ.م.د. خميس نبع صايل

١٤٤٢هـ ٢٠٢٠م

الخلاصة

تعتبر الصحراء الغربية في العراق من أكبر المناطق القاحلة في العراق التي تعاني من نقص حاد في المياه، ويرجع ذلك بسبب تغير الظروف المناخية وسوء التخطيط وإدارة الموارد المائية. تخزين المياه يمكن أن يخفف من الآثار السلبية للجفاف من خلال بناء السدود وضمان إمدادات المياه. يعد اكتشاف المواقع المناسبة لتجميع مياه الأمطار (RWH) لدعم تخطيط وإدارة موارد المياه قضية معقدة ويمكن أن تستغرق وقتًا طويلاً. ساعدت تقنيات المعلومات الجديدة، مثل بيانات نظام المعلومات الجغرافية (GIS) والاستشعار عن بعد (RS) على تسهيل عملية اختيار الموقع في مرحلة التخطيط لحصاد مياه الأمطار. تتضمن هذه الدراسة ثلاثة أهداف: (1) إنشاء خريطة رقمية للتربة باستخدام نموذج الشبكة العصبية الاصطناعية (ANN) المتكامل مع بيانات نظام المعلومات الجغرافية والاستشعار عن بعد RS والبيانات الحقلية، (2) تقدير الجريان السطحي لأودية حجلان والفحمي وزغدان باستخدام طريقة (SCS-CN) مع نظم المعلومات الجغرافية، و (3) الكشف عن مواقع حصاد مياه الأمطار المناسبة من خلال دمج RS وGIS مع تقنية قرار متعددة المعايير. أظهرت النتائج أن نموذج الشبكات العصبية (RBNN) قد أثبت نجاحه في التنبؤ بالتوزيع المكاني للتربة الطينية، الطمي والرمل. كما لوحظ أن الخطأ التربيعي لمتوسط الجذر (RMSE) للطين والطمي والرمل كان 4.2٪ و9.5٪ و11.0٪ على التوالي. علاوة على ذلك، ارتبط الانعكاس الطيفي والتربة الطينية ارتباطًا وثيقًا بقيمة معامل الارتباط البالغة (0.749). علاوة على ذلك، من بين 25 عينة حددتها هيئة المسح الجيولوجي الأمريكية، كان لأربع عينات فقط اختلافات طفيفة بين فئة نسيج التربة المقدرة والمقاسة. أظهرت نتائج دمج SCS-CN مع نظام المعلومات الجغرافية أن عمق الجريان قد تراوح من 12.5 مم إلى 20.3 مم من (48 مم) لأقصى عاصفة من الأمطار سجلت في محطة حديثة خلال عام 2018، بينما كمية الجريان السطحي للعاصفة كانت 7,388,700 و12,750,000 و9,851,590 متر مكعب لحجلان وفحيمي وزغدان على التوالي. تم استخدام سبعة معايير في عملية اختيار الموقع بطريقة WLC: الجريان السطحي، والانحدار، وقوام التربة، واستعمالات الأراضي وغطائها (LULC)، والبعد من المناطق الزراعية، والبعد من المناطق السكنية، والبعد من الطرق. بينما تم استخدام

ترتيب المجاري المائية والبعد من الفوالق في طريقة Boolean overlay. أشارت النتائج إلى أن الخريطة النهائية لمنطقة الدراسة يمكن تقسيمها إلى ثلاث فئات من الملائمة: (1) مناسبة للغاية 6% (117 كم مربع)، (2) مناسبة بشكل معتدل 4% (78 كم مربع)، و (3) أقل مناسبة 9% (1758 كم مربع) من المنطقة المدروسة. تمت الإشارة إلى أنه يمكن تنفيذ سد ترابي واحد لكل وادي على طول مجاري المياه الرئيسية. يمكن اعتماد هذه المنهجية منخفضة التكلفة والفعالة من حيث الوقت في المناطق القاحلة لتبني حصاد مياه الأمطار كاستراتيجية فعالة للتعامل مع ندرة المياه المتزايدة.