Student thesis series INES nr 271

Water harvesting in Erbil Governorate, Kurdistan region, Iraq

Detection of suitable sites using Geographic Information System and Remote Sensing

Author: Hasan Mohammed Hameed

2013
Department of Physical Geography and Ecosystems Science
Lund University
Sölvegatan 12
S- 223 62 Lund
Sweden

Hasan Mohammed Hameed, Water harvesting in Erbil Governorate, Kurdistan region, Iraq. Detection of suitable sites using Geographic Information System and Remote Sensing

Master degree thesis, 30 credits in Geomatics.

Supervisor: Prof. Petter Pilesjö.

Department of Physical Geography and Ecosystems Science, Lund University, Sweden

Water harvesting in Erbil Governorate, Kurdistan region, Iraq
Detection of suitable sites using Geographic Information System and Remote Sensing

---

Hasan Mohammed Hameed

Master degree thesis in Geomatics, 30 credits

Department of physical Geography and Ecosystem Science
Lund University

Supervisor
Prof. Petter Pilesjö
Department of Physical Geography and Ecosystem Science
Lund University

April 2013

Abstract

The drought effects on Iraq, and specifically on the Kurdistan region, is on the rise due to the climate change. Management of the water resources has become necessary to solve this problem. The aim of this study is to identify suitable zones for rainwater harvesting in Erbil governorate, Iraqi Kurdistan Region, by using Geographic Information System (GIS) and Multi Criteria Evaluation (MCE) as a tool for decision support. Multi criteria evaluation is carried out in Geographic Information System to help the decision makers in determining suitable zones for rainwater harvesting. The criteria which were taken into account for multi criteria evaluation are; soil texture, slope, rainfall data (2000-2011), land use/cover and drainage network. The soil conservation service model was used to estimate the runoff depth. Land use/cover was extracted from LANDSAT satellite imagery (2006) by using remote sensing technique (Idrisi software). An analytic hierarchy process (AHP) method was used to estimate the weight for each criterion. The weighted linear combination method was used to incorporate the criteria weight in the multi criteria evaluation operation. The multi criteria evaluation is supporting determination of suitable areas for rainwater harvesting, and suitable zones to construct small and medium dam sites. The total suitable area for water harvesting is 36% of the study area, where 14% represents moderate suitability while 33% indicate very low suitability. Macro catchment is significant in the selection of suitable areas for rainwater harvesting. A contour line map and the drainage network, represented as a Triangulare Irregular Network (TIN), were used to suggest six sites for small and intermediate dams. The total water capacity of these dams is about 165 million cubic meters.

.

Keywords: geographic information system, remote sensing, multi criteria evaluation, analytic hierarchy process and macro catchment rainwater harvesting.

Acknowledgment

I owe sincere and earnest thankfulness to my supervisor, **Petter Pilesjö,** who made me believe in myself and guided me through the whole process of writing my thesis. I am sure that this thesis would not have been possible without his support. I would like to show my gratitude to **Karin Larsson** for her help in the practical part of my thesis. I am truly indebted and thankful to Dr. **Muslih Mustafa** the president of Soran University and Dr. **Howri Mansurbeg**, vice president for scientific affairs of Soran University to support me to study at Lund University. It is a great pleasure to thank my friends and colleagues, especially Dr. **Abdul Ghani Hasan**, for their help and moral support. Lastly I wish to thank my family and many close friends for giving me encouragement and enthusiasm to finish my master degree.

Dedication

This thesis is dedicated to:

My father, who passed away before I get my degree.

My mother, my wife and children (Dlkhush, Ali and Abdulallah) , who suffered being away from me for two years.

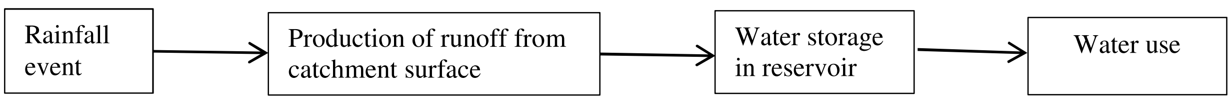
Contents

List of Figures

List of the Table

1 Introduction

Rainwater harvesting is the process of collection and storage of rainfall by runoff for different purposes such as agriculture, livestock, domestic use, industry and ground water recharge (Mzirai 2010) as well as commercial use, institutional use and flood control (Roebuck 2007). The flowchart below demonstrates the fundamental process of rainwater harvesting.



Flowchart illustrating the fundamental rainwater harvesting processes (Roebuck 2007).

The system of rainwater harvesting depends on the catchment area in which the runoff is generated, and utilization area or receiving area, which is the area where the runoff is used (Mzirai 2010). Rainwater Harvesting can be divided into two classes:

- **Micro catchment** which means that the rainfall is conserved where it falls, and can use water stored directly in the field or utilization area. The properties of this system consist of small semi-circle pits, strip catchment tillage, semi-circle bunds, contour bunds and meskat-type systems (Girma 2007). The area of a micro catchment is less than 1000 m^2 (Zakaria et al 2012).

- **Macro catchment** involves harvesting of water from a basin area ranging from 0.1 hectare to several thousands of hectares. Macro catchment may be located near or far from the Utilization area (Girma 2007). This system is implemented with intermediate water storage outside the utilization area. The slope of a macro catchment area is ranging from 5 to 50%. This system needs storage structure and transfer infrastructure such as channels, natural streams and gullies to convert the water storage in the utilization area (Zakaria et al 2012).

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

Gathering rainwater could be significantly improved by applying a specific technique such as macro rainwater harvesting. Applying a system of macro catchment will augment the agricultural production, especially when it is integrated with an irrigation system such as supplementary irrigation or deficit irrigation. This method indicates that during critical stages of crop growth a limited amount of irrigation for the rain-fed agriculture, which leads to improve the crop productivity and management of water resources, can be added (Zakaria et al 2012). The macro catchment runoff harvesting with supplemental irrigation will increase the agricultural production twice even if supplementary irrigation is not used during dry spells (Adekalu et al 2009).

The amount of rainfall has decreased in recent year in the Iraqi Kurdistan region (Heshmati 2009). Therefore, it is necessary to search for systems storing the water from the rainfall and permanent streams runoff to be used as supplemental irrigation in the dry spells. Normally agriculture is fed-rain in the region. Because of this, farmers have left agriculture in the dry season, especially at the end of spring and summer. There are some studies indicating that using harvested runoff water with supplemental irrigation could lead to an increase in the agricultural production of a factor two (Zakaria et al 2012).

Power deficit is another problem in the region, so storage of water will help in energy production to meet the needs of electricity, especially in the summer. In addition, stored water can be utilized for drinking and livestock and as a result of this, reducing the immigration from the villages to cities or other places due to the lack of water over the year. After several years of drought, floods due to heavy rainfall happened in the Iraqi Kurdistan region in January 2013. Rainfall then exceeded its normally average levels compared to the previous ten years. It is thus necessary to able to store water to avoid flooding and instead use the access water in the dry spells.

All above-mentioned reasons lead us to use macro catchment for rainwater harvesting, by constructions of dams and reservoirs to save runoff water for a long time. The Kurdistan Government Region has plans to build several dams in different places (small and medium sizes) to develop the agriculture sector in the region by using the stored water during the dry spells.

1.1 Potential agriculture

The agricultural sector is vital to boost the economy in many countries. Agriculture has potential to be an active contributor to the economy of the Kurdistan region (UNDP 2010). Agriculture is the second most important source of economy after the oil because of the suitable climate and soil, in combination with the richness and variety of water resources such as groundwater, rivers and springs.

There are two types of agriculture crops in Iraqi Kurdistan: (I) cereals which mostly depend on the rain-fed water, and (II) vegetables, fruits and legumes which mostly are irrigated (Heshmati 2009). The total area of Iraqi Kurdistan is about 80,000 square kilometers. Arable land is about 72.3%. It is divided into 34.5% cropland, 15.5% forests, 20% natural rangeland, and 2.3% orchards. The remaining land is non-arable. Most areas of the Kurdistan region lie where rainfall is guaranteed or semi-guaranteed (UNDP 2010). Agriculture mainly depends on rain-fed irrigation. About 90% of land is rain-fed agriculture (Bakleh 2006). The main crops produced are wheat, tobacco, barley, fruit and cotton. The wheat produced is about 50%, barley 40%, cotton 30%, fruit 50% and tobacco 98% of the total production of Iraq, with large ability to boost production in all areas (USAID 2008).

1.2 Water resources

The water resources in Kurdistan are characterized by the existence of many rivers, streams, springs, and ground water sources. In addition, there are lakes and reservoirs such as Dokan, Derbandikhan, and Dohuk. The most important water resource is however rainfall and snow.

Generally, the climate varies from cold and snow in the winter to warm and dry in the summer. The climatic is semi-arid. Precipitation occurs from October to May, reducing from NE to SW. Figure 1 illustrates the precipitation in northern Iraq. Average annual rainfall starts from 250 mm in the south of the Erbil area to more than 1200 mm in the high mountains bordering Iran in the northeast and Turkey in the north (Omer 2011).

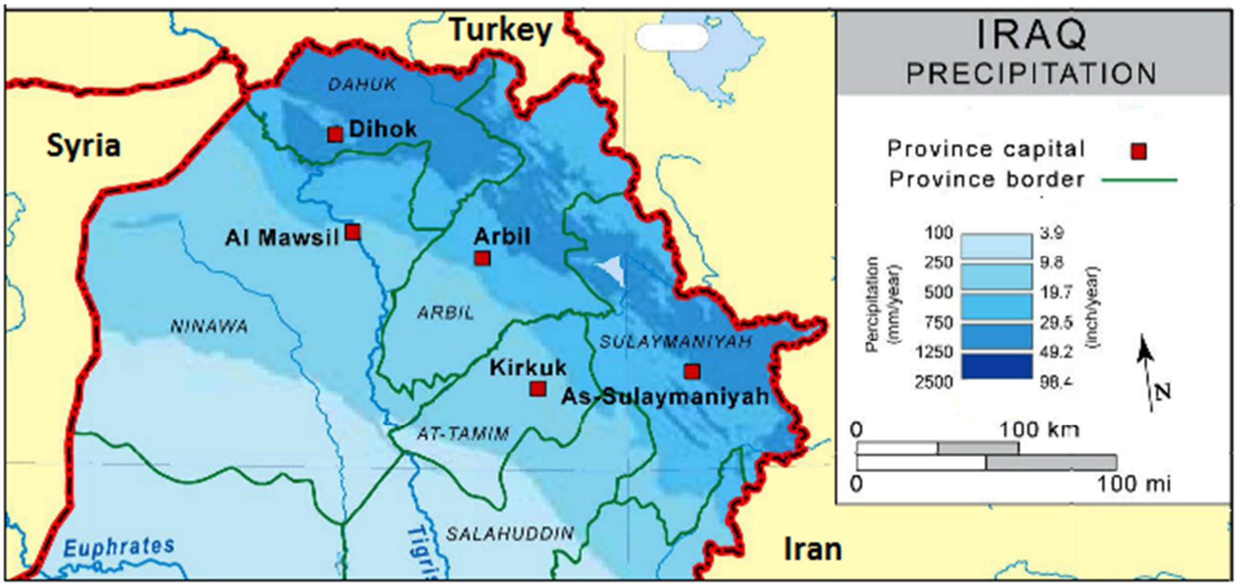


Figure 1 - Precipitation in northern Iraq.
From: Omer 2011

Surface water resources consist of rivers and streams. About 40% of the surface water comes from outside the Kurdistan region. The major rivers are Greater Zab, Lesser Zab, Khabur, Sirwan and Awa Spi (See Figure 2). All of these tributaries flow into the river Tigris in Iraq. River Tigris is located in the south of the Kurdistan region (UNDP 2011).

Greater Zab tributary is the main tributary of the Tigris, and passes through Erbil Governorate and then flows into the Tigris. The Greater Zab comes from the Wan Lake in Turkey. It enters Iraq (Kurdistan region) at Al-Amadieh city. The length of Greater Zab is 392 km. Furthermore, there are five sub-tributaries that flow into Greater Zab (Shamezenan, Row Kochek, Rawandous, Bastourah and Khazir). The annual discharge rate of Greater Zab is 4.190 MCM (Million Cubic Meters), while the annual flow rate of the Tigris River at Mosul city is 17.173 MCM (Heshmati 2009).

Lesser Zab tributary passes through the Sulaimanyah governorate. It is an international river between Iraq and Iran. Lesser Zab originates from mountains in Iran. The river enters the border of Iraq (Kurdistan region) at the Bedrazhour region. It is the main river that provides the major water source to Dukan Dam in Sulaimanyah Governorate. The length of Lesser river is 400 km, and its catchment area is around 22,250 km^2. The annual discharge rate of Lesser zab is 7.07 MCM (Heshmati 2009).

Khabur tributary is also an international river, between Iraq and Turkey. It enters Kurdistan at Zakho district in Dohuk governorate. It originates from the high mountains on the border of Iraq and Turkey. The length of Khabur is 160 km and its catchment area is about 6,268 km^2. The annual discharge rate of Khabur tributary is 2.10 MCM (Heshmati 2009).

Sirwan tributary originates from Iran and has a length of 385 km in the Kurdistan region. Its catchment area is approximately 17,850 km^2. 70% of this area is located in Iran and only 30% is in Kurdistan. The annual discharge of Sirwan river is 5.86 BCM (Billion Cubic Meters) which is 13.5% of the Tigris river discharge.

Awa Spy tributary stems from the Kurdistan region. The annual water flow of Awa Spy is 790 MCM with a catchment area and length of 1,100 km^2 and 230 km respectively. It flows into Tigris at Blad city in Tkrit governorate (Heshmati 2009).

Figure 2 - The rivers and lakes in the Iraqi-Kurdistan region
From: DNSFPA 2008

The Kurdistan region of Iraq is famous for springs. There are many springs supplying fresh water. The sources of springs are groundwater and sub-surface water, which depend on the rain and snowfall. Therefore increase in rain and snow will increase the water flow in the springs. The majority of the springs are located in three governorates of Kurdistan region, namely Erbil, Sulaimanyh and Duhok (Heshmati 2009).

1.3 Drought

Many countries in the Middle East are suffering from drought conditions. These countries are e.g. Iraq, Turkey, Iran and Syria because of decreasing rainfall (UNDP 2011). Lack of water storage and irrigation water shortage impact the agricultural sector. Additionaly, the increased water consumption by the industrial and domestics sector has exaggerate the drought condition. Figure 3 illustrates a comparison between available water resources in the year 2000 and 2010 in different Middle East countries. The available water resources have reduced in some countries, especially in Iraq and Syria (UNDP 2011).

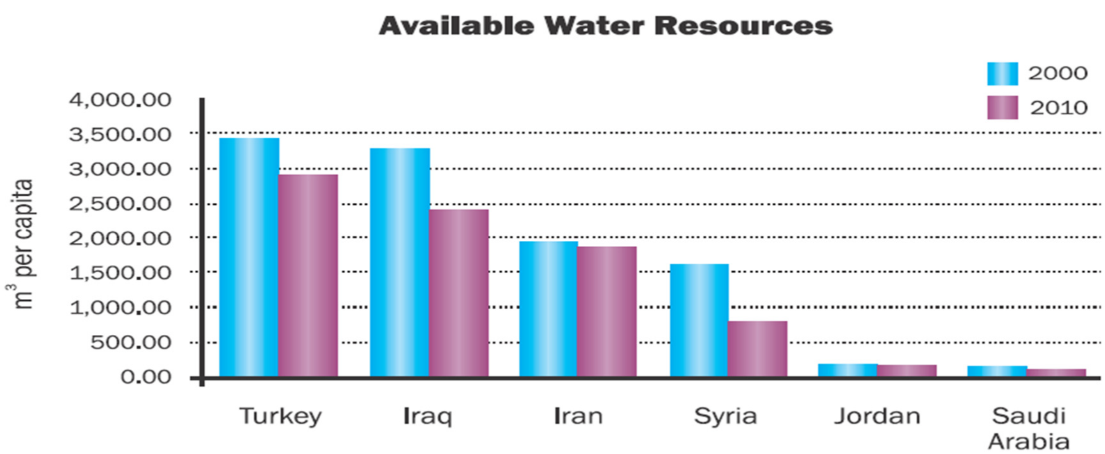


Figure 3 - Available water resources in the Middle East 2000 – 2010
From : UNDP 2011

Since 2007, Iraq has announced a drought condition mainly because of reduced precipitation in the past years. Another reason is that Iran, Syria and Turkey have constructed a lot of dams on the tributaries which flow into Iraq. For example, Turkey has planned to implement the project of Southeast Anatolia (Güneydoğu Anadolu Projesi, GAP), which is a construction of 22 Dams along the Euphrates and Tigris rivers (Jongerden 2010). The project has started by the construction of the Ataturk dam on the Euphrates river which started in 1992. The dam lake capacity is estimated to 70 billion cubic meter. In 2007, Turkey started to implement the second dam of the GAP project (Ilisu Dam) on the Tigris river, and the size of storage is estimated 11.4 billion cubic meters. Upon completion of all projects of GAP, Turkey can control 80% of the water flow in the Euphrates and Tigris rivers (Yasiri 2007).

The agriculture sector has been retreating in production since 2002. A food and agriculture organization (FAO) report showed that the input of agriculture has decreased from around 9% in the year 2002 to 4% in the year 2009. Crop coverage throughout Iraq has decreased around 40%

between 2002 to 2009 (IAU 2010). This decline in production is mainly explained by insufficient rainfall in the past years due to changing climate conditions. The lack of rainfall has scared the farmers and they are not ready to take risks in farming. This problem is found on the plain southern part of the Kurdistan region, which represent the fertile lands with a high agriculture potential (Heshmati 2009).

The arable area in Erbil Governorate is 6262.8 square kilometer, but only 4039.7 square kilometer of it were cultivated in 2006, mainly because of decreasing amount of rainfall in that year. Figure 6 indicates the average of rain and snowfall in the Iraqi Kurdistan region. Most of the arable land, which depends on the rain-fed water has to change to the irrigation system in order to set a guaranteed level of harvest at the end of the cropping season (Heshmati 2009).

Iraqi Kurdistan Region is suffering from climate change (UNDP 2011). During the previous years up to 2007, Iraqi Kurdistan has received half of its normal precipitation (UNDP 2011). The decreased rainfall rate has affected the agriculture sector and water resources. Ground water table and river flow are decreasing and springs are drying. Drought has resulted in decrease in the number of springs. There were around 683 springs in the Kurdistan region. Only 380 springs were still active and used in 2004, and 166 of these were still being used in summer 2009 (UNESCO 2009).

In Erbil Governorate, the average annual rainfall from 1941 to 1970 was 425mm (Fadhil 2010). However, recent precipitation data from 2007-2008 indicate a rainfall reduction of about 70% as compared to this value. Figure 4 shows the total rainfall of year 2007 and 2008 in comparison with average values from 1941 to 1970 in different districts of Erbil (Fadhil 2010).

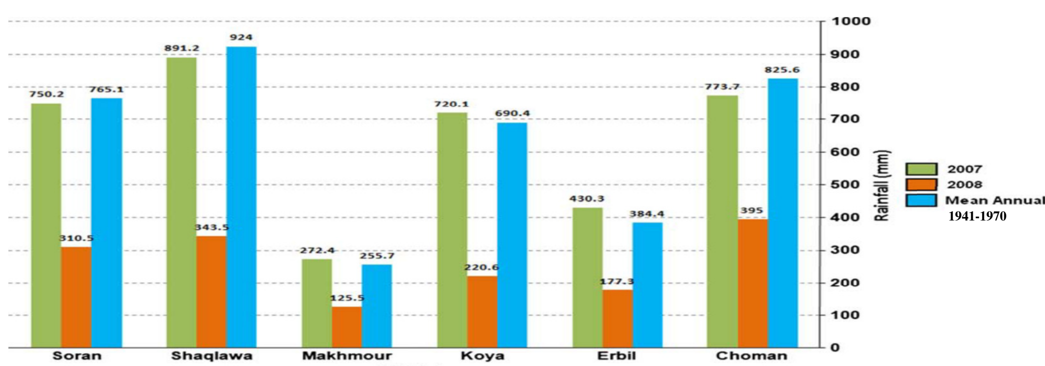


Figure 4 - Comparison of rainfall between 1941-1970 and 2007-2008.
From: Fadhil 2010.

1.4 Objective

Considering the problems of drought in the Erbil Governerate, Iraq, the overall aim of a study is to find suitable areas for rainwater harvesting. Moreover, there are some specific aims that were considered:

1- Estimate rainwater harvesting potential, and generate a suitability map for rainwater harvesting, in Erbil Governorate, Iraq.

2- Identify suitable sites for water reservoirs through location of small and medium dams.

3- Compute the characteristics of the suitable sites including storage capacity, height and length of the Dams.

1.5 Previous studies

There are many studies about water resources and water harvesting in the world. In this section, some of the previous studies about water harvesting are presented.

Oweis et al. (2006) developed a water harvesting strategy in dry environments of West Asia and North Africa. This study focused on the limited resource for improved agricultural production by water productivity in dry and semi-dry areas. Most of the rainwater is lost by evaporation in drier environmentals, and therefore the productivity of the rainwater is extremely low. Improving the agriculture sector in these areas depend on the concentration of rainwater through runoff to the crops. In addition, the study found that over 50% of the lost water could be stored at a very little cost. Ketsela (2007) displayed the problem of dry spells in the central Rift Valley in Ethiopia. The study used a GIS based suitability model to create suitability maps by integrating different factors through Multi Criteria Evaluation (MCE). Micro catchments were used to identify suitable areas for water harvesting.

Munyao (2010) conducted a study using freely available remote sensing products and GIS to determine rainwater harvesting sites in Unguja Island, which is the main Island of Zanzibar (Tanzania). Micro and Macro catchments were used to make maps of rainwater harvesting suitability and identify several possible impoundment sites by combining remote sensing data, GIS and hydrological modeling with the analytic hierarchy process using Multi Criteria Evaluation (MCE).

Mzirai et al. (2010) made a test of the effect of macro catchments on the agricultural production at the Chome-Makanya catchment in the Pangani basin in Tanzania. They stated that using harvesting runoff water as supplemental irrigation in the dry period increased yield production by more than 120% compared to crops that received rain-fed water only. Weerasinghe et al. (2011) developed a spatial analysis model named Geographic Water Management Potential (GWMP) to identify suitable locations for applying water supply management. The Geographic Water Management Potential model in two different study areas; Nile catchment (Egypt) and the Sao-Francisco catchment (Brazil), which have different geographic locations and climatic conditions. The model outcomes were validated versus field data. The correlation between the locations of existing regional reservoirs and dams were found to be 83% by using the Geographic Water Management Potential model. The result of the Geographic Water Management Potential model indicates that it can be used to determine potential sites for rainwater harvesting in a given catchment area.

Zakaria et al. (2012) studied macro-catchment water harvesting systems in Iraq. This study indicated problems of water storage at the Northern Sinjar mountain. Six macro catchments were selected. The watershed modeling system (WMS) was applied to estimate the rainwater harvesting through the runoff surface. The purpose of rainwater harvesting is supplemental irrigation in the region.

1.6 Study area

Kurdistan Region is located in the north of Iraq. The total number of inhabitants is 4.8 million people. The governorates of the Iraqi Kurdistan region are similar in geology, hydrology and climate conditions. The area consists of mountainous lands, uphill and fertile plains (UNDP 2010). The main landscape in the north and northeast of the Kurdistan region is the Zagros mountains. The highest peak in the Zagros mountains is 3600 m above sea level (ASL). Snow covers high altitudes in the winter. The agricultural area is around 34%, while grasses and forests are the major land cover of the region. The area is characterized by an anticline/syncline system. The south of the region is the plains of the Tigris river. The land of Kurdistan region is the best in Iraq for agricultural production (Fadhil 2010). Figure 5 shows the study area (Erbil Governorate) in the Kurdistan region in northern Iraq.

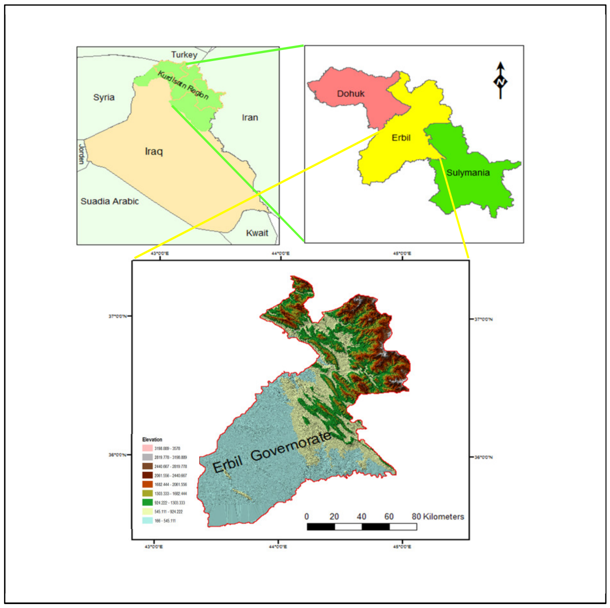


Figure 5 - Location of the study area

Erbil is one of the governorates of the Kurdistan region. The location of Erbil governorate is between latitudes 35˚ 30´ and 37˚ 15 N, and longitudes 43˚ 22´ and 45˚ 05´ E. The Erbil border extends to Iran in the East and to Turkey in the north. The city Erbil is the capital of the Kurdistan region

.

The plains in the south of Erbil governorate are important parts of the agricultural production. Erbil governorate is located between the two rivers known as the Greater Zab in the west and the Lesser zab in the east (Kahraman 2004). The area of the governorate is around 15074 km^2. It consists of seven districts (Erbil, Makhmur, Koisnjaq, Shaqlawa, Choman, Soran and Merqasur) (IAU 2011). In Erbil Governorate 41% of the area is arable land and 59% is non-arable land. 93% of agricultural crops depend on rainfall and only 7% of the land is irrigated (Fadhil 2010).

1.7 Climate

The climate of the Kurdistan region is comprised of cool snowy winters and warm dry summers. The plains in the south have semi-arid climate conditions. Usually precipitation starts in October and ends in May (Fadhil 2010). Erbil governorate climate can be classified into two main categories:

1. **Mediterranean climate region**: this is in the north and northeast of Erbil governorate. This region is characterized by abundant rains between 600 and 800 mm per year.
2. **Warm climate region of steppes**: This region is located in the south and south-west of Erbil governorate. The average temperature is approximately 18 C°. Rainfall changes over the year. Rainy days are low in this region compared to the Mediterranean climate region. The rainfall is less than 500 mm per year, and therefore the winter agriculture is at risk of drought (Kahraman 2004).

Rain and snow in Kurdistan are changing from year to year since precipitation depends on the geographical location and climatic conditions of the region. Changing amount of precipitation has impacted the water levels in the rivers and springs. In recent years, the amount of precipitation has decreased, which has resulted in lack of irrigation water required for agriculture. Figure 6 shows the change precipitation in the governorates of Kurdistan for the period 2000 to 2006 (Heshmati 2009).

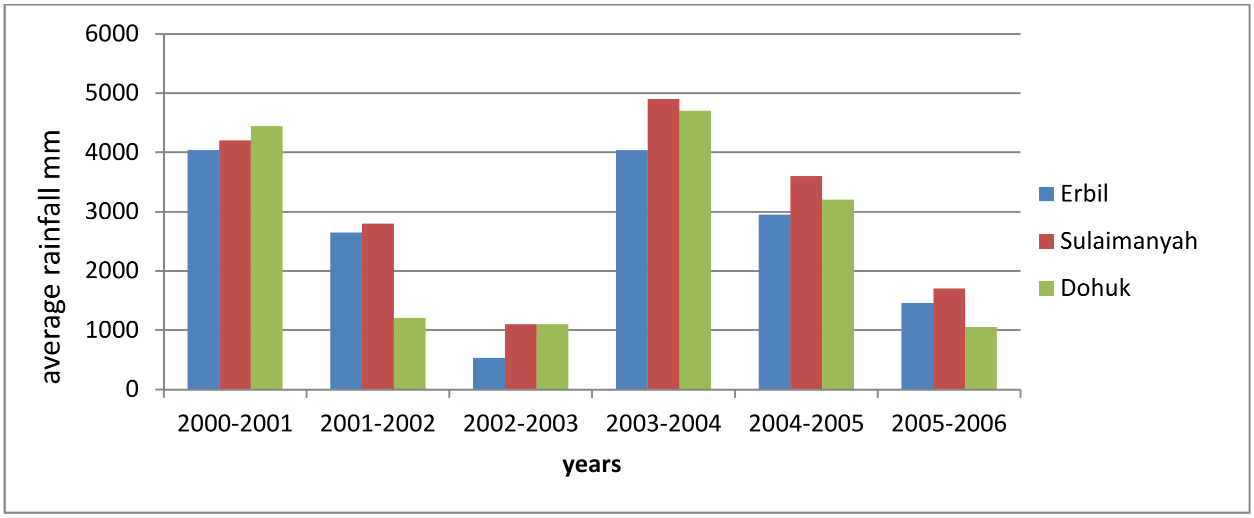


Figure 6 - Rain and snowfall 2000-2006
From: Heshmati 2009.

The annual temperature is gradually changing over the region. It decreases from south and south-west to north and north-east while the precipitation increases in this direction. There is an inverse relationship between temperature and elevation in the governorate. Table 1 illustrates the difference between temperature and elevation at some stations.

Station	Elevation (HASL) m	Average Temperature in the winter (C˚)	Average Temperature in summer (C˚)
Rawndus	1008	1.6	27.8
Salahaddin	1088	3.9	30.7
Erbil	414	7.9	32.6
Makhmur	270	8.7	35.4

Table 1 - Average temperature and elevation of stations
from north to south in Erbil governorate (HASL: Height above mean sea level) . From: Kahraman, 200.

January is the coldest month of the year. The average temperature is 1.6, 3.9, 7.9 and 8.7˚C for the Rawndus, Salahaddin, Erbil and Makhmur stations respectively. The temperature decreases in high mountain areas such as the Rawndus station, while it increases in undulating and plain zones such as the Makhmur station.

July is the hottest month of the year. The average temperature is 27.8 and 35.4˚C for the Rawndus and Makhmur stations respectively. The climate of the study area tends to be continental because there are no large water bodies in the region. This climate affects directly or indirectly the other weather elements such as atmospheric pressure that control the system, speed, direction and quality of wind. It also effects the evaporation and limits crop production (Kahraman, 2004).

1.8 Soil

Soil is one of the important resources in achieving food security through direct association with agricultural production. The depth of the soil is changing over the study area. The soil in the mountain areas, which are located in the north and northeast, is shallow. The soil in the mountains has been created from the original rocks and it has a low potential for agriculture, but it is rich in the natural rangeland (Kahraman 2004).

The valley and plain area, which is located in the south of study area has favorable conditions of soil for agriculture as it consists of chestnut soils, dark brown soils and black soils. It is some of the best soils for agriculture because of great depth and good texture. It is also rich in organic matter. The semi-mountainous areas and most plains are covered with red soil and brown soil structure (Kahraman 2004). Figure 7 explains the soil type of the study area.

Figure 7 - Soil map of Iraq
The soil texture of the study area (Buringh 1960)

Soil texture and color are different in the plain and the mountain regions. The texture of soils in the plain regions consists of loam clay sand, loam silt and silt clay, with an average depth of 140 cm. Color of soil varies between light yellow to dark brown. The texture of the soil in the mountainous regions is sandy clay, loam silt or loam clay sand, with an average depth of 130 cm. The soil color is between brown and dark brown. Figure 7 shows a soil map of Iraq focusing on the study area (Erbil Governorate) in the north of Iraq.

2 Data and Methodology

The result of this study depends on the different types of data which were collected from different sources. The data obtained to determine suitable areas for rainwater harvesting are: Digital Elevation Model (DEM), Climate data, Soil map, Satellite Imagery (Landsat 7 ETM+) and the main roads of the region.

2.1 Data

1. Digital Elevation Model (DEM) was obtained from the United State Geological Survey (USGS) website (http://gdex.cr.usgs.gov/gdex/). The DEM has 30 m resolution. The format of data is raster data. The datum of the data is WGS-84.

2. Climate data were provided by the Ministry of agriculture and water resources of the Kurdistan Region Government, Iraq. The rainfall data is monthly from 2000 to 2011. There are 19 climatological stations in the study area.

3. The soil map of the Iraqi Kurdistan region is obtained from the Ministry of Agriculture and Water resources of the Kurdistan Region Government, Iraq. The soil map was prepared by the FAO coordinate the office in Erbil city, 2001. The soil map describes texture, depth and color of the soil in the region. The data type of this map is raster format JPG. The scale of the original paper map is 1:1,000,000.

4. Satellite Imagery (Landsat 7 ETM+) was downloaded from Earth Science Data Interface (ESDI) (http://glcfapp.glcf.umd.edu:8080/esdi/index.jsp). The image was taken by the satellite on 19 of May 2006. The resolution of the six bands, including bands number 1 to 5 and band number 7, as raster layers is 30 m. These data are used to describe the land use of the study area. The geo-reference of the satellite image is WGS_84 Datum project 38N.

5. The main roads of the region with Geographic Coordinate System WGS_84 are stored in a vector layer. It was downloaded from the below website: (http://www.diva-gis.org/gData).

2.2 Preparing Data and Modeling

Referring to previous studies, five criteria were chosen for determination of suitable areas for water harvesting, i.e. runoff, slope, drainage, soil texture and land use or land cover (Mkiramwinyi 2007).

2.2.1 Digital Elevation Model (DEM)

The hydrological parameters flow accumulation stream network and slope were derived from the Digital Elevation Model with 30 m resolution. A GIS package (ArcGIS 10) was used to extract the hydrological parameters. Before using the DEM to estimate any parameters, all sinks were removed in order to keep continuity of flow to the catchment outlet. Figure 8 illustrates the Digital Elevation Model after filling sinks.

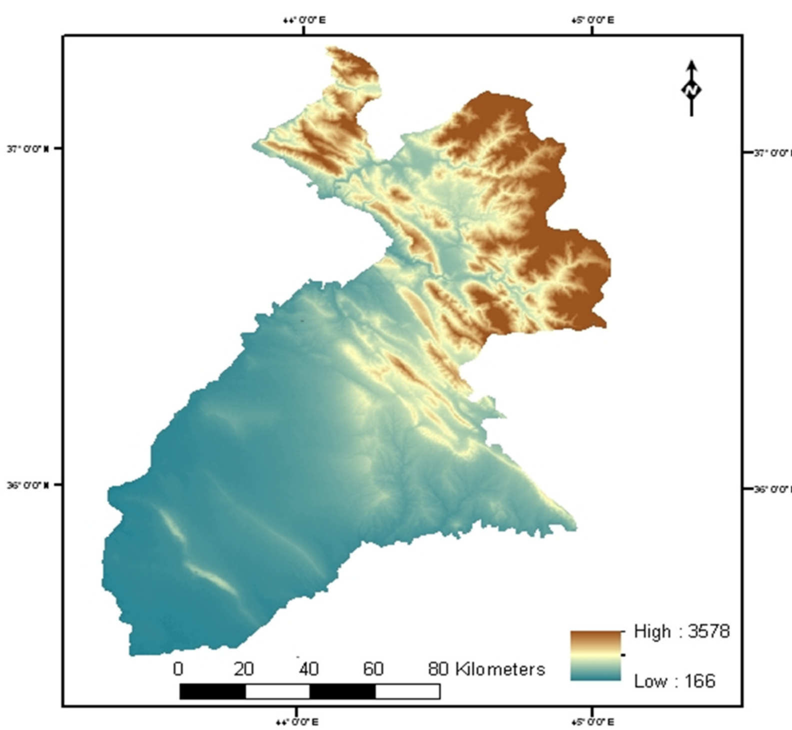


Figure 8 - Digital Elevation Model of the study area

To extract the flow accumulation and drainage pattern the following steps were carried out:

1. Flow direction assigns each cell's direction where water flows to. It determines the cell's direction by using the deterministic 8 model to identify the flow direction of the central cell to its neighboring cells (Moghadas 2009). Each cell will get a unique number based on its direction. There are eight feasible flow directions determined by unique numbers; East = 1; Southeast = 2; South = 4; Southwest = 8; West = 16; Northwest = 32; North = 64; Northeast = 128" (CNOAA 2011).

2. Flow accumulation is estimated from the flow direction grid, indicating how many upstream cells that flow (gives water) to each cell. The flow accumulation function is necessary for drainage definition.

3. Defining a threshold for drainage flow accumulation by determining the cell, with values more than the threshold was used to identify streams in the study area. The given threshold is compared with the value of each cell in the flow accumulation estimation.

4. Strahler classification is used to assign a numeric order to link a drainage network. After classifying the network drainage it can be converted into a vector layer. Figure 9 shows the distribution of streams in the study area. Drainage network is necessary to select the site of the dam, and also to compute the basin area of the dam using flow accumulation.

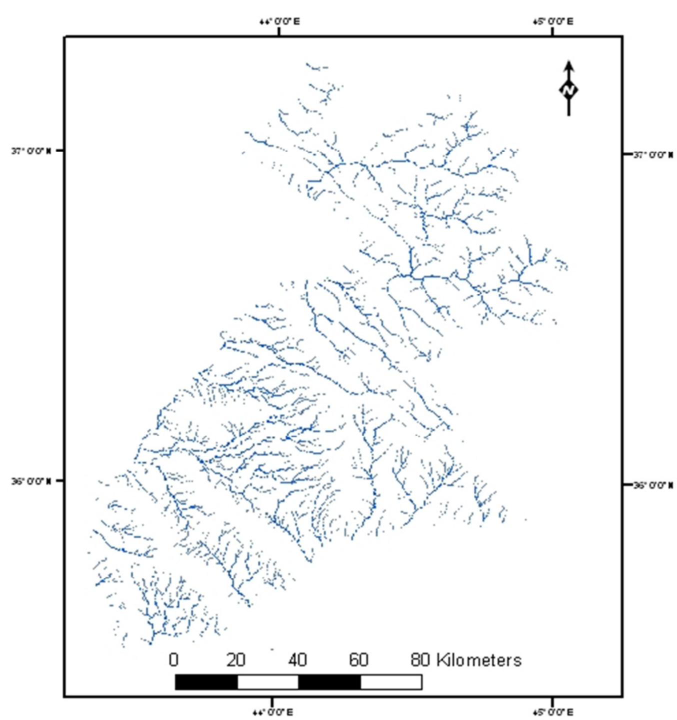


Figure 9 – Drainage (streams) of the study area resulted from flow accumulation

The drainage network in the north of the study area is deeper and dense more than in the south because the north is more undulating, mountainous , which give that area more diverse runoff.

2.2.2 Analysis of rainfall distribution from rain gauges network

The rainfall stations in the Erbil governorate are scattered all over the study area, which will give a suitable distribution to estimate the distributed rainfall. Rainfall point measurements represent monthly values within the period 2000 to 2011.

Interpolation was used to estimate rainfall for areas not having rainfall point measurements. Nineteen rainfall stations are used to interpolate the rainfall for the area. Figure 10 shows the location of the rainfall station in the Erbil governorate.

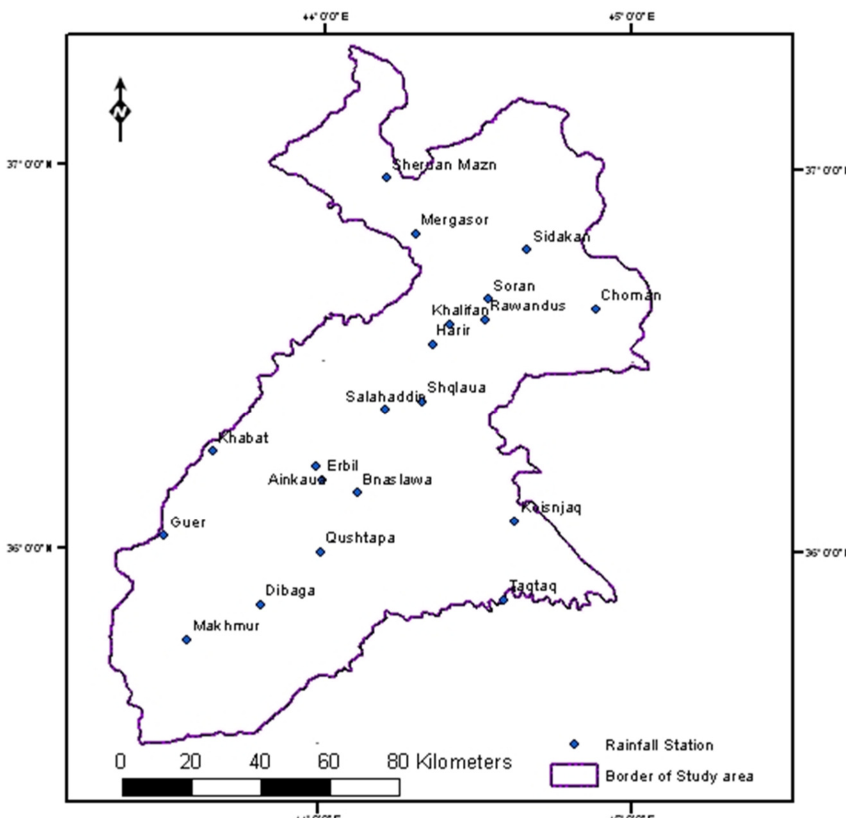


Figure 10 - Distribution of meteorological rainfall stations in the study area.

Kriging is a common method of interpolation (geostatistical interpolation technique), which is used to estimate values at unmeasured locations (Longley 2011). Optimal interpolation of kriging depends on the possibility to estimate values based on observed z values of neighboring data points, weighted according to spatial covariance values (Bohling 2005). The method is based on both the distance and the geographic orientation of known data points when estimating values in unknown areas (Vertical Mapper Guide 2009). The general formula for Kriging interpolation is:

$$Z(s_o) = \sum_{i=1}^{n} \lambda_i Z(s_i) \qquad (1)$$

where :

$Z(s_i)$ is the measured value at the i^{th} site.

λi is an unknown weight for the measured value at the i^{th} site.

n is the number of measured values.

$Z(s_o)$ is the predicted value.

The weights of measured values do not only depend on the distance between the measured points and the prediction location. However, the weights depend on the overall-spatial arrangement of the measured points within the Kriging interpolation (ArcGIS Desktop 9.3 help 2009). Kriging uses different weighting functions depending on the distance, and directions to the sample points. Kriging must estimate every possible distance weighting function before starting the interpolation. This process can be done by generating an experimental semivariogram of the data set, and select the mathematical model that gives the best fit of points in the semivariogram. The model offers a smooth, continuous function for identifying suitable weights for increasingly distant data points. The geostatistical analyst toolbars in ArcGIS 9.3 were used to interpolate the rainfall data set. Figure 11 illustrates the interpolated rainfall.

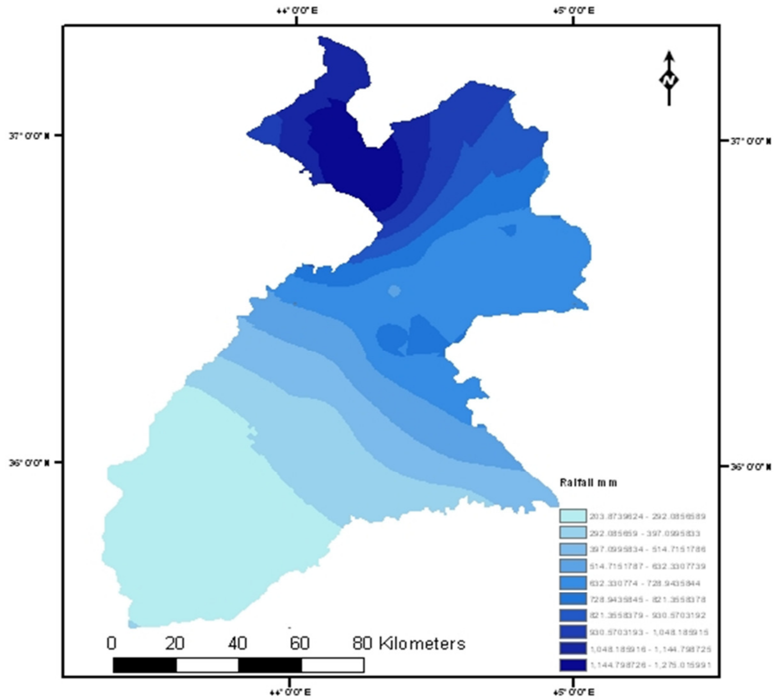


Figure 11 - Spatial distribution of average yearly rainfall in the study area

There is variation in the amount of rainfall. The proportion of rainfall in the northern part of the study area, characterized by high elevation, is twice the southern part. The maximum amount of rainfall in the northern part is about 1275 mm/year, and the minimum value is about 575 mm/year, while the maximum amount in southern part is about 612 mm/year, and the minimum value is about 206 mm/year.

2.2.3 Land Cover / Land Use

Land cover was extracted from Satellite Imagery (Landsat 7 ETM+) registered 19 May 2006 with a spatial resolution of 30 meters. Idrisi 15 Andes (Clark Lab 2006) was used to derive the land cover. A different land cover/land use classes were applied through supervised classification. Combination of three bands as false color composite image with the reference map and Google map were used to define training sites. A training site is an example of an information class, such as built up, farmland, grass and forest. The training site characterization was used to create signatures for each information class. The maximum likelihood algorithm was used to classify land cover using the mean, variances and covariance data from the signature to estimate which class each pixel belongs to (Idrisi Andes 2006).

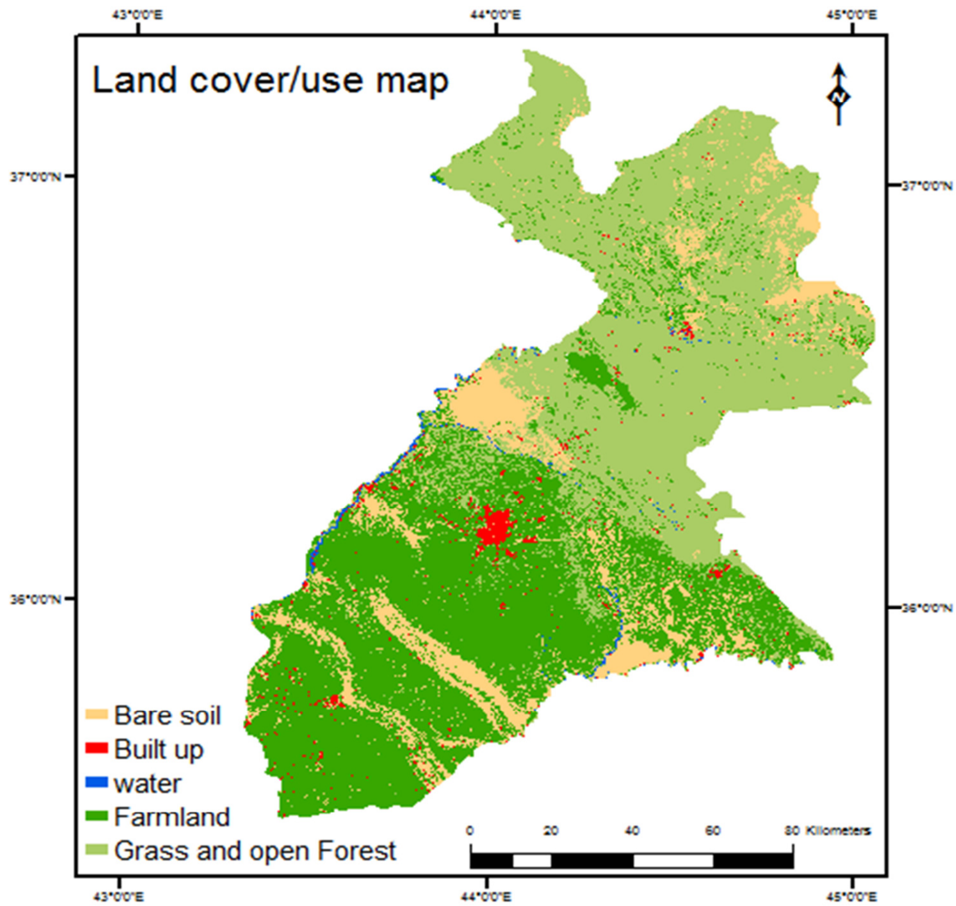


Figure 12 - Land cover of the study area

Five types of land cover were found in the study area: bare soil, built up, water, farmland and grass with open forest (see Figure 12). Land cover is an important criterion when selecting suitable areas for water harvesting. On the other hand, land cover can be used to estimate the runoff depth by using the Soil Conservation Service Model (Moges 2004). Description of land cover to estimate the runoff depth will be further discussed in Section 2.2.6. The vegetation plays a significant role on the infiltration capacity of the soil. The amount of runoff lost to interception on leaves and stacks of vegetation which depends on the growth stage and the type of vegetation. Interception values of vegetation land cover are between 1 and 4 mm (Moges 2004). For example, dense grass cover has a bigger storage capacity than a cereal crop. Organic matter and the root system in the soil increase the soil porosity, thus leading to increased infiltration of the soil. Dense vegetation cover causes slow runoff, particularly on gentle slopes where the surface flow takes more time to infiltrate into the soil. Consequently, the runoff on bare land is more than on an area covered by vegetation (Moges 2004).

2.2.4 Soil map

The reconnaissance soil of the three northern governorates, soil map of Kurdistan Region, was saved in raster format (JPG). ArcGIS 9.3 was used to geo-reference the soil map and then converted to vector data, which here 15 classes were distinguished (see Figure 13). However, only 9 classes were found in the Erbil governorate .Lithosolic soils in sand and gypsum, shallow to moderate deep, gravel to very gravelly and lime-rich silt loam characteristics were found in the area which are represented by the code number 2 and 5 in the Figure 13. The zones 1 and 4 represent brown soils, medium and shallow phase over Bakhtiary gravel, lime rich non gravel and gravel silt clay with surface cracks. The zone 3 refers to brown soils, medium and shallow phase over Bakhtiary gravel, lime-rich non gravel, silt loam. The zone 13 represents chestnut soils, stony and sloping phases, shallow to moderate deep with variable texture and gravel content frequent badland areas, on exposed clay stone. The zone 12 represents rough broken and stony land, shallow to moderate deep, loamy to clay soils with variable gravel and stone content. The zones 11 and 15 represent rough mountainous land, shallow loamy with variable stone content, rock outcrops (Buringh 1960).

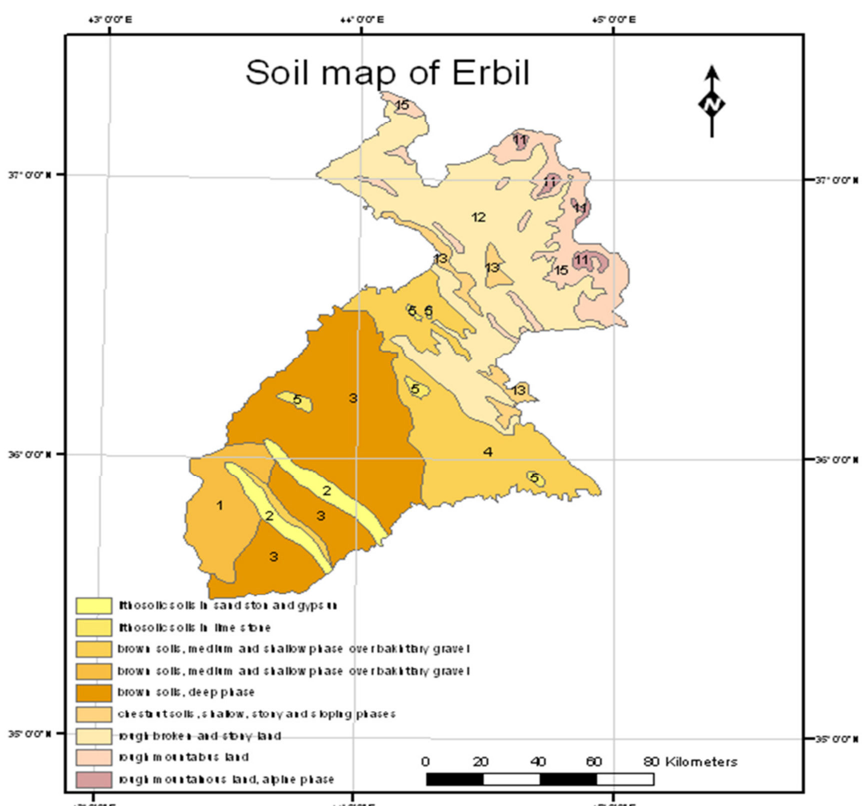


Figure 13 - Soil types in the study area

2.2.5 Slope

The slope is generated from a topographic ratio, which represents the ratio of the elevation difference between two points divided by the horizontal straight distance between the two points (Winnaar 2007). The slope is derived from the Digital Elevation Model (DEM), and classified into 5 slope percentage classes according to the FAO slope classification (Winnaar 2007). Table 2 shows the classification of slope in five zones.

No.	Slope class	Slope %
1	Flat	< 2
2	Undulating	2 – 8
3	Rolling	8 -15
4	Hilly	15 – 30
5	Mountainous	>30

Table 2 - Slope classification
From: Winnaar 2007.

Slope steepness is a very important factor for assigning and implementing rainwater harvesting. Mountainous areas that have high rainfall are considered as suitable areas high generate runoff (Winnaar 2007). Figure 14 illustrates the slope of the study area according to FAO. The study area has gentle slopes on the southwest part while the north and northeast have steep slopes and deep valleys.

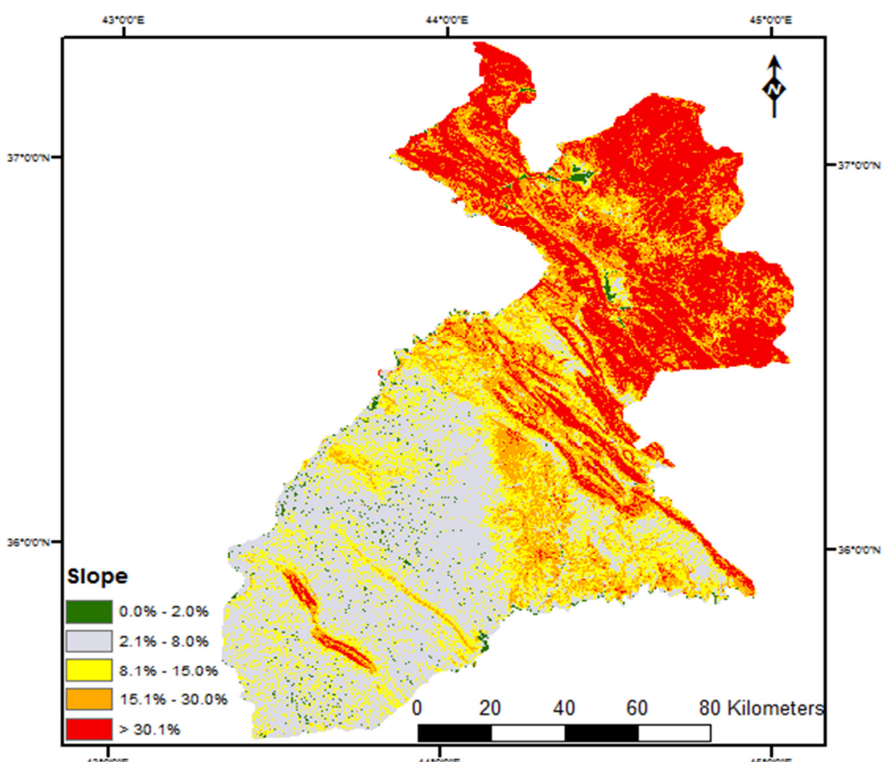


Figure 14 - Slope classification map of Erbil governorate

2.2.6 Soil Conservation Service - Curve Number model

Estimation of runoff depth is an important component for determination of suitable areas for rainwater harvesting. The runoff depth is used to assess the potential water supply during a runoff event (Melesse et al 2002). Soil Conservation Service and Curve Number (SCS) modeling was used to estimate the runoff depth in the study area. Remote Sensing was used to derive the land cover map. ArcGIS 9.3 was used to interpolate the rainfall data and digitizing the soil map of the study area. The output of the Soil Conversation Service model has been used to extract the depth of the runoff from the rainfall for water harvesting planning (Gupta 1997). The equation of the Soil Conservation Service model can be expressed as below (Maidment 1993):

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

where:

Q = runoff depth (mm)

P = rainfall (mm)

S = potential maximum retention after runoff starts (mm)

I_a = initial abstraction (mm)

Initial abstraction includes all losses before runoff starts, infiltration, evaporation and water intercepted by vegetation. (Melesse et al 2002) was assigned I_a =0.2S by analyzing the data of rainfall for many small agriculture basins. Therefore, referring to equation 2, the Soil Conservation Service equation can be expressed as:

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \qquad (3)$$

Potential maximum retention (S) can be calculated by the Curve Number (CN) as below (Melesse et al 2002):

$$S = \frac{25400}{CN} - 254 \qquad (4)$$

The soil conservation service (SCS) model depends on the runoff Curve Number (CN). Curve Number is estimated via the effect of soil and land cover on the rainfall runoff processes. The range of the Curve Number (CN) is between 1 (100% rainfall infiltration) and 100, Lower values of the Curve Number indicate lower runoff, while higher values of Curve Number refer to higher values of runoff (Melesse et al 2002).

2.2.7 Estimating Curve Number

Curve Number is used to characterize the runoff properties for a certain soil and land cover/land use. The soil conservation service runoff equation uses the curve number value as input parameter (HydroCAD 1986). Curve Number is estimated per pixel for the study area, via the land cover map and soil map that was reclassified into Hydrologic Soil Groups and hydrologic condition (see Table 3 below). Infiltration depends on the soil property which effects the relation between rainfall and runoff. The Soil Conservation Service Model divides all soils into four Hydrologic Soil Groups according to the United State Geology Survey (USGS) land use and land cover classification system (A, B, C and D) (Maidment 1993). The classification of soil to hydrologic soil group depends on infiltration rates and the soil texture composition (Melesse et al 2002). Table 3 defines the Hydrologic Soil Groups, based on the USGS classification system. Only classes B,C and D were found in the study area.

Soil Group	**Runoff Description**	**Soil texture**
A	Low runoff potential because of high infiltration rates.	Sand, loamy sand and sandy loam
B	Moderately infiltration rates leading to a moderately runoff potential	Silty loam and loam
C	High / moderate runoff potential because of slow infiltration rates	Sandy clay loam
D	High runoff potential with very low infiltration rates	Clay loam, silty clay loam, sandy clay, silty clay, and clay

Table 3 - Soil groups and corresponding soil texture.
From: (Maidment 1993)

Table 3 can be used to find the hydrologic soil groups of the study area depending on the soil type (see Section 2.2.4). Figure 15 illustrates the Hydrologic Soil Groups in the study area.

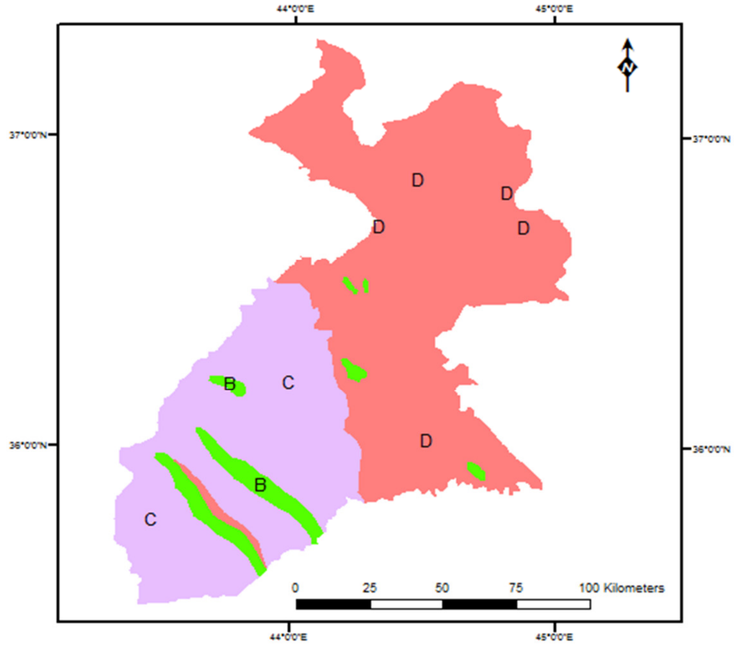


Figure 15 - Classified soil map into hydrologic soil groups (B, C, D) in the study area

The high runoff potential is present in the north of the study area because this area is a stony landscape with low infiltration and steep slopes. The soil texture is clay stone or silt clay to clay. A moderate runoff potential occurs in the southern of the study area because the landforms in this region are fluctuating between undulating and plain terrain. The soil texture is silt loam to loam.

Hydrologic condition refers to the effect of the land cover, and represents the surface conditions in the basin in relation to infiltration and runoff (Munyao 2010). The land cover that is presented in Figure 12 can be used together with a map of hydrologic soil group in ArcGIS to match the hydrologic soil group with the land cover (see Appendix 1). Table 4, extracted from appendix 2, presents the values of curve number based on the USGS classification system (A, B, C, and D).

	Hydrologic Soil Group			
Land cover	A	B	C	D
Bare Soil	77	86	91	94
Built up	61	75	83	87
Water	100	100	100	100
Farmland	72	81	88	91
Grass and open forest	43	65	76	82

Table 4 - Runoff curve number for combinations of different land cover and hydrological soil groups

The curve numbers were thus generated using the United State Geology Survey (USGS) land cover and Hydrologic Soil Group classification system (Maidment 1993). The curve number value for each hydrologic soil group and corresponding land cover class are presented in Table 4 (Ebrahimian 2012). A high value of the Curve Number (such as 94) refers to an area that has a high runoff potential and low infiltration. A low value of the Curve Number (such as 43) indicates an area that has a low runoff potential and high infiltration. In Figure 16 the Runoff Curve Number for the study area is presented.

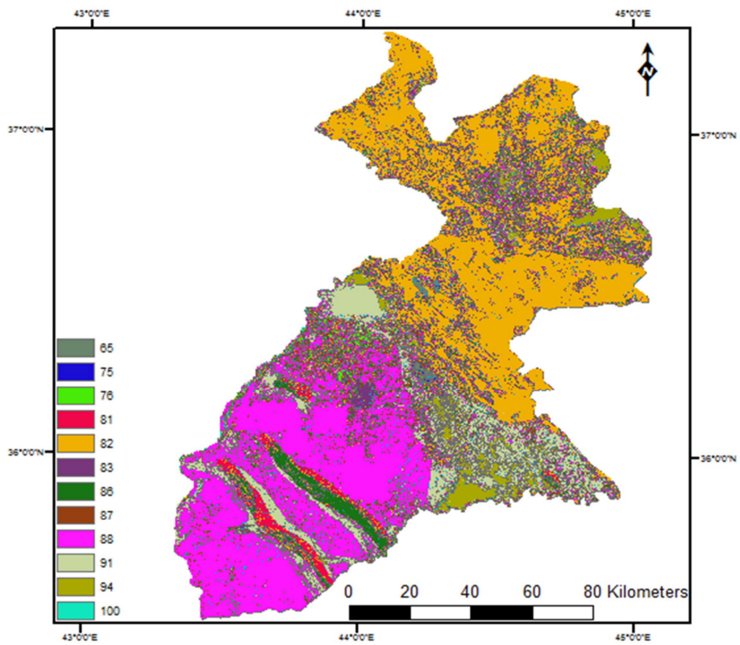


Figure 16 - Curve number map for the study area

2.2.8 Evaluation Runoff depth

After generating the curve number map, the next step was to compute the values of the maximum potential retention (S) which indicate the initial abstraction of rainfall via vegetation and soil. By using Equation 4, the value of S for each pixel was calculated. Runoff depth was then estimated by applying Equation 3. Figure 17 shows runoff depth in the study area.

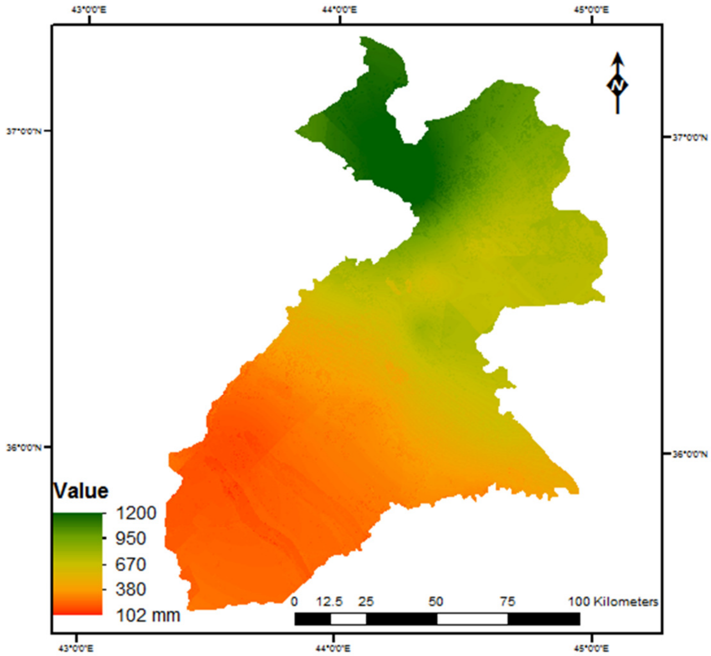


Figure 17 - Runoff depth potential map for the study area

2.3 Evaluation of rainwater harvesting sites

All factors do not have the same importance for determination of potential rainwater harvesting areas. Therefore different weights were identified for the different factors. Site suitability for rainwater depends on the determination of the best site from a set of potential sites by analyzing all the characteristics of the candidate sites. Pairwise comparison was used to estimate the weights of criteria, known as the Analytical Hierarchy Process (AHP). This method follows the Multi Criteria Evaluation (Drobne et al 2009). The analytical hierarchy process selects the best rainwater sites by using the Multi Criteria Evaluation module (Al-Harbi 2001). The ArcGIS environmental has good tools to support planning and decision making to choose and select suitable areas.

2.3.1 Selection criteria

Determination of the criteria is based on the availability of data for the study area. In this study the runoff, land cover, slope, drainage network, soil type and the roads were used. The criteria of runoff depth at each pixel is highly important in determining which area that has more rain water compared to other areas. Runoff depth at each pixel has been estimated by using the Soil

Conservation Service (SCS) model, which is explained in the methodology part (see Section 2.2.6) of this study. Runoff depth varies between 102 to 1200 mm per year. Referring to previous studies, the depth of runoff should not be less than 300 mm per year in order to determine suitable areas for rainwater harvesting (Tsiko 2011).

Different slope classes effect runoff volume and infiltration, and therefore the rainwater harvesting is highly based on the type of slope (Munyao 2010). The amount of runoff increase with slope. Hence, slope can be used to identify the suitability of a rainwater harvesting system for a macro catchment area (Tombo 2007). The Food and Agriculture Organization (FAO) has classified slope into 5 classes based on percentage, i.e. less than 2 % is flat, 2 – 8 % is undulating, 8-15 % is rolling, 15 – 30 % is hilly, and more than 30 % is mountainous. The slope of rainwater harvesting in a macro catchment should not be less than 2 %, and not more than 30% (Munyao 2010).

The water harvesting system also depends on drainage density. High drainage density in an area with suitable rainfall leads to higher runoff. Drainage density is also important in determining suitable sites for storage or dam structures. Table 5 explains the classification of the catchment area based on the Sardar Sarovar Dam Project in India.

Term	Area km^2
Catchment	30000-40000
Sub-Catchment	7000-8000
Watershed	800-1000
Sub-Watershed	150-300
Macro-Watershed	30-50
Micro-Watershed	5-10

Table 5 - Classification of catchment area
From: Sardar Sarovar Project

Soil texture is important for rainwater harvesting because it identifies uptake infiltration rate and storage of water in the soil (Tumbo 2007). In this study five classes of soil texture are applied, fine soil, fine / medium, medium, medium / coarse, and the last one is coarse soil. These classes are based on size and spacing of soil particles, which identify the flow of water. Fine soils have high percentage of silt and clay particles, resulting in a very high water holding capacity, while coarse soils such as sand or loamy sands have large pore spaces, and thus have a high infiltration rate. Fine and medium soils are better than coarse and medium coarse soils for rainwater harvesting (Tumbo 2007). Table 6 demonstrates the suitability of soil texture for rainwater harvesting.

	Optimally suitable	Highly suitable	Moderately suitable	Marginally suitable	Not suitable
Soil texture	Clay	Silty clay	Sandy clay	Sandy clay loam & sandy loam	Other class

Table 6 - Suitability level of soil texture
From: Tumbo 2007

41 % of the study area is plain and used for agriculture (mainly in the south). The northern part consists of undulated and mountainous regions containing grasslands, bare soils and open forests. The rainfall in the northern part of the study area is higher than in the southern part. Hence, the cultivated lands were avoided and we only focused on the undulating and mountainous areas to find suitable sites for water harvesting. The main roads of the study area were used as a criterion due to the geomorphology of the area. Since the dominant part of the area, particularly the northern part, is covered with Rocky Mountains and the roads play a vital role in terms of accessibility to the region, any changes of the road network affect the socio-economic aspects of the area. Boolean operations were assigned to select the areas around the roads.

2.3.2 Multi attribute decision analysis

In GIS, multi criteria decision analysis is considered as a process to combine and convert spatial data into decisions. The procedure of Multi Criteria Decision Making (MCDM) consists of rules to define a relationship between the input and output data. There are two important restrictions for spatial multi criteria decision analysis methods: firstly, the GIS possibilities of data acquisition, storage, retrieval, manipulation and analysis. Secondly, the multi criteria decision making method's has capability to combine the geographical data (Drobne et al 2009).

There are different methods to combine the decision criteria in the multi criteria decision analysis. In this study, a Weighted Linear Combination (WLC) is used. This weighted linear combination is employed to calculate the sum of the weighted criteria.

To execute the Weighted Linear Combination method, an analytic hierarchy process is used, known as pairwise comparison. The weighted linear combination is executed in two steps within the GIS environment: firstly, the weights associated with criteria map's layers are determined.

Secondly; the priority for all hierarchical levels including the level representing alternatives are combined (Drobne et al 2009).

2.3.3 Weighted linear combination (WLC)

The weighted linear combination works on the concept of weighted averages. The decision maker identifies weights of relative importance directly to each criterion. The weighting is done by multiplying the weight of the factor by its standardized membership value as shown in Equations 5. This method can be implemented by using the spatial analysis toolbar's in the ArcGIS environment. The weighted linear combination is based on the following equation:

$$S = \sum w_i \, . \, x_i \qquad (5)$$

where
S is suitable area.

w_i is weight of criteria i.

x_i is the membership value of criteria i.

When applying boolean constraints, Equation 5 is modified by multiplying the suitability area computed from different criteria by the product of constraints. For example, in this study the constrain was the road layer, then Equation 6 applied:

$$S = \sum w_i \; x_i \, . \, \Pi \, C_j \qquad (6)$$

where

C_j is the criteria score of the constraint j (Drobne et al 2009).

2.3.4 Standardization of criteria weights

The criteria were calculated from different scales, and therefore it is necessary to convert the criteria to a standardized scale before applying Equation 5 (Ronad 2006). The standardized criteria membership values are calculated by using the minimum and maximum values as scaling points. As shown in the equation below:

$$x_i = \left[\frac{R_i - R_{min}}{R_{max} - R_{min}}\right] * SR \quad (7)$$

where R_i is the raw score of factor i, R_{min} is the minimum score, R_{max} is the maximum score, and SR is the range or raw score (Ronad 2006).

By using the Equation 7, it is possible to re-organize the values of criteria from different scales to the unified scale. This fuzzy set membership function uses the range between 0 to 1 for real number scale or 0 to 255 for byte scale. The high values of the fuzzy set membership function represent very appropriate values for decision-making (Drobne et al 2009).

2.3.5 Selecting criteria weights

The information about the relative importance of criteria is very important for decision makers. Multi criteria decision making contains factors of varying importance. Multi criteria decision making is based on the weight of each factor making the determination of weight a main step in defining the decision maker's preferences (Drobne et al 2009). A multi criteria evaluation (MCE) module is used for selecting criteria weights. The multi criteria evaluation (MCE) module used is embedded in the integrated land and water information system (ILWIS, ITC-software). Land and water information system is integrated by Geographic Information System (GIS) and Remote Sensing (RS) software. There are three options available in the integrated land and water information system - multi criteria evaluation module for selecting criteria weights; the direct method, pairwise comparison or rank ordering (Munyao 2010).

In this study, pairwise comparison, known as the Analytic Hierarchy Process (AHP), was used. This method was developed by Saaty (1977). The pairwise comparison method includes the comparison of each factor against every other factors in pairs (Ronad 2006). The weights of criteria in Saaty's technique are computed by applying the main eigenvector of the square reciprocal matrix of pairwise comparisons between the two factors (Drobne et al 2009). The pairwise comparison compares two criteria to determine which criterion is more important than an other for a given objective. Table 7 explains the rating between two criteria on a 9-point continuous scale (Girma 2007).

Intensity of importance	Definition
1	Equal importance
2	Equal to moderate importance
3	Moderate importance
4	Moderate to strong importance
5	Strong importance
6	Strong to very strong importance
7	Very strong importance
8	Very to extremely strong importance
9	Extreme importance

Table 7 - The scale of pairwise comparison
From: Drobne et al 2009

To fill the matrix in Table 8 below, one needs to put values from the pairwise comparison in the lower left diagonal of the matrix (Gray color). The cells in the upper right diagonal of the matrix (Green color) are the inverse values of the lower left triangle. This method needs to use principal eigenvector of a pairwise comparison matrix to compute the best-fit set of the weights, which is explained below:

1- Calculate the summation of values in each column of the pairwise comparison matrix (see Table 8).
2- Divide each cell in the matrix by it is column total (see Table 9).

	Runoff Depth	Slope	Soil texture	Drainage	Land use
Runoff Depth	1	2	3	4	5
Slope	0.5	1	2	3	4
Soil texture	0.33	0.5	1	2	3
Drainage	0.25	0.33	0.5	1	2
Land use	0.2	0.25	0.333	0.5	1
Summation	2.28	4.08	6.83	10.5	15

Table 8 - The summation of values in each column
From: Mkiramwinyi 2007

From the resulting in the Table 9 calculates the average of each row. These averages represent the relative weights of the criteria. Table 9 shows the result of the pairwise comparison matrix to calculate the weights of factors.

	Runoff Depth	Slope	Soil texture	Drainage	Land use	Weight %
Runoff Depth	0.437	0.489	0.439	0.380	0.333	0.42
Slope	0.218	0.244	0.292	0.285	0.266	0.26
Soil texture	0.145	0.122	0.146	0.190	0.2	0.16
Drainage	0.109	0.081	0.073	0.095	0.133	0.10
Land use	0.087	0.061	0.048	0.047	0.066	0.06

Table 9 - Pairwise comparison matrix for macro catchment areas

2.3.6 Estimating consistency of pairwise comparison

The precision of pairwise comparison is evaluated by the calculation of the Consistency Ratio (CR). The consistency ratio is used to estimate the relative weightings of each criterion. The consistency ratio is the ratio between the Consistency Index (CI) and the Random Index (RI). If the result of the consistency ratio is less than 10 % the comparison between the factors is acceptable. Otherwise, the consistency ratio allows for re-evaluation of comparisons.

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} \qquad (8)$$

We can find the Random Index (RI) from the specific table prepared by Saaty (1977), depending on the order of the matrix. Five criteria were used in this study, and therefore the value of random index is 1.12. Table 10 shows the values of the random index according to the number of criteria.

Number of criteria	2	3	4	5	6	7	8
Random Index	0.00	0.58	0.90	1.12	1.24	1.32	1.41

Table 10 - Random index for different number of criteria
From: Drobne et al 2009

The consistency Index (CI) can be calculated by the following steps:
Multiply the weight of the first criterion (runoff depth = 0.42) in the Table 9 by the total of the first column of the original pairwise comparison matrix which is equal to 2.28 in the Table 8. Then multiply the weight of the second criterion (slope) by the total of the second column of the original pairwise comparison matrix. Repeat this procedure for all weight criteria. Finally, the summation of these values gives the consistency vector ($\lambda = 5.09$), which is used to compute the consistency index according to equation 9.

$$CI = \frac{\lambda - n}{n - 1} \quad (9)$$

where

λ is the value of the consistency vector, and

n is the number of criteria.

The value of the consistency index from the above process is 0.022. The consistency ratio of this study is 2 %, which is less than 10%, so the comparison between the factors is acceptable.
Refer to the consistency ratio of the criteria weights which was acceptable, the next step is to assign the fuzzy logic which concept to give all sites a value representing its degree of stability in order to find the suitability weights of the rainwater harvesting through using the weight linear combination method (Equation 5).

After estimating the suitable sites for rainwater harvesting, a boolean intersection operation was used to remove all areas that roads pass through by using a buffer of 250 meters. Then all cell values plus surroundings of the road were set to zero, while other cell values of the raster were set to one within the study area. The road layer (buffer) was multiplied by the layer of rainwater harvesting suitability by using Equation 6.

3 Result and discussion

3.1 Rainfall analysis

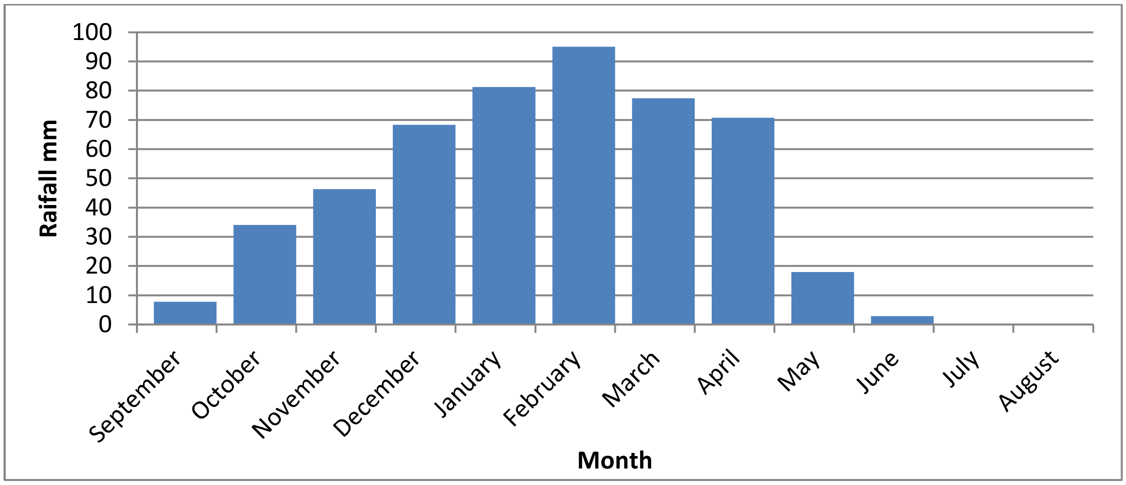


Figure 18 - Average of monthly rainfall in the study area 2000 – 2011

The climate of the study area changes between the Mediterranean climate region and the warm climate region of the steppes. This type of the climate is characterized by wet and dry periods (Kahraman 2009). The average rainfall per month for the 11-year period shows that the wet season begins in October and ends in May. The dry season occurs from June to September. Figure 18 illustrates the average rainfall per month during the period 2000 - 2011. The main rainfall season, from December to April, contributes 77% of the total mean annual runoff. The short rainfall season, May to June and September to December, contribute 23% of the mean annual runoff volume while during the dry rainfall season is July and August, the amount of rainfall is almost zero.

Comparison of the mean monthly rainfall measured by 19 gauges in the study area were made on a yearly basis. Figure 19 shows the variation of the mean rainfall between different years. The mean annual rainfall was around 590 (mm/year). The amount of rainfall fluctuates from year to year during the 11 years. The minimum average annual rainfall was 290 mm and 450 mm in 2007-2008 and 2008-2009 respectively, while the maximum average annual rainfall was 740 mm and 730 mm in 2002-2003 and 2003-2004 respectively. The amount of mean annual rainfall in 2007-2008 was not enough to meet crop needs. The quantity of average annual rainfall to grow economical crop is in the order of 300-600 mm per year (Zakaria et al 2012).

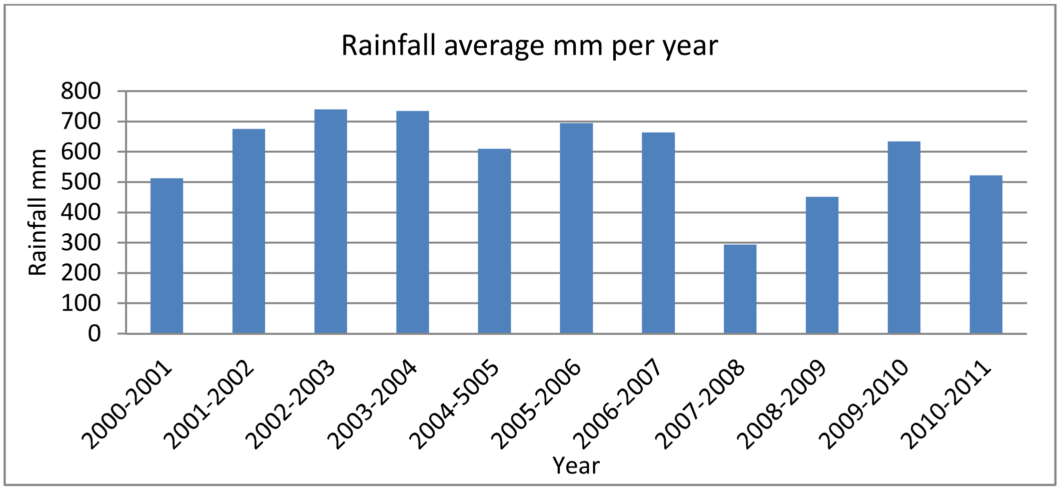


Figure 19 - Comparison of the mean annual rainfall for 19 stations 2000-2011

A significant relationship exists between the elevation of the climatological station and the average annual rainfall. A linear relationship between rainfall and the elevation was found. The equation of the relationship can be expressed as

$$y = 0.6953x + 80.32 \qquad (10)$$

where x is the elevation, and y is the annual mean rainfall. The coefficient of determination (R^2) value is more than 80%. The best-fit trend line shows that rainfall in the study area increases by nearly 70 mm/year per 100 m extra height. Figure 20 shows the relationship between the altitude and mean annual rainfall recorded by the 19 stations in the study area. The lowest elevation of a climatological station is 230 m, which is located in the south of the study area. The highest elevation of a climatological station is 1273 m which is located in the north of the study area. The elevation clearly effects the amount of rainfall.

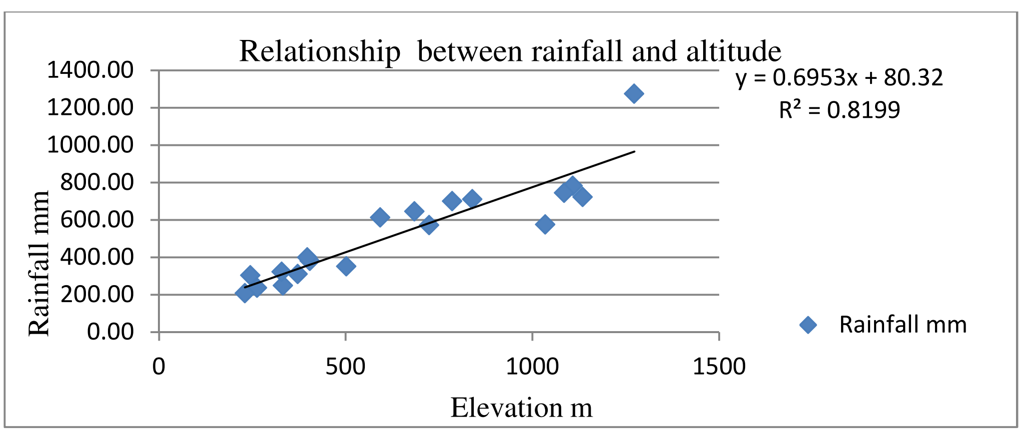


Figure 20 - The relationship between rainfall and altitude in the study area

When dividing the study area into two regions (south west and north east); the elevation of the first region was set to less than 520 m, and the elevation of the second region was set to more than 520 m. The stations Koisnjaq, Soran, Harir, Rawandus, Khalifan, Salahaddin, Sidakan, Shqlaua, Choman and Mergasor were receiving 73% of the total annual mean rainfall 2000-2011, and are all located in the elevation zone above 520 m. The stations Guer, Khabat, Makhmur, Taqtaq, Dibaga, Qushtapa, Ainkaua, Erbil and Bnaslawa were receiving 27% of the total annual mean rainfall. These stations are located in the zone with an elevation less than 520 m. The main cultivated areas in the study area are located on the region with less than 520 m elevation, with the range of 200 mm to 500 mm of annual mean rainfall. This area needs supplementary irrigation for increasing the crop yields, and mitigate interseasonal crop failures. Comparison of the rainfall patterns between low and high elevation climatological stations strongly indicate that the mean annual rainfall in the upper elevation zone is higher than in the lower elevation zone.

The soil conservation service model was used to estimate the runoff to generate the runoff depth map from rainfall distribution in the study area, as mentioned in Section 2.2.8. The map of runoff depth (see Figure 17) has been classified into two zones, moderate and high runoff potential. About 41 % of the study area has a moderate runoff potential, while a high runoff zone covers an area of 59 %.

3.2 Rainwater harvesting potential map

The multi-layer merging of runoff depth, slope, land cover/land use, soil texture, drainage network, and road (buffer) gave suitability units for determining rainwater-harvesting sites. Criterion layers were integrated in ArcGIS by using Multi Criteria Evaluation (Weight Linear Combination) in the model builder. A suitability rainwater-harvesting map was developed, displaying the potential locations for water harvesting in Erbil governorate (see Figure 21).

The multi-criteria evaluation analysis has helped in determining general suitability areas for rainwater harvesting. Five comparable units were indicating potential sites for water harvesting, namely; high suitability, medium high suitability zone, moderate suitability, low suitability and very low suitability. The no suitable zone was represented by restricting areas (built up layer). Figures 21 and 22 show potential sites for rainwater harvesting and the percentage of area covered by different suitability zones for water harvesting.

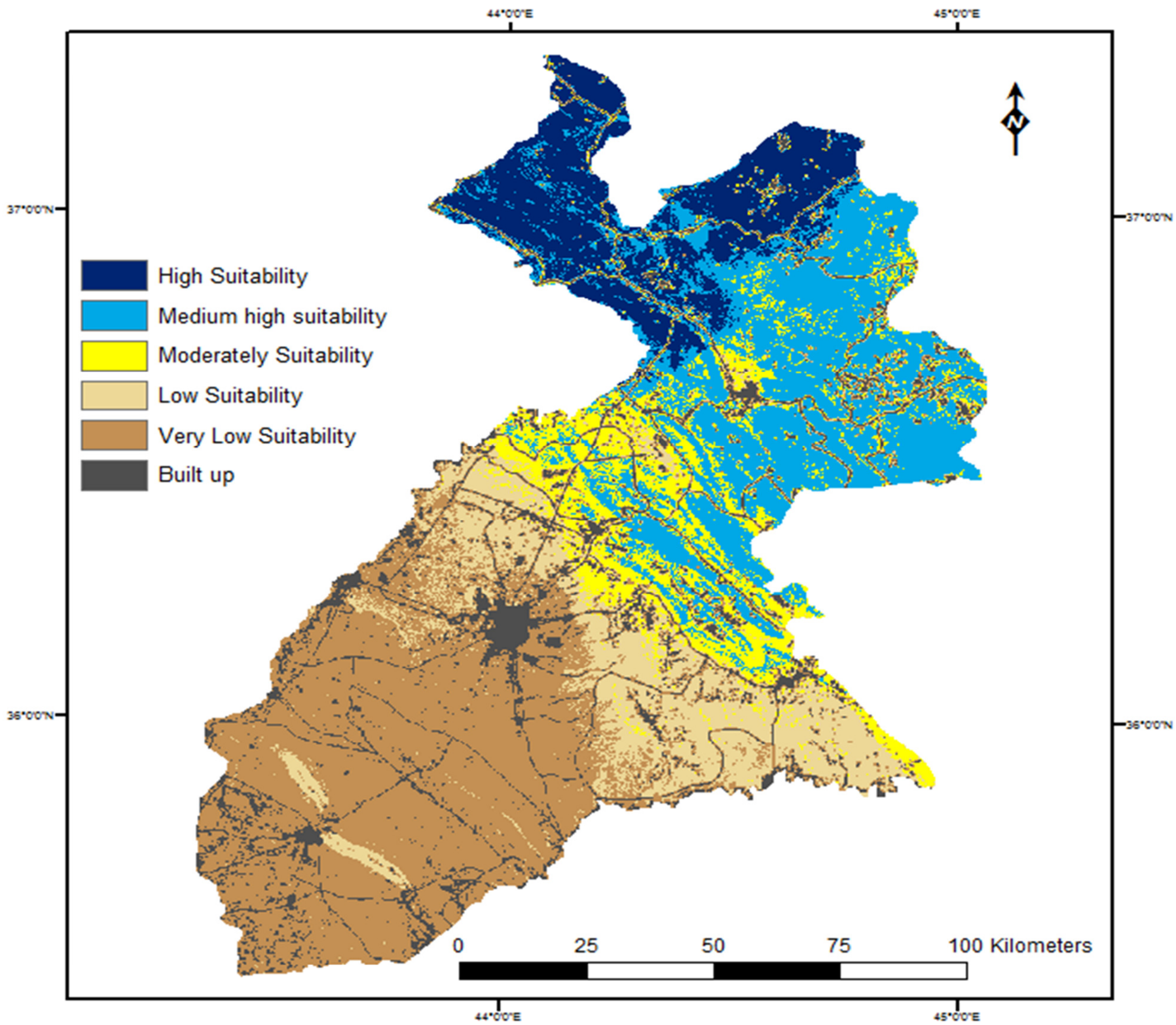


Figure 21 - Rainwater harvesting potential map for the study area

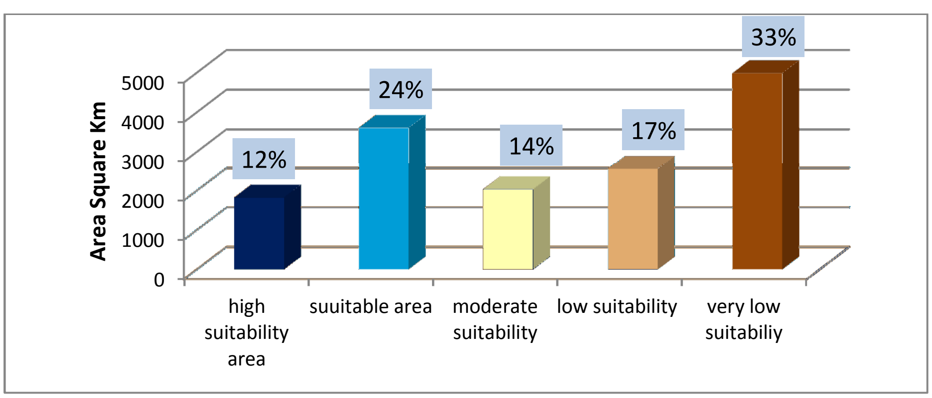


Figure 22 - Percentage of area covered by different rainwater harvesting suitability

Most of the northern part of the study area was determined as being suitable for water harvesting. The northern zone is clearly concentrated in the area with steep slopes and dense hydrological network. The major areas that are determined as suitable zones for water harvesting are located above 520 m in elevation, and on slopes steeper than 15 percent. The major areas that are identified as low and very low suitability zones are located in the southern part of the study area. These zones are located below 520 m in elevation, and on slopes lower than 8 percent. The zones determined as low and very low suitability for water harvesting were more strongly influenced by the runoff depth and slope than by other criteria. The potential sites map for water harvesting shows that the suitable and high suitability areas cover about 5400 square km. The area of low and very low suitability zones is about 7500 square km, while the moderate suitability area was only 2100 square km.

3.3 Sites proposed for small and medium dams

Based on the rainwater harvesting potential layer as well as the drainage network layer, the contour line layer and the Triangulated Irregular Network (TIN) layer with Digital Elevation Model (DEM) were used to suggest the type of structures to be built at the various locations identified. Possible dam locations were chosen based on estimates of the available runoff that could be stored in the dams. The proposed structures are small and medium dams in the study area. Location of Dams was selected by using the rainwater harvesting potential layer with drainage network and the contour line layer, 5 meter interval. The volume and height of dams were computed from triangulated irregular network by using the tools of ArcGIS software. The length of Dams was calculated from the profile of the dam, which extracted from the digital elevation model by using the tools of ArcGIS software. Figure 23 shows the number and locations of small and medium dams proposed in the study area.

The check dams should be on the drainage network. The drainage was derived from the digital elevation model, as mentioned in Section 2.2.1. Figure 9 indicates to the drainage network in the study area. Drainage was classified according to the Strahler Ordering. The northern part of the study area is mainly hilly and mountainous with deep drainage networking compared to the southern part, which is plain or has gentle slopes with depthless drainage network. Seven orders of drainage network were extracted from the digital elevation model. Location of the Dam 2 is situated on 4^{th} order of drainage. Location of the Dam 3, Dam 5 and Dam 6 are situated on 5^{th}

order of the drainage while location of Dam 4 and Dam 1 (Figure 23) are situated on 6th and 7th order of drainage respectively. The preferred sites for these dams are located where drainage is narrow to get a minimum cost for the structures. The location of the dams should be designed to control the water over a monsoon. A location of a dams may be situated in the nearness of habitation. Water stored in the dams could be used for irrigation of surrounding lands, or could be transferred to the southern part of the study area by the drainage network, providing supplemental irrigation during the dry spells.

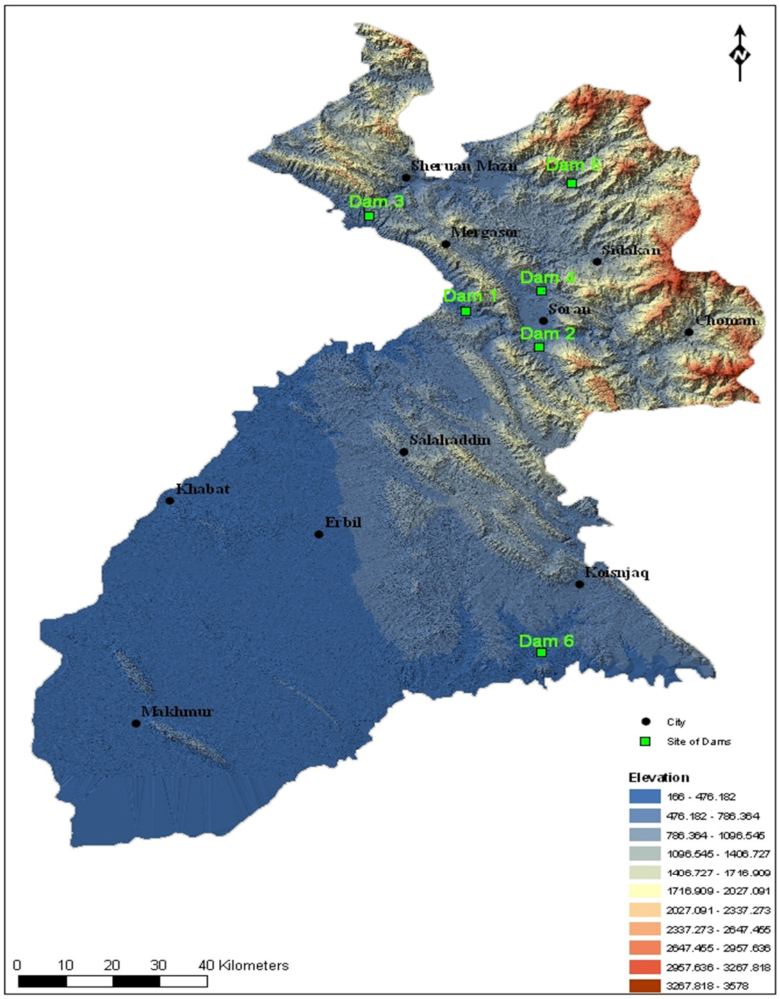


Figure 23 - Location of small and medium dams (dam 1 to dam 6) in the study area

3.4 Profile of the Dams and the storage of reservoir

The suitability map for rainwater harvesting can be used to find or propose suitable sites for small and medium dams. The characteristics of the selected Dams including a profile of the dam, height and length of dams, storage capacity and their basins area, were considered.

Drainage network and contour lines per 5 m interval were used to find appropriate locations for the dams. The Triangular Irregular Network layer was used to estimate the storage capacity of the dam via ArcGIS 10 tools. The size of the dam depends on the storage capacity and the height of the dam (Robinson 2006). According to Table 11 there are three types of dams; small dams, medium dams and large dams. In this study only small and intermediate potential dams for water harvesting have been identified. Table 11 illustrates the type of dam depending on the size and height of the dam.

Category	Storage (m^3)	Height (meter)
Small Dam	< 1,234,000 and ≥ 61,600	< 12.5 and ≥ 7.5
Intermediate Dam	≥ 1,234,000 and < 61,675,000	≥ 12.5 and < 30.5
Large Dam	≥ 61,675,000	≥ 30.5

Table 11 - Size classification of dams
From: Robinson 2006

The length of the dam as well as the height are derived from the Elevation Digital Model by using the ArcGIS 10 tools. Figure 24 shows different levels of water that can be stored in the location of Dam1 and the profile of the dam. It is located at 36° 40’ N, 44° 21’ E. The elevation of the dam is 423 m above sea level.

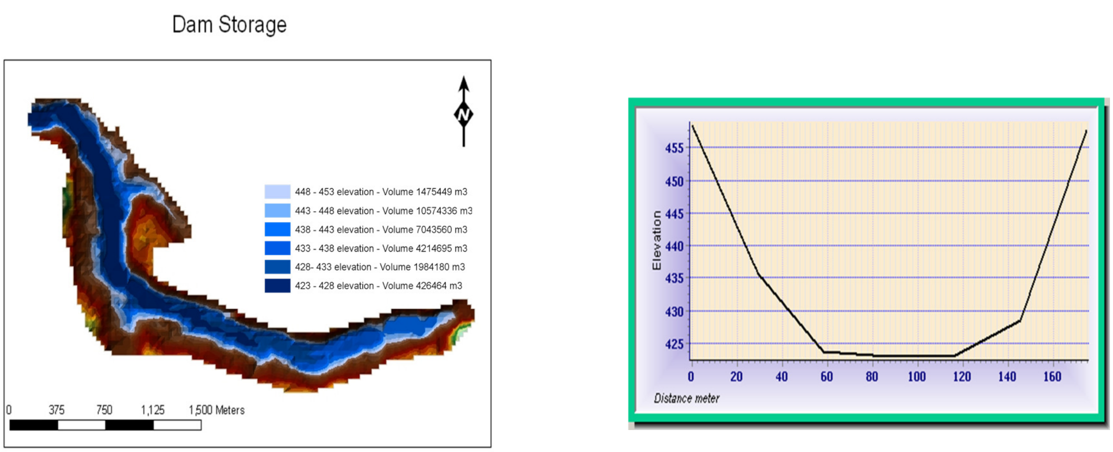


Figure 24 - The storage capacity of Dam 1 to the left, and profile of Dam 1 to the right

Table 12 shows different height of Dam 1 and storage capacity. The maximum height of Dam 1 is 30 m, and the maximum storage capacity measured from the bed of the drainage to the top of the dam is 14.7 million cubic meter. According to Table 11, Dam 1 is classified as an intermediate dam. The area of Dam 1 basin is about 1765 square km.

Proposed dam	Elevation m	Dam height m	Dam length m	Storage capacity m^3
Dam1	423	0	0	0
	428	5	95	426,464
	433	10	107	1,984,180
	438	15	130	4,214,695
	443	20	140	7,043,560
	448	25	155	10,574,336
	453	30	163	14,753,449

Table 12 - The elevation of dam 1 and the storage capacity

The second suggested location for Dam 2 is located at 36° 36’ N, 44° 31’ E (see Figure 23) with an elevation of 716 m above sea level. Figure 25 illustrates the profile of Dam 2 and the storage capacity

Dam Storage

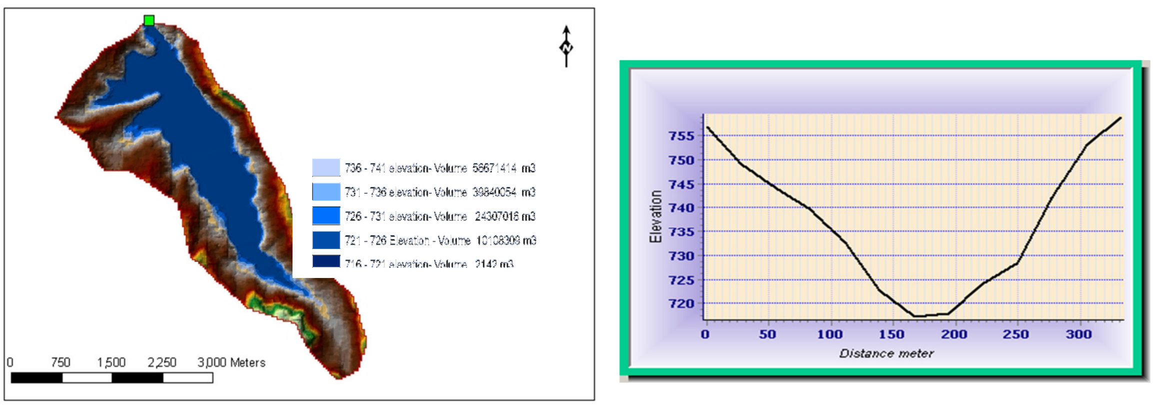


Figure 25 - The storage capacity of Dam 2 to the left and profile of Dam 2 to the right

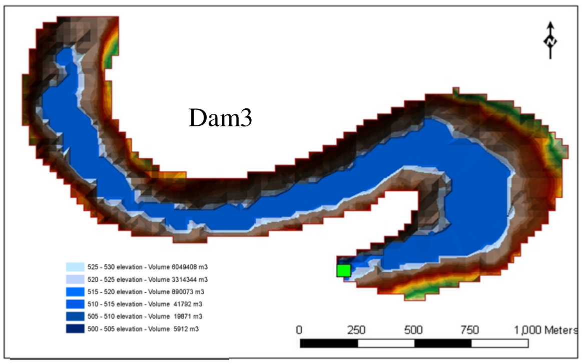
Proposed dam	Elevation m	Dam height m	Dam length m	Storage capacity m^3
Dam 2	716	0	0	0
	721	5	88	2,142
	726	10	108	10,108,309
	731	15	148	24,307,016
	736	20	195	39,840,054
	741	25	205	56,671,414

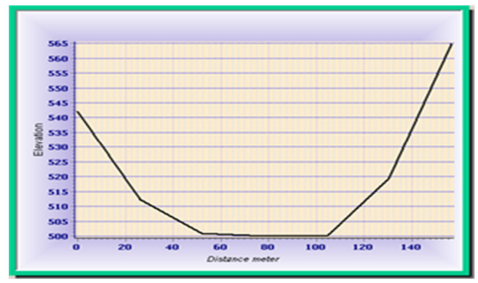
Table 13 - The elevation of Dam 2 and the storage capacity

The maximum height of the dam 2 is 28 m, and the maximum storage capacity measured from the bed of the drainage to the top of the dam is around 56 million cubic meter. According to the Table 11, Dam 2 is classified as an intermediate dam. The area of Dam 2 drainage basin is 125 square km, and the volume of runoff from the catchment of Dam 2 is about 1210 million cubic meter.

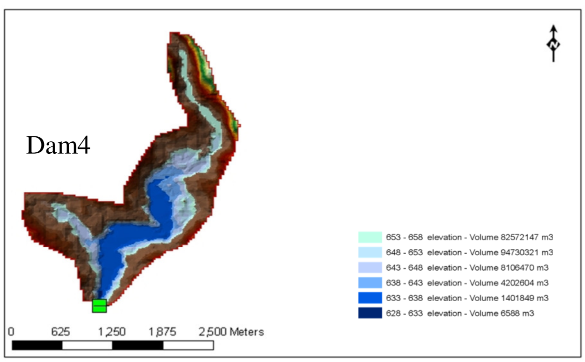
The locations of dam do not represent all the possible water harvesting sites, but only te best locations are selected for analysis purpose. Figure 26 shows Dam 3-Dam 6 possible dam sites in the study area as well as the dam profiles

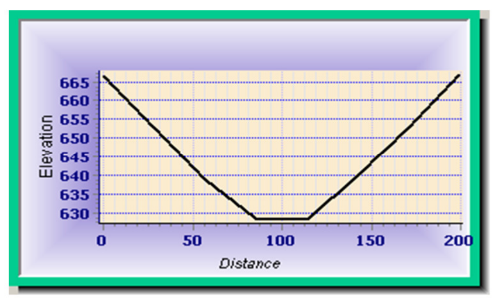
Dam Storage



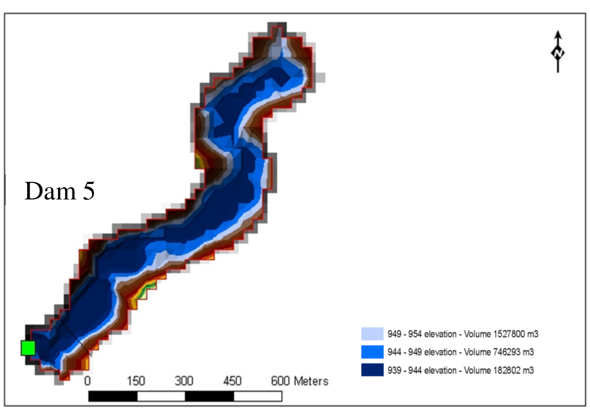


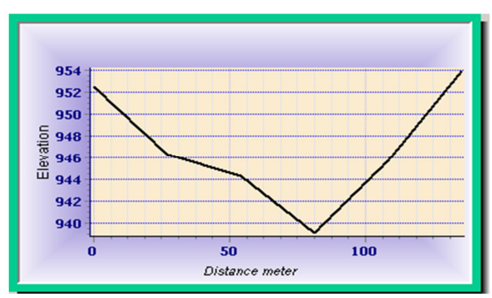
Dam Storage





Dam Storage





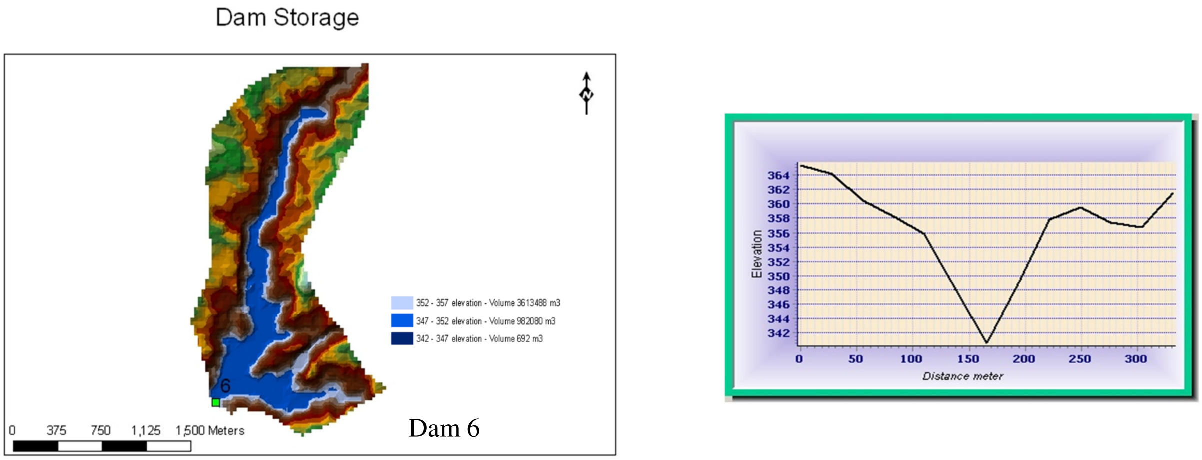


Figure 26 - Profiles and storage capacities of Dam

Dam 3 in Figure 26 is located at 36° 53' N, 44° 19' E with an elevation of 500 m above sea level. The maximum water capacity of Dam 3 is around 6 million cubic meters if 30 meter height. The maximum length of Dam 3 is 128 meter. The catchment area of the Dam 3 is 1198 square kilometer, while the volume of runoff of this catchment is about 1434 million cubic meter. The classification of Dam 3 is an intermediate dam.

Dam 4 is situated at 36° 43' N and 44° 32' E. The elevation of Dam 4 is 628 m above sea level with around 83 million cubic meter of storage capacity. The height of Dam 4 is 30 meter, and the maximum length of Dam 4 is 162 meter. The catchment area is 795 square kilometer, and the estimate runoff volume of Dam 4 is about 645 million cubic meter. The category of Dam 4 is an intermediate dam.

Dam 5 and Dam 6 are classified as small dams according to the Table 11. The storage capacity is 1.5 and 3.6 million cubic meters respectively. The maximum height is 15 meters for both dams. The coordinates of Dam 5 and Dam 6 are 35° 57' N, 44° 36' E and 35° 55' N, 44° 32' E respectively. The length of Dam 5 and Dam 6 are 136 and 112 meter. The runoff volumes of the catchments are 207 and 169 million cubic meter respectively. Table 14 shows the suitable locations of the suggested dam sites as well as the storage capacities of the dams.

Proposed dam	Elevation m	Dam height m	Dam length m	Storage capacity m^3
Dam 3	500	0	0	0
	505	5	65	5,912
	510	10	84	19,871
	515	15	102	41,792
	520	20	110	890,073
	525	25	122	3,314,344
	530	30	128	6,049,408
Dam 4	628	0	0	0
	633	5	50	6,588
	638	10	80	1,401,849
	643	15	100	4,202,604
	648	20	120	8,106,470
	653	25	156	94,730,321
	658	30	162	82,572,147
Dam 5	939	0	0	0
	944	5	44	182,802
	949	10	106	746,293
	954	15	136	1,527,800
Dam 6	342	0	0	0
	347	5	50	6,929
	352	10	82	982,080
	357	15	112	3,613,488

Table 14 - Locations and storage capacities of the proposed dam sites

The location of Dam 1, Dam 2 and Dam 4 were selected in the suitable area for water harvesting while Dam 3 and Dam 5 are situated in the high suitability area. Only dam 6 is located in the moderately suitability area. The available data were used to estimate suitable area for water harvesting in Erbil governorate, and possible dam sites were selected. But there are other criteria, such as geology and socioeconomy, which were not available to use in this study. In addition, the spatial distribution of the villages with population.

4 Conclusions

A multi criteria evaluation model has been used to help decision markers to select suitable zones for water harvesting in arid and semi-arid areas in Iraqi Kurdistan. GIS supports multi criteria evaluation combining different types of criteria to obtain the best decision. A complex problem can then be easier to solve, and the ambiguous judgment can become accurate by using the multi criteria evaluation. Multi criteria evaluation was useful by using the weighted linear combination in a consistent way in order to construct a suitability map for rainwater harvesting technologies.

Different kinds of factors were taken into consideration for multi criteria evaluation including; land cover, soil texture, slope and runoff depth. Land cover was extracted from a LANDSAT satellite image with 30-meter resolution. The soil map was digitized from the soil map of the Kurdistan Region Governorate, Iraq. The slope map was derived from the digital elevation model. In addition, the soil conservation service model was used to estimate the runoff depth in the study area. The values of these criteria were re-classified into numerical values ranging from zero to one in order to obtain a unified scale to each layer with a resolution of 30 meter.

Criteria maps were integrated by using the weighted linear combination to obtain a suitability map consisting of five comparable classes; high suitability, medium high suitability, moderate suitability, low suitability and very low suitability. A boolean operation of logical AND was used to determine different zones. A buffer operation was carried out for the road layer and overlaid with the suitability map for rainwater harvesting, it is excluding the roads from the study. The suitability map is useful to decision-makers and planners to quickly determine areas that have rainwater harvesting potential than other areas. For example check dams can be located in these areas.

The soil conservation service model was applied by using mean annual rainfall for the period 2000 to 2011 in Erbil area to estimate the runoff depth. The analysis of rainfall indicates that a significant amount of annual runoff depth can be harvested. The result showed that the volume of runoff depth was greater than the water capacity of the reservoir volumes. These excess amounts of the water give guarantee to fill the reservoirs in the rainy season. The results also indicate that there was a large difference between the quantity of runoff in the northern part and the southern part of the study area. The minimum runoff depth in the south part is about 103 mm, while the maximum runoff depth is more than 1000 mm, in the northern part of the study area.

The runoff in the middle and the northern part of the study area very suitable for water harvesting. The suitability of the north for water harvesting gives a good opportunity to store water and transfer this water by diversion canals to the southern part of the study area.

The total high suitable and suitable areas are 36%, while the moderately suitable area is 14%. The remaining part, representing low and very low suitability, is 50%. Application of rainwater harvesting should be done in connection with a field survey, because the spatial resolution of the analysis does not guarantee that every site in an area classified as low suitable areas is indeed low suitable areas. There may be spots of suitable areas for rainwater harvesting. On the other hand, any location in an area classified as highly suitable does not guarantee that it is highly suitable because some of these locations may be tourism areas or archaeological areas or settlement areas or influenced by social factor preventing implementation of hydraulic structures.

This study also showed that integrated geographic information analysis and fuzzy logic are appropriate in determining suitable zones and candidate sites for locating water reservoirs in the Erbil governorate, Iraqi Kurdistan Region. The six possible sites for building small and medium dams were determined by use of geographic information system and multi criteria evaluation.

Map quality depends on the quality and accuracy of the data, including how data were gathered, processed and produced. High quality data provide more reliable and efficient output. In addition, the allocation of weights to the different criteria effects the quality of the estimated map since the identification and allocation of weights to a high degree influence the multicriteria analysis. In this study weights were selected based on previous studies. However, both the data quality and the allocation of weights are sources of errors in this study.

People in several parts of the Kurdistan region are suffering from water shortage. Therefore, application of macro rainwater harvesting will affect them directly to minimize the water crisis in the region. However, one should not forget the socio-economic aspects of water harvesting. For this project to be applied in reality, the social and economic factors should be studied more in detail, and seriously be taken into account due to the complex culture and traditions of people living in the study area.

References

Adekalu, K.O, Balogun, J.A, Aluko, O.B, Okunade, D.A, Gowing J.W, and Faborode M.O, Runoff water harvesting for dry spell mitigation for cowpea in the savannah belt of Nigeria. Agricultural Water Management. 96, 1502–1508, Nigeria 2009.

Al-Harbi, Kamal M. Al-Subhi, Application of the AHP in project management, Department of Construction Engineering and Management, King Fahd University of Petroleum & Minerals, International Journal of Project Management 19 (2001), SaudiArabia.

ArcGIS Desktop 9.3 help, ESRI, 2009, (http://webhelp.esri.com/arcgisdesktop/9.2/index.cfm?TopicName=Using%20kriging), Accessed, September 2012.

Askar, Maysoon Khalil & Rasul, Hedi A, Integrated Water Resources Management for Alana Valley in Kurdistan Region – Iraq, University of Salahaddin, Erbil, 2010.

Boers, Th.M, Rainwater Harvesting in Arid and Semi-Arid Zones, International Institute for Land Reclamation and Improvement, P.O.BOX 45,6700 AA Wageningen, The Netherlands, 1994

Bakleh, Khaled, Kurdistan Business Agenda, Center for International Private Enterprises, report, November 2006.

Bohling, Geoff, Assistant Scientist, Kanasa University, Geological Survey Department, October 2005, (http://people.ku.edu/~gbohling/cpe940/Kriging.pdf)

Bui, Quang Binh, locating suitable dam site along the Tien Yen river, Quang Ninh province by employing GIS and Multi Criteria Analysis, Division of Geomatics, University of Gävle, Sweden 2010.

Buringh, DR. P, Soil and Soil Conditions in Iraq, Ministry of Agriculture, Baghdad, Iraq, 1960.

Buringh, P, soils and soil conditions in Iraq, directorate general of agricultural research and projects, ministry of agriculture, Baghdad, 1960.

Clark Labs, Clark University, IDRISI Source Code © 1987-2006 J. Ronald Eastman, 950 Main Street, Worcester MA 01610-1477 USA, http://www.clarklabs.org.

CNOAA, United State Department of Commerce National Oceanic and Atmospheric Administration, National Weather Service, Office of Hydrologic Development, 1325 East West Highway, Sikver Spring, MD 20910, March 2011.

DNSFPA, Defense National Security and Foreign Policy Analysi in the Dynamic System of International Relation and Diplomacy , Fogg War, December 2008 , (http://foggofwar.blogspot.se/2008/12/iraqs-kurd-problem.html)

Drobne, Samo and Lisec, Anka, Multi-attribute Decision Analysis in GIS: Weighted Linear Combination and Ordered Weighted Averaging, University of Ljubljana, Faculty of Civil and Geodetic Engineering, Slovenia 2009.

Eastman, J. Ronald, Idrisi Andes Guid to GIS and Image Processing, Clark University, USA 2006.

Ebrahimian, M., Nuruddin, A. Ainuddin, Soom, M. A. B. Mohd, Sood, A. M, Application of NRCS-curve number method for runoff estimation in a mountainous watershed, Caspian J. Env. Sci. 2012, Vol. 10 No.1 pp. 103~114, University of Guilan, Printed in I.R. Iran.

Fadhil, Ayad Mohammed, Drought mapping using Geoinformation technology for some sites in the Iraqi Kurdistan region, Soil and Water Science Department, Agriculture College, SalahaddinUniversity-Hawler,Kurdistan Region, Iraq, April 2010.

Gupta, K.K, Deelstra, J. and K.D, Remote Sensing and Geographic Information Systems for Design and Operation of Water Resources Systems, April 1997, IAHS Publ. no. 242).

Heshmati, Almas, integrated water resources management in Kurdistan Region, Nova Science Publishers, New York, 2009.

HydroCAD® Stormwater Modeling - Since 1986, http://www.hydrocad.net/subcat.htm

http://www.khatuzeen.org/english/content/about_kurdistan.asp)

http://www.khatuzeen.org/english/content/about_kurdistan.asp.

Idrisi Andes Guide to GIS and Image Processing, Clark University, USA 2006. Inter-Agency Information and Analysis Unit (IAU),February2011, (http://www.iauiraq.org/gp/print/GP-Erbil.pdf).

Idrisi Andes Guide to GIS and Image Processing, Clark University, USA 2006.

Jongerden, Joost, Dams and Politics in Turkey: Utilizing Water Development Conflict, Middel East Policy, the Social Sciences Department of the Wageningen University in the NetherlandsVol.XVII,No. 1, Spring 2010. http://www.academia.edu/278072/Dams_and_Politics_in_Turkey_Utilizing_Water_Developing_Conflict

Kahraman, Layla M., Geographical analysis of the characteristics of soils and the problems of the province of Arbil and scalability land productivity, Erbil, 2004.

Ketsela, Girma Moges, Identification of potential rain water harvesting areas in the Central Rift Valley of Ethiopia using a GIS-based approach, wageningen university, netherland 2007.

Kurdistan Regional Government,2010 http://www.krg.org/a/d.aspx?r=140&l=12&s=03010300&a=18656&s=010000

Longley, Paul A, Goodchild, Mike ,Maguire, David J, Rhind, David W, Georaphic information system and science, editor2, 2011,p336.

Maidment, David R, HandBook of Hydrology, University of Texas at Astin, Texas USA 1993.

Marek, Mark A., Hydraulic Design Manual, 2011 by Texas Department of Transportation (512) 302-2453 all rights reserved, USA.

Melesse, Assefa M, Shih, S.F, Spatially distributed storm runoff depth estimation using Landsat images and GIS, Computers and Electronics in Agriculture, University of Florida, Gainesville, FL 32611-0570, USA 2002

Mkiramwinyi, F.O, Mbilinyi, B.P, Tumbo, S.D, Munishi, P.T.K, and Mahoo, H. F, Development of a methodology for Identifying Potential Sites for Rainwater Harvesting: a Case of Makanya Catchment in TANZANIA, Sokoine University of agriculture, Department of Forest Economics, P.O. Box 3011, Morogoro, Tanzania 2007.

Moges, Yitebitu, Water Harvesting Techniques: Training and Construction Manual, Consultancy Sub-report, No. 2, Tropical Forestry, March 2004.

Mzirai, O. B and Tumbo, S. D, Macro-catchment rainwater harvesting systems challenges and opportunities to access runoff, Journal of Animal & Plant Sciences,. Vol. 7, Issue 2: 789- 800, Tanzania 2010.

Munyao, John Ngila, Use of Satellite Products to Assess Water Harvesting Potential in Remote Areas of Africa,International Institute for Geo-Information Science and Earth Observation Enschede, the Nwtherlands, February 2010.

Ramakrishnan, D, Bandyopadhyay, A and Kusuma, K N, SCS-CN and GIS-based approach for identifying potential water harvesting sites in the Kali Watershed, Mahi River Basin, India, Department of Earth Sciences, Indian Institute of Technology, 2009.

Robinson, Jim, DCR Dam Safety Technical AdvisoryTable 1 Briefing, Department of Conservation and Recreation, Coserving Virginia's Natural and Recreational Resources, June 2006, USA. (http://www.dcr.virginia.gov/documents/dstbl1.pdf).

Roebuck , Richard Michael. "A whole life costing approach for rainwater harvesting systems", Ph.D. Dissertation, University of Bradford, UK 2007.

Omer, Tara Mohamed Anwar, Country Pasture/Forage Resource Profiles IRAQ, Food and Agriculture Organization of the United Nations (FAO), Research and Extension, FAO, Viale delle Terme di Caracalla, 00153 Rome, Italy, 2011.

Oweis, Theib and Hachum, Ahmed, Water Harvesting And Supplemental Irrigation For Improved Water Productivity Of Dry Farming Systems In West Asia And North Africa, International Center for Agricultural Research in the Dry Areas (ICARDA), Aleppo, Syria 2006.

Sardar Sarovar Project, the river Narmada in Gujarat, India, http://ssp.maharashtra.gov.in/CatchmentAreaTreatment.php

Shahab Moghadas, Long-term Water Balance of an Inland River Basin in an Arid Area, North-Western China, Lund University, January 2009.

Tsiko, Rodney G, Integrating Geographical Information Systems, Fuzzy Logic and Analytical Hierarchy Process in Modelling Optimum Sites for Locating Water Reservoirs. A Case Study of the Debub District in Eritrea, School of Geography, Faculty of Environment, University of Leeds, 2011.

Tumbo S.D, Determination of Suitability Levels for Important Factors for Identification of Potential Sites for Rainwater Harvesting, Soil Water Management Research Group, Mwanza, Tanzania 2007.

UNDP, United Nations Development Programmer Iraq, Drought Impact Assessment, Recovery and Mitigation Framework and Regional Project Design in Kurdistan Region (KR), January 2011.

USAID, Development Assessment, Final Report, December, Kurdistan Region Economic 2008.

UNESCO, Dale Lightfoot, Survey of Infiltration Karez(springs) in Northern Iraq: History and Current Status of Underground Aqueducts, (A report prepared for UNESCO by Department of Geography, Oklahoma State University, September 2009.

Vertical Mapper Guide, Version 3.7, December 2009, (http://www.scribd.com/doc/51278214/51/Suggested-Reading-on-Interpolation-

Techniques).Accessed, September 2012.

Weerasinghe, H, U. A. Schneider and A. L¨ow, Water harvest- and storage- location assessment model using GIS and remote sensing, University of Hamburg, Hamburg, Germany,2011.

Winnaar, G. de , G.P.W. Jewitt, M. Horan, A GIS-based approach for identifying potential runoff harvesting sites in the Thukela River basin, South Africa, Physics and Chemistry of the Earth 32 (2007) 1058–1067.

Yasiri, Safi, Project (GAP) Turkish Results hazardous to life in Iraq and the region, Newspaper (ALmada) Baghdadiya, Iraq 2007.
http://www.alshirazi.com/world/article/89.htm

Younggu Her,Land use classification in Zambia using Quickbird and Landsat imagery, Biological Systems Engineering, Virginia Tech., Blacksburg, June 2007.

Zakaria, Saleh, Al-Ansari, Nadhir, Knutsson, Sven, Aldeen, Mohammad Ezz-, Rain Water Harvesting and Supplemental Irrigation at Northern Sinjar Mountain, Iraq, Journal of Purity, Utility Reaction and Environment Vol.1 No.3, May 2012, 121-141.

Appendices

Appendix (1) shows the resulting union between the land cover and Hydrologic Soil Group.

Soil type	HSG	Land Cover
lithosolic soils in sand ston and gypsun,Shallow to moderate deep, gravel to very gravelly lime-rich silt loam to silt clay loam.	B	bare soil
lithosolic soils in sand ston and gypsun, Shallow to moderate deep, gravel to very gravelly lime-rich silt loam to silt clay loam.	B	built upl
lithosolic soils in sand ston and gypsun, Shallow to moderate deep, gravel to very gravelly lime-rich silt loam to silt clay loam.	B	water
lithosolic soils in sand ston and gypsun, Shallow to moderate deep, gravel to very gravelly lime-rich silt loam to silt clay loam.	B	farmland
lithosolic soils in sand ston and gypsun, Shallow to moderate deep, gravel to very gravelly lime-rich silt loam to silt clay loam.	B	grass and open forest
lithosolic soils in lime stone, Shallow to moderate deep, gravel to very gravelly lime-rich silt loam to silt clay loam.	B	bare soil
lithosolic soils in lime stone, Shallow to moderate deep, gravel to very gravelly lime-rich silt loam to silt clay loam.	B	built upl
lithosolic soils in lime stone, Shallow to moderate deep, gravel to very gravelly lime-rich silt loam to silt clay loam.	B	water
lithosolic soils in lime stone, Shallow to moderate deep, gravel to very gravelly lime-rich silt loam to silt clay loam.	B	farmland
lithosolic soils in lime stone, Shallow to moderate deep, gravel to very gravelly lime-rich silt loam to silt clay loam.	B	grass and open forest
brown soils, medium and shallow phase over bakhtiary gravel, lime rich non gravel and gravel silt clay to clay with surface cracks.	D	bare soil
brown soils, medium and shallow phase over bakhtiary gravel, lime rich non gravel and gravel silt clay to clay with surface cracks.	D	built upl
brown soils, medium and shallow phase over bakhtiary gravel, lime rich non gravel and gravel silt clay to clay with surface cracks.	D	water
brown soils, medium and shallow phase over bakhtiary gravel, lime rich non gravel and gravel silt clay to clay with surface cracks.	D	farmland
brown soils, medium and shallow phase over bakhtiary gravel, lime rich non gravel and gravel silt clay to clay with surface cracks.	D	grass and open forest
brown soils, medium and shallow phase over bakhtiary gravel, lime rich non gravel and gravel silt clay to clay with surface cracks.	C	bare soil
brown soils, medium and shallow phase over bakhtiary gravel, lime rich non gravel and gravel silt clay to clay with surface cracks.	C	built upl
brown soils, medium and shallow phase over bakhtiary gravel, lime rich non gravel and gravel silt clay to clay with surface cracks.	C	water
brown soils, medium and shallow phase over bakhtiary gravel, lime rich non gravel and gravel silt clay to clay with surface cracks.	C	farmland
brown soils, medium and shallow phase over bakhtiary gravel, lime rich non gravel and gravel silt clay to clay with surface cracks.	C	grass and open forest
brown soils, deep phase, lime –rich non gravel , silt loam to silt clay loam.	C	bare soil
brown soils, deep phase, lime –rich non gravel , silt loam to silt clay loam.	C	built upl
brown soils, deep phase, lime –rich non gravel , silt loam to silt clay loam.	C	water
brown soils, deep phase, lime –rich non gravel , silt loam to silt clay loam.	C	farmland
brown soils, deep phase, lime –rich non gravel , silt loam to silt clay loam.	C	grass and open forest
chestnut soils, shallow, stony and sloping phases, gravel content frequent badland areas, on exposed clay stone.	D	bare soil
chestnut soils, shallow, stony and sloping phases, gravel content frequent badland areas, on exposed clay stone.	D	built upl
chestnut soils, shallow, stony and sloping phases, gravel content frequent badland areas, on exposed clay stone.	D	water
chestnut soils, shallow, stony and sloping phases, gravel content frequent badland areas, on exposed clay stone.	D	farmland
chestnut soils, shallow, stony and sloping faces, gravel content frequent badland areas,	D	grass and open forest
rough broken and stony land, loamy to clay soils with variable gravel and stone content.	D	bare soil

rough broken and stony land, loamy to clay soils with variable gravel and stone content.	D	built upl
rough broken and stony land, loamy to clay soils with variable gravel and stone content.	D	water
rough broken and stony land, loamy to clay soils with variable gravel and stone content.	D	farmland
rough broken and stony land, loamy to clay soils with variable gravel and stone content.	D	grass and open forest
rough mountaious land, loamy to clayey soils with variable stone content, Rock outcrops.	D	bare soil
rough mountaious land, loamy to clayey soils with variable stone content, Rock outcrops.	D	built upl
rough mountaious land, loamy to clayey soils with variable stone content, Rock outcrops.	D	water
rough mountaious land, loamy to clayey soils with variable stone content, Rock outcrops.	D	farmland
rough mountaious land, loamy to clayey soils with variable stone content, Rock outcrops.	D	grass and open forest
rough mountainous land, alpine phase, loamy to clayey soils with variable stone content,	D	bare soil
rough mountainous land, alpine phase, loamy to clayey soils with variable stone content,	D	built upl
rough mountainous land, alpine phase, loamy to clayey soils with variable stone content,	D	water
rough mountainous land, alpine phase, loamy to clayey soils with variable stone content,	D	farmland
rough mountainous land, alpine phase, loamy to clayey soils with variable stone content,	D	grass and open forest

Appeddix (2) Table of runoff Curve Number (CN) (Munyao 2010).

Description of Land Use	Hydrologic Soil Group			
	A	**B**	**C**	**D**
Paved parking lots, roofs, driveways	98	98	98	98
Streets and Roads:				
Paved with curbs and storm sewers	98	98	98	98
Gravel	76	85	89	91
Dirt	72	82	87	89
Cultivated (Agricultural Crop) Land*:				
Without conservation treatment (no terraces)	72	81	88	91
With conservation treatment (terraces, contours)	62	71	78	81
Pasture or Range Land:				
Poor (<50% ground cover or heavily grazed)	68	79	86	89
Good (50-75% ground cover; not heavily grazed)	39	61	74	80
Meadow (grass, no grazing, mowed for hay)	30	58	71	78
Brush (good, >75% ground cover)	30	48	65	73
Woods and Forests:				
Poor (small trees/brush destroyed by over- grazing or burning)	45	66	77	83
Fair (grazing but not burned; some brush)	36	60	73	79
Good (no grazing; brush covers ground)	30	55	70	77
Open Spaces (lawns, parks, golf courses, cemeteries, etc.):				
Fair (grass covers 50-75% of area)	49	69	79	84
Good (grass covers >75% of area)	39	61	74	80
Industrial Districts (72% impervious)	81	88	91	93
Residential Areas:				
1/8 Acre lots, about 65% impervious	77	85	90	92
1/4 Acre lots, about 38% impervious	61	75	83	87
1/2 Acre lots, about 25% impervious	54	70	80	85
1 Acre lots, about 20% impervious	51	68	79	84
Bare soil	77	86	91	94
Water	100	100	100	100
Woods- Grass combination	43	65	78	82

Appendix 3 the average of rainfall per year

Id	Station Name	Rainfall mm	altitude meter
1	Makhmur	237.5	263
2	Dibaga	249	332
3	Qushtapa	311	372
4	Guer	208	230
5	Bnaslawa	350.7	502
6	Erbil	381	404
7	Ainkaua	399.96	397
8	Khabat	304	245
9	Taqtaq	321.58	329
10	Koisnjaq	612.4	593
11	Shqlaua	782.56	1108
12	Salahaddin	575.45	1035
13	Harir	571.6	724
14	Khalifan	710.8	839
15	Rawandus	699.58	785
16	Soran	645.4	684
17	Choman	723	1135
18	Sidakan	743.8	1085
19	Mergasor	1275.1	1273

Institutionen för naturgeografi och ekosystemvetenskap, Lunds Universitet.

Student examensarbete (Seminarieuppsatser). Uppsatserna finns tillgängliga på institutionens geobibliotek, Sölvegatan 12, 223 62 LUND. Serien startade 1985. Hela listan och själva uppsatserna är även tillgängliga på LUP student papers (www.nateko.lu.se/masterthesis) och via Geobiblioteket (www.geobib.lu.se)

The student thesis reports are available at the Geo-Library, Department of Physical Geography and Ecosystem Science, University of Lund, Sölvegatan 12, S-223 62 Lund, Sweden. Report series started 1985. The complete list and electronic versions are also electronic available at the LUP student papers (www.nateko.lu.se/masterthesis) and through the Geo-library (www.geobib.lu.se)

230 Cléber Domingos Arruda (2011) Developing a Pedestrian Route Network Service (PRNS)
231 Nitin Chaudhary (2011) Evaluation of RCA & RCA GUESS and estimation of vegetation-climate feedbacks over India for present climate
232 Bjarne Munk Lyshede (2012) Diurnal variations in methane flux in a low-arctic fen in Southwest Greenland
233 Zhendong Wu (2012) Dissolved methane dynamics in a subarctic peatland
234 Lars Johansson (2012) Modelling near ground wind speed in urban environments using high-resolution digital surface models and statistical methods
235 Sanna Dufbäck (2012) Lokal dagvattenhantering med grönytefaktorn
236 Arash Amiri (2012)Automatic Geospatial Web Service Composition for Developing a Routing System
237 Emma Li Johansson (2012) The Melting Himalayas: Examples of Water Harvesting Techniques
238 Adelina Osmani (2012) Forests as carbon sinks - A comparison between the boreal forest and the tropical forest
239 Uta Klönne (2012) Drought in the Sahel – global and local driving forces and their impact on vegetation in the 20th and 21st century
240 Max van Meeningen (2012) Metanutsläpp från det smältande Arktis
241 Joakim Lindberg (2012) Analys av tillväxt för enskilda träd efter gallring i ett blandbestånd av gran och tall, Sverige
242 Caroline Jonsson (2012) The relationship between climate change and grazing by herbivores; their impact on the carbon cycle in Arctic environments
243 Carolina Emanuelsson and Elna Rasmusson (2012) The effects of soil erosion on nutrient content in smallholding tea lands in Matara district, Sri Lanka
244 John Bengtsson and Eric Torkelsson (2012) The Potential Impact of Changing Vegetation on Thawing Permafrost: Effects of manipulated vegetation on summer ground temperatures and soil moisture in Abisko, Sweden
245 Linnea Jonsson (2012). Impacts of climate change on Pedunculate oak and Phytophthora activity in north and central Europe
246 Ulrika Belsing (2012) Arktis och Antarktis föränderliga havsistäcken
247 Anna Lindstein (2012) Riskområden för erosion och näringsläckage i Segeåns avrinningsområde

248 Bodil Englund (2012) Klimatanpassningsarbete kring stigande havsnivåer i Kalmar läns kustkommuner
249 Alexandra Dicander (2012) GIS-baserad översvämningskartering i Segeåns avrinningsområde
250 Johannes Jonsson (2012) Defining phenology events with digital repeat photography
251 Joel Lilljebjörn (2012) Flygbildsbaserad skyddszonsinventering vid Segeå
252 Camilla Persson (2012) Beräkning av glaciärers massbalans – En metodanalys med fjärranalys och jämviktslinjehöjd över Storglaciären
253 Rebecka Nilsson (2012) Torkan i Australien 2002-2010 Analys av möjliga orsaker och effekter
254 Ning Zhang (2012) Automated plane detection and extraction from airborne laser scanning data of dense urban areas
255 Bawar Tahir (2012) Comparison of the water balance of two forest stands using the BROOK90 model
256 Shubhangi Lamba (2012) Estimating contemporary methane emissions from tropical wetlands using multiple modelling approaches
257 Mohammed S. Alwesabi (2012) MODIS NDVI satellite data for assessing drought in Somalia during the period 2000-2011
258 Christine Walsh (2012) Aerosol light absorption measurement techniques: A comparison of methods from field data and laboratory experimentation
259 Jole Forsmoo (2012) Desertification in China, causes and preventive actions in modern time
260 Min Wang (2012) Seasonal and inter-annual variability of soil respiration at Skyttorp, a Swedish boreal forest
261 Erica Perming (2012) Nitrogen Footprint vs. Life Cycle Impact Assessment methods – A comparison of the methods in a case study.
262 Sarah Loudin (2012) The response of European forests to the change in summer temperatures: a comparison between normal and warm years, from 1996 to 2006
263 Peng Wang (2012) Web-based public participation GIS application – a case study on flood emergency management
264 Minyi Pan (2012) Uncertainty and Sensitivity Analysis in Soil Strata Model Generation for Ground Settlement Risk Evaluation
265 Mohamed Ahmed (2012) Significance of soil moisture on vegetation greenness in the African Sahel from 1982 to 2008
266 Iurii Shendryk (2013) Integration of LiDAR data and satellite imagery for biomass estimation in conifer-dominated forest
267 Kristian Morin (2013) Mapping moth induced birch forest damage in northern Sweden, with MODIS satellite data
268 Ylva Persson (2013) Refining fuel loads in LPJ-GUESS-SPITFIRE for wet-dry areas - with an emphasis on Kruger National Park in South Africa
269 Md. Ahsan Mozaffar (2013) Biogenic volatile organic compound emissions from Willow trees
270 Lingrui Qi (2013) Urban land expansion model based on SLEUTH, a case study in Dongguan City, China