ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

SCHOOL OF CIVIL ENGINEERING AND ARCHITECTURE

DEPARTMENT OF GEOMATICS ENGINEERING

POTENTIAL SITES SELECTION FOR RAINWATER HARVESTING USING MCE AND GIS TECHNIQUES: ADAMA SUBWATERSHEDS, ETHIOPIA.

A THESIS SUBMITTED TO THE POST GRADUATE STUDIES OF ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN GEODESY AND GEOMATICS ENGINEERING.

BY

MESERET TADESSE H/GEBRIEL

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ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

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A Thesis Submitted to the Post Graduate Studies of Adama Science and Technology University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Geodesy and Geomatics Engineering.

By

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May, 2017

Declaration

I, the under signed declare that this thesis entitled" Potential Sites Selection for Rainwater Harvesting Using MCE and GIS Techniques: Adama Subwatersheds " Is my original work, and has not been presented by any other person for an award of a degree in this or any other university. And all sources of materials used for these have been duly acknowledged.

Candidate:

MESERET TADESSE H/GEBRIEL

Signature ____________________

As master research advisors, we here by certify that we have read and evaluated this MSc. Research prepared under our guidance, by MESERET TADESSE H/GEBRIEL entitled: Potential Sites Selection for Rainwater Harvesting Using MCE and GIS Techniques: Adama Subwatersheds.

We recommend that it can be submitted as fulfilling the MSc. Thesis requirements.

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Approval

As members of the examining board of the final MSc. open defence, we certify that we have read and evaluated the thesis prepared by Meseret Tadesse H/Gebriel entitled: Potential Sites Selection for Rainwater Harvesting Using MCE and GIS Techniques: Adama Subwatersheds and recommended that it has been accepted as fulfilling the thesis requirement for the degree of Master of Science in Geodesy and Geomatics Engineering.

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ABSTRACT

Rainwater harvesting (RWH) is collection and storage of rainfall by runoff for different purposes such as agriculture, livestock, domestic use, industry and groundwater recharge as well as flood control. This study was aimed to Potential Sites Selection for RWH in Adama Subwatersheds using MCE and GIS techniques and specifically To drive the suitability maps for pond and Insitu RWHTs *in the study area, to evaluate existing RWH structures based on the proposed suitability map and observed data of the study area and to quantify the water balance components of the watersheds using ArcSWAT model. Thematic maps of the dominant factors were developed and reclassified based on the importance to identify the potential areas for RWH using MCE and GIS techniques in the ArcGIS software version 10.3. These were: slope, soil texture, soil depth and LULC maps. Weighted overlay analysis was carried out by combing each reclassified raster maps for pond and in-situ RWHTs factors with their corresponding weights developed in IDRISI Selva 17.0 software for each parameter of pond and in-situ RWHTs using ArcGIS overlay spatial analysis tools. The results obtained for pond RWHT were: the very highly suitable areas with 58.14 km^2 (9.63 %) and the very suitable area was 423.92 km^2 (70.2 %) followed by suitable area of 121.82km^2(20.17 %) in the study area. In the meanwhile suitability map for in-situ was covered by 20.06 km^2 (3.32 %), 458.07 km^2 (75.86 %) and 125.75 km^2 (20.82 %) with the suitability levels of very highly suitable, very suitable, and suitable area respectively. The majority or 91% of existing pond structures were found not functioning during evaluation due to seepage, evaporation and silting. The outputs in the analysis of SWAT model simulation, the lowest runoff was occurred in the year of 2015 amounted to 6.58mm, 3.98mm and 10.72mm for Northern, Northwest and Southern watersheds. While the highest runoff occurred in the year 2012 rose to159.25mm, 124.91mm and 197.69mm respectively for each watershed in the study area. Suitability maps for RWHTs were depicted that the majority parts of the study area had the potential of RWH for agriculture activities. SWAT modeling proved that how different water balance components, such as recharge and runoff, vary significantly both spatially throughout the watersheds and temporarily through time.*

Finally, MCE approach in ArcGIS environment and the hydrological modelling with SWAT software had a potential to select suitable areas for RWH and to quantify water balance components for planning and managing rainwater resource in the study area and where with water shortage areas.

Keywords: Dominant factor, GIS, In-situ, Pond, RWH and SWAT

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ABBREVIATIONS

ABAUABO	Awash Basin Authority Upper Awash Branch Office
ADF	African Development Fund
ADP	Area Development Program
AHP	Analytic Hierarchy Process
AGRL	Agricultural Land-Generic
ASARs	Arid and semi-arid regions
ASSP	Agricultural Sector Support Program
ASTER	Advanced Space borne Thermal Emission and Reflection Radiometer
AWIDA	Adama Wereda Irrigation Developmental Authority
AWRLAEP	Adama Wereda Rural Land Administration and Environmental Protection
CIS	Corrugated Iron Sheet
CN	Curve Number
DA	Development Agent
DEM	Digital Elevation Model
DPPA	Disaster Prevention and Preparedness Agency
EMA	Ethiopian Mapping Agency
ERDAS	Earth Resource Data Analysis System
ERHA	Ethiopian Rainwater-harvesting Association
FAO	Food and Agricultural Organization
FFW	Food
GPS	Global Positioning System
HAY	Hay
HRUs	Hydrologic Response Units
IRDPs	Integrated Rural Development Projects
LULC	Land use Land cover
MCDM	Multi Criteria Decision

MCE	Multi Criteria Evaluation
MDG	Millennium Development Goals
MoARD	Ministry of Agricultural Rural Development
MSL	Mean Sea Level
NGOs	Non-governmental organizations
NMA	National Meteorological Agency
OLI	Operational Land Imager
PSNP	Productive Safety Net Program
RELMA	Regional Land Management Unit
RS	Remote Sensing
RVMLZ	Rift Valley Maize Haricot Bean Livelihood Zone
RWH	Rain Water Harvesting
RWHM	Rain water Harvesting and Management
RWHTs	Rain Water Harvesting Techniques
SCS	Soil Conservation Service
SPAW	Soil Plant Atmosphere Water field and pond hydrology
SSI	Subsurface irrigation
SUGC	Sugarcane
SWAT	Soil and Water Assessment Tool
ToT	Training of technologies
TRCA	Toronto and Region Conservation Authority
TVET	Technical and Vocational Education Training
UNEP	United Nations Environment Programme
URMD	Residential-Medium Density
USA	United States of America
USDA	United States Department for Agriculture
UTM	Universal Transverse Mercator
WBC	Water Balance Component

WH	Water Harvesting
WHT	Water Harvesting Technology
WVE	World Vision Ethiopia

CHAPTER ONE

INTRODUCTION

1. 1 Background

Rainwater harvesting (RWH) is the collection and storage of rainfall by runoff for different purposes such as agriculture, livestock, domestic use and groundwater recharge (Oweis and Hachum, 2009) as well as flood control (Critchley and Siegert, 1991).Runoff is collected mainly from ground catchments such as ephemeral streams, road/footpath drainage, hill slope and gullies (runoff-based water harvesting). The storage is either in different structures (tanks, ponds, dams, etc.), mainly for supplemental irrigation systems, or soil profile for in situ water harvesting (Ngigi, 2003).

However, rainwater harvesting practice is not new in Ethiopia and has a history of dates back as early as 560 BC during the Axumite Kingdom. The promotion and application of RWH techniques as alternative interventions to address water scarcity in Ethiopia was emphasized through government-initiated soil and water conservation programs. It was started as a response to the 1971–74 droughts with the introduction of food-for-work (FFW) programmers. They were intended to generate employment opportunities to the people affected by the drought for agriculture and water supply purposes (Meselech, 2003). The seasonal and annual rainfalls in Ethiopia are unpredictable and variable with more risk of crop failure in arid and semi-arid regions due to less water availability during the growing seasons (Awulachew et al., 2005; Tesfaye and Walker, 2004). According to the reports (UNEP, 1998; Falkenmar et al., 1990), the population growth in Ethiopia will be nearly 120 million people and the per capita water availability will drop to about 947m3/person per year by the year 2025 cited in (Meselech, 2003).Water is a scarce resource in agricultural (crop and livestock) production in many parts of the country in general and in the rift valley in particular. The lowlands, which are largely inhabited by pastoralists of extensive livestock production lack of water is a critical problem. The study area, Adama Watershed, is located in the Rift valley area. Its agriculture depends on rainfall for crop production. “Meher” (that extends from June to September) is the main rainy season in which food crops are grown. Even in this period, the occurrence of rainfall is unreliable. Late or early occurrence, uneven distribution, interruption and insufficiency of the rainfall are common in the area (Yesuf and Kiyoshi, 2006).

These facts strongly support the need to focus on development and promotion of rainwater harvesting technologies as one of the alternatives to enhance water availability for different uses including food production, livestock and domestic water supply.

The success of RWH systems depend heavily on the identification of suitable sites and their technical design (Al-Adamat et al., 2010).The selection of appropriate sites or different RWH technologies in larger areas is a great challenge (Prinz, Oweis, and Oberle, 1998). Thus, MCE and GIS techniques has attempted to select the rainwater harvesting potential areas integrated with remote sensing technique and ArcSWAT hydrological spatial analyst tools that used to quantify runoff based rain water harvesting potentially the study area.

1.2 Statement of the problem

Adama Subwatersheds are found in the hot Great East African Rift Valley and the area is characterized by erratic rainfall, frequent drought, crop failure, and lack of permanent water sources like streams and lakes. Awash is the only river that crosses the Subwatersheds and only few villages have the access to this river. Except those few rural Kebele located along the course of Awash River, the rest are totally depending on rainfall for crop production (Yusuf and Kiyoshi, 2006).

In the year of 2006, the majority Wereda of East Shewa Zone including the study area were identified for emergency food aid due to declining crop and livestock production caused by climate changes in the area (DPPA, 2006). According to the report of Adama Wereda Disaster Prevention and Preparedness Office (AWDPPO, 2016), the rural Kebeles of the Wereda were exposed for drought and food insecurity for the last two decades.

Currently, (AWDPPO, 2016) reported that out of 37 rural Kebeles of the study area, 30 Kebeles (86%) are affected by the drought and food insecurity due to shortage of water resulted from weather irregularities. As a result more than 70,000 people of the Wereda are food insecure. Particularly, six rural Kebeles of the Wereda(namely Beqoji Dawaro,Chuka Hurufa, Ejersa Mersa, Dabula Sajo,Humo Fechasa and Shanan Selassie) are constantly affected by drought due to insufficient amount of rainfall every year (AWDPPO, 2016).Therefore, the problems related to food insecurity due to water shortage need urgent solutions, especially in the study area. Unless sustainable food production technologies are adopted, the problems on poverty and food security will remain elusive. One promising technology for rainfed agriculture is rainwater harvesting. This is one of the options that increase the amount of the water per unit cropping area; reducing drought and enables use of runoff beneficially (Oweis and Hachum, 2009).

So investigation of selecting the potential areas for RWH using MCE approach in Arc GIS environment and quantifying the water balance components in swat model are better and enhancing methods for implementing and utilizing rain water harvesting as source of water for agriculture purposes to solve water shortage in the study area.

1.3 Research questions

- How to drive the suitability maps for pond and Insitu RWHTs in study area?
- How to evaluate the existing RWH structures in the study area?
- How to quantify the water balance components in the watersheds of the study area?

1.4 Objective

1.4.1 General Objective

The general objective of the research is to select RWH potential sites using MCE and GIS techniques in the Subwatersheds of Adama.

1.4.2 Specific Objectives

- To drive the suitability maps for pond and Insitu RWHTs in Adama Subwatersheds
- To evaluate the existing Rainwater Harvesting Structures in Adama Subwatersheds
- To quantify water balance components and sediment loading for Adama Subwatersheds

1.5 Scopes

Since the selection of RWH sites is a broad subject matter, it is difficult to address all issues in this study. Therefore, this study is restricted in place and issue of concern. Geographically, it is delimited to Adama Subwatersheds East Shewa Zone, Oromia National Regional State of Ethiopia. As far as the problem is broad, the selection of RWH sites by using GIS techniques and SWAT model to quantify the water balance components is limited in the study area.

1.6 Significant of the study

Selecting potential sites for RWH in the study area depending on the various factors that contribute to select the potential areas greatly improves availability of water to food secure and reduces water shortage that causes food insecurity in the study area, using MCE approach in Arc GIS environment and SWAT model. In addition the study can be used as input for irrigation sectors to identify RWH sites and for other research projects to provide literature on the application of multi-criteria decision analysis using GIS and SWAT model for mapping of RWH areas and quantify water balance components in the study area and other related. Moreover, the finding has great importance in presenting possible intervention to minimise the pressure of shortage of water and motivates researchers to conduct further study using it as a reference.

Generally, the study helps the concerned bodies to plan and manage rainwater in the study area and as a whole in the country where similar problems happen.

1.7 Limitation of the study

Throughout the process of conducting the study, the researcher faced problems such as: roof based RWHT was not applied in the study due to less amount of rainwater harvesting that would generated on roof cover of rural settlements of the study area and it is not enough for agricultural purposes. Similarly, Rainfall was not taken as factor for suitability mapping for both pond and Insitu RWHTs due to its range was only in one class (i.e. very highly suitable class) when it reclassified based on FAO rainfall classification for RWH.

The lack of adequate meteorological data based on the plan of the researcher to get climate data (daily humidity, wind speed and solar radiation) for the study area. The limited period of years not more than 10 years for those data were used for SWAT model simulation to fill the gaps the researcher.

CHAPTER TWO

LITRATURE REVIEW

2.1 Introduction

This aspect of the study reviews the various literatures related to the topic under consideration in order to cover critical facts and findings which have already been identified by previous researchers and numerous studies in and around RWH.

2.2 Concept and Definition of RWH

The principle of agricultural rainwater harvesting is based on the concept of depriving part of the land of its share of precipitation, which is usually small and non-productive, and giving it to another part to increase the amount of water available to the latter part, which originally was not sufficient, and to bring this amount closer to the crop water requirements so that an economical agricultural production can be achieved. Such concentration of precipitation in a smaller area is called water harvesting (WH) and may be defined in various ways such as: (Oweis and Hachum, 2009).

- The process of collecting natural precipitation from prepared watersheds for beneficial use.
- Collecting and concentrating various forms of run-off from precipitation and for various purposes.
- The process of concentrating precipitation through run-off and storing it for beneficial use.

The concept of WH, as described above, is different from the traditional soil-water conservation practices in which no part of the land is purposely deprived of its share of water. Soil-water conservation practices aim at preventing surface run-off and keeping rainwater in place, whereas WH makes use of, and even induces, surface run-off. In the WH process the run-off-producing area is adjacent to the cropped area, and part of the land and most of the precipitation water will become productive. More importantly, agricultural production becomes possible, and the WH systems might be for a single purpose or for multi-purpose and built to serve domestic, agricultural, animal or environmental uses (Oweis and Hachum, 2009).

2.3 History and development of RWH

The Various forms of water harvesting (WH) have been used traditionally throughout the centuries. Some of the very earliest agriculture, in the Middle East, was based on techniques such as diversion of "wadi" flow (spate flow from normally dry watercourses) on to agricultural fields. In the Negev Desert of Israel, WH systems dating back 4000 years or more have been discovered. These schemes involved the clearing of hillsides from vegetation to increase runoff, which was then directed to fields on the plains. Floodwater farming has been practised in the desert areas of Arizona and northwest New Mexico for at least the last 1000 years. The Hopi Indians on the Colorado Plateau cultivate fields situated at the mouth of ephemeral streams. Where the streams fan out, these fields are called "Akchin". Describe micro catchment techniques for tree growing, used in southern Tunisia, which were discovered in the nineteenth century by travellers. In the "Khadin" system of India, floodwater is impounded behind earth bunds, and crops then planted into the residual moisture when the water infiltrates. The importance of traditional, small scale systems of WH in Sub-Saharan Africa is just beginning to be recognized. Simple stone lines are used, for example, in some West African countries, notably Burkina Faso, an earth bunding systems are found in Eastern Sudan and the Central Rangelands of Somalia (Critchley and Siegert, 1991**)**.

A growing awareness of the potential of water harvesting for improved crop production arose in the 1970s and 1980s, with the widespread droughts in Africa leaving a trail of crop failures. The stimulus was the well-documented work on WH in the Negev Desert of Israel. However much of the experience with WH gained in countries such as Israel, USA and Australia has limited relevance to resource-poor areas in the semi-arid regions of Africa and Asia. In Israel, research emphasis is on the hydrological aspects of micro catchments for fruit trees such as almonds and pistachio nuts. In the USA and Australia WH techniques are mainly applied for domestic and livestock water supply, and research is directed towards improving runoff yields from treated catchment surfaces. A number of WH projects have been set up in Sub-Saharan Africa during the past decade. Their objectives have been to combat the effects of drought by improving plant production (usually annual food crops), and in certain areas rehabilitating abandoned and degraded land (Critchley and Siegert, 1991). However few of the projects have succeeded in combining technical efficiency with low cost and acceptability to the local farmers or agro pastoralists. This is partially due to the lack of technical "know how" but also often due to the selection of an inappropriate approach with regard to the prevailing socio-economic conditions (Critchley and Siegert, 1991).

2.4 Advantages of Rainwater Harvesting

Rainwater harvesting systems can provide water at or near the point where water is needed or used. The systems can be both owner and utility operated and managed. Rainwater collected using existing structures (i.e., rooftops, parking lots, playgrounds, parks, ponds, flood plains, etc.), has few negative environmental impacts compared to other technologies for water resources development. Rainwater is relatively clean and the quality is usually acceptable for many purposes with little or even no treatment. Additionally, some other advantages of Rainwater Harvesting Include (Calfoforo, nd):

a. Rainwater harvesting can co-exist with and provide a good supplement to other water sources and utility systems, thus relieving pressure on other water sources.

b. Rainwater harvesting provides a water supply buffer for use in times of emergency or breakdown of the public water supply systems, particularly during natural disasters.

c. Rainwater harvesting can reduce storm drainage load and flooding in city streets.

d. Users of rainwater are usually the owners who operate and manage the catchment system; hence, they are more likely to exercise water conservation because they know how much water is in storage and they will try to prevent the storage tank from drying up.

e. Rainwater harvesting technologies are flexible and can be built to meet almost any requirements. Construction, operation, and maintenance are not labour intensive.

2.5 Classification of RWH

Different authors have classified water harvesting methods in various ways and standardized classification system has not yet been developed (Nigig, 2003). Classification of runoff-based RWH technologies depends:

- Source of runoff (external) or within-field catchments;
- Methods of managing the water (maximizing infiltration in the soil, storing water in reservoirs and inundating cropland with floods); and
- Use of water (domestic, livestock, crop production, gully rehabilitation, etc.).

RWH systems operate at different scales (house hold field and catchment/basin), and can affect water availability.

Rainwater harvesting can also be divided into In-situ RWH Systems, roof catchment systems and Runoff Catchment Systems (MDG, 2007). All RWH systems have three components those are Catchment area/run-off area, Storage facility and Target or use (Oweis and Hachum, 2009).

a. Catchment area/run-off area: varying from a few square meters (micro catchment) to as large as several square kilometers (macro catchment): the part of the land where a portion or all of the precipitation which falls on it runs off its boundaries. It can be agricultural, rocky or marginal land, or even a rooftop or a paved road.
b. Storage facility: the place where the run-off water is held from the time it occurs until it is utilized by crops, animals, human beings and/or other uses. Storage can be: (i) above the soil surface as in surface reservoirs or ponds; (ii) in the soil profile as soil moisture; and/or (iii) underground in cisterns or as groundwater in aquifers
c. Target or use: the beneficiary of the stored water. In agricultural production, the target is the plant or the animal, whereas in domestic use, it refers to human beings and their needs.

2.5.1 In-situ Rainwater harvesting

In-situ RWH refers to all activities in which rainwater is harvested and stored within the soil profile for crop production and it enhances infiltration and water holding capacity in the soil profile (Yosef and Asmamaw, 2015). It may include open-sky RWH systems such as terraces, pitting, bunding methods and external catchment systems such as trapezoidal bunds. Since In-situ water conservation is achieved mainly using conservation agriculture and micro catchments. This technology can be practiced in areas with low topography in arid or semiarid climates. Conservation farming involves minimizing soil disturbance through reduced or zero tillage, maximizing soil cover, and using crop rotations or associations. Indeed, conservation farming refers to the simultaneous practice of such as ripping, tied ridges, basins, strip tillage, ditches, drainage etc., as a gateway to progressively achieve minimal soil disturbance (Oduor and Gadain, 2007). In situ rainwater conservation Owing to its simplicity and low investment costs, the development of in situ rainwater harvesting techniques could be viable amongst the smallholder rainfed systems. Depending on rainfall patterns and local soil characteristics, appropriate application of in-situ and micro-catchment techniques could improve the soil water content of the rooting zone by up to 30% (Biazin, 2012). The most commonly applied micro-catchment rainwater harvesting techniques in sub-Saharan Africa include pitting, contouring, terracing and micro-basins. Some of the techniques may have different names in different regions and minor differences in design and use (Biazin, 2012).

Pitting**:** These are small circular pits dug to break the crusted soil surface. In West Africa where they are called 'Zay', the pits are about 30 cm in diameter and 20 cm deep. Seeds are planted in the middle of the pits (Hatibu and Mohoo, 1999).

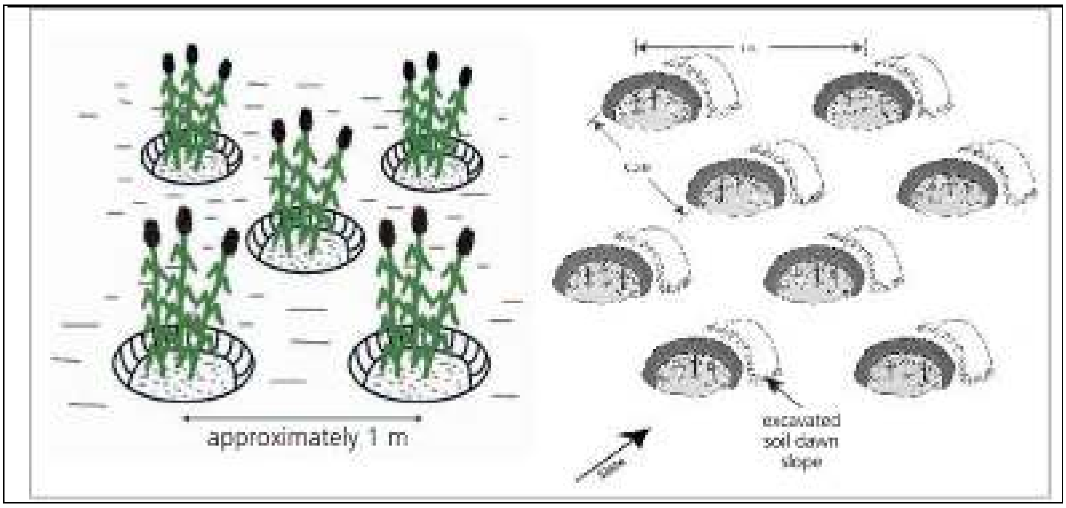


Figure 2.1: Layout of Pit in-situ RWH (Hatibu and Mohoo, 1999)

Figure 2.2: In-situ RWH system (Rocheleau et al., 1988 cited in Prinz and Singh, 2000)

2.5.2 Roof Catchment Systems

Roof catchment, is generally practiced as a way to obtain relatively clean drinking water as well as water for domestic purposes. This method involves a relatively small catchment area, the size of the individual's roof of their house, with gutters and pipes to guide the water into a tank on the ground. Often a tap is attached to the tank for individuals to access this water (Mbilinyi *et al*., 2005). There is concern over whether or not the water is clean enough for drinking, as pollutants in the atmosphere have been known to be present in rainfall. Today water harvesters must be wary of pesticide contamination, high mineral levels, bacteria and other impurities in their runoff water". Most roof catchment systems have screens and purification systems built into the infrastructure to remove leaves and twigs from the water as well as to purify the water prior to use (Palmback, 2004) cited in (Ibrahim, 2012).

Figure 2.3: Roof catchment system (Oyewumi, 2013).

2.5.3 Runoff catchment system

Rainwater harvesting using ground or land surface catchment areas can be a simple way of collecting rainwater. Compared to rooftop catchment techniques, ground catchment techniques provide more opportunity for collecting water from a larger surface area. By retaining the flows (including flood flows) of small creeks and streams in small storage reservoirs (on surface or underground) created by low cost (e.g. Earthen) dams, this technology can meet water demands during dry period for storing water for agricultural and livestock purposes (Nigig, 2003).

RWH systems with storage for supplemental irrigation are becoming popular in semi-arid districts of Kenya (e.g., Machakos). They have also been introduced in Ethiopia (near Nazareth) on experimental basis by (Oduor, 2005). Moreover, small storage systems are all over parts of Ethiopia (e.g. Tigray),and other places around Africa Initial results from RWH experiments in Machakos district, which focused on the feasibility of using earth dams for supplemental irrigation of maize have been encouraging(Oduor, 2005).

Check dams: A raised wall is constructed using stone, concrete and gabion across gully to pond/store the stream flow behind it for irrigation purpose (using either gravity or lifting mechanism) and reducing the runoff velocity and enhancing gully rehabilitation. The width of the dam wall ranges between 1–2 m while the height varies between 2– 4 m depending upon the gully depth. The length of the check dam depends on the gully width while the spacing between adjacent check dams is determined based on the availability of water and a potential land that can be irrigated. The gully area needs to be well protected against further erosion (Mekdaschi and Liniger, 2013)

Figure 2.4: Check dam (Mekdaschi and Liniger, 2013).

Sand dams: are larger than subsurface dams and weirs as they can be raised to several meters above ground in sandy riverbeds. Coarse sand carried by the flow is deposited upstream of the dam and gradually fills the streambed while lighter material is carried over it in periods of high flow. Water is stored within the porous space of the deposited coarse sand. This artificial aquifer increases in thickness over time. Additionally, the sand reduces evaporation and contamination of the water in the sand body behind the dam rendering the water suitable for livestock, domestic supply or small-scale irrigation (Mekdaschi and Liniger, 2013).

Figure 2.5: Sand dam (Mekdaschi and Liniger, 2013).

Runoff water that collects on the ground in homesteads, farms, paths and rural roads is channelled via mitre drains into already existing channels with silt traps. Immediately after the silt traps, the runoff water is conveyed to surface or underground reservoirs. The underground reservoirs are either closed or open. Closed reservoirs include sausage or spherical tanks while open ones are both lined or unlined ponds and tanks **(**Oduor and and Gadain, 2007).

According to Yusuf and Kiyoshi (2006) report, 89 RWH structures or ponds were constructed in the three years of 2003 to 2005 in the Adama Wereda through area development program (ADP) funded by world vision Ethiopia (WVE). The fact that the area is characterized by porous type of soil and very high rate of evaporation, the ADP has selected concrete lined hemispherical underground structure that can store 55 to 60 m^3 of rainwater. The diameter of the structure is 6m and its depth is 3 meters. At completion, the structure is covered either by cone shaped reinforced concrete or corrugated iron sheet as shown in figure 2.6. Nature of the soil in the area, volume of water to be stored, durability of the structure, implementation cost and capacity of the households to manage the structure were the major criteria to select this type of structure (Yusuf and Kiyoshi, 2006).

Figure 2.6 CIS roofed pond (Yusuf and Kiyoshi, 2006).

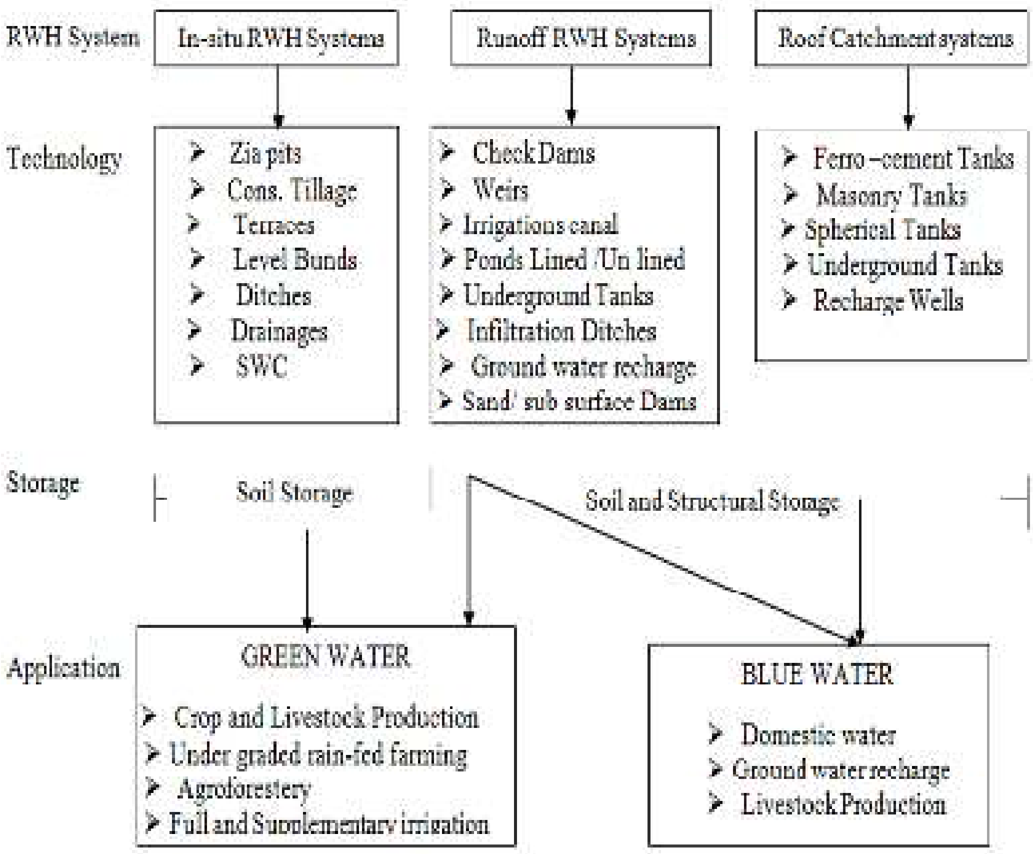


Figure 2.7: Adopted classification of RWH systems (MDG, 2007).

2.6 RWH in Ethiopia

In Ethiopia water harvesting was dated back as early as Axumit period (500BC) (Habitamu, 1999). It was a time when rainwater was harvested and stored in ponds for agricultural and water supply purposes. The evidences were found and justified by anthropologist (Fattovich, 1990) for remains of ponds that were used for irrigation purpose during this period, cited in (Alemu and Kidane, 2015).

A roof water harvesting setup is still visible in the remains of one of the oldest; palaces in Axum; the palace of the legendary Queen of Sheba. Other evidences include the remains of one of the old castles in Gondar, constructed in the 15-16th century, which used to have a water harvesting set up and a pool that was used for religious rituals by the kings. In south of the country, the Konso people have had a long and well established tradition of building level terraces to harvest rainwater to produce sorghum successfully under extremely harsh environment; low, erratic and unreliable rainfall conditions. As reported, Awulachew et al., 2005, Ethiopia's agriculture is predominantly rainfed with a potential of nearly 3.5 million ha of land suitable for irrigated agriculture The population has grown dramatically over the last three decades, increasing from 25 million in the 1960s to nearly 90 million in 2014 leaving a pressure on the agricultural land, forests and the environment at large. Thus, rainwater harvesting and management (RWHM) play paramount roles for increasing gain yields and support the growing population and the majority of rural dwellers in Ethiopia are among the poorest in the country, with limited access to agricultural technology, limited possibilities to diversify agricultural production given underdeveloped rural infrastructure and little or no access to agricultural markets and technological innovations (Awulachew et al., 2005).

The promotion and application of rainwater harvesting techniques as alternative interventions to address water scarcity in Ethiopia were started through government-initiated soil and water conservation programmes. It was started as a response to the 1971–74 droughts with the introduction of food-for-work (FFW) programmes, which were intended to generate employment opportunities to the people affected by the drought. The earlier rainwater harvesting activities included, among others, construction of ponds, micro-dams, bunds, and terraces in most drought-affected areas in Tigray, Wello and Hararghe regions (Kebede, 1995) cited in (Meselech,2003). Non-governmental organisations (NGOs) involved in Integrated Rural Development Projects (IRDPs) and the water sector in many parts of the country also undertake rainwater-harvesting interventions. These interventions include conservation of rainwater by making use of physical structures and rainwater harvesting for domestic and irrigation purposes through pond and micro-dam construction and roof catchment schemes (Meselech, 2003)

Ministry of Agricultural Rural Development (MoARD) and respective regional Bureau have planned and implemented aggressive and ambitious WH programs in the three years of 2003 to 2005 along the country's food security programs. The major on-going government program of WH is the one associated with the Productive Safety Net Program (PSNP) and is being carried out in 192 Weredas. In the PSNP WH is the main entry point. The number of food insecure, thus Safety Net Weredas, is increasing from time to time. Of the donor funded programs, African Development Fund (ADF) assisted WH and Subsurface irrigation (SSI) under the Agricultural Sector Support Program (ASSP) is the major one, carried out in all regions and coordinated by the MoARD (Yusuf and Kiyoshi, 2006).

WH is also promoted under World Food Program assistance of managing environmental resources to enable transitions to more sustainable livelihoods project in seven regions. There are also many region specific projects. The strategy followed for dissemination/upgrading WHT under the government program is packaging technologies, preparation of technical guidelines and construction manuals, conducting (Training of technologies (ToT) that includes practical demonstration for regional, Zonal and Wereda experts. There are Technical and Vocational Education Training (TVET) colleges and Farmers' Training Centres, which are also supplemented by Development Agent (DA), cantered practical demonstration and training. Presently, one of the common approaches being pursued for the promotion of WHT is the Community Based Participatory Watershed Development (Yusuf and Kiyoshi, 2006).

The beginning of establishing rainwater-harvesting associations in many countries of the southern and eastern Africa traces back to the efforts of the Regional Land Management Unit (RELMA). Ethiopian Rainwater-harvesting Association (ERHA) was founded on 17 December 1999 in Addis Ababa. The founding members of ERHA, totalling about 60 in number, consisted of individuals with diverse professional backgrounds including water and related fields of engineering, agriculture, health, education, environment and other fields of natural and social sciences. ERHA is a non-governmental, non-political and non-profit-oriented national organisation consisting of individuals with genuine interest in promotion of rainwater-harvesting technologies to address shortage of water for domestic supply and food production. ERHA's overall objective is to contribute towards enhanced and sustainable food security status in Ethiopia through promoting feasible rainwater-harvesting technologies for sustainable development and conservation of natural resources (Meselech, 2003).

2.7 GIS for RWH

The A geographic information system (GIS) is designed to visualize, store and analyse the information about the locations, topology, and attributes of spatial features. In most GIS programs, data are stored and managed in a relational database embedded in the system. A GIS program can perform regular database management tasks in addition to its spatial analysis capabilities. For this reason, GIS can be considered as a relational database management system with a map interface for data presentation. In GIS, locational data and their map representations are dynamically linked so that any changes made in the databases are reflected immediately on its map presentation. The linkage between the map and databases makes GIS an ideal and strong tool for spatial data visualization and analysis (Bao et al., 1997) cited in (Ali, 2009).

(Oduor, 2005) describes the mapping by GIS (Geographic Information Systems), of the rainwater harvesting potential in Africa. The project provides an advocacy tool, which shows in spatial domains the expansive opportunities for RWH in Africa, and some ten selected countries; Botswana, Ethiopia, Kenya, Malawi, Mozambique, Rwanda, Tanzania, Uganda, Zambia and Zimbabwe. It produced a GIS database that captures the major factors associated with RWH (rainfall, topography, soils population density, land use). These baseline thematic maps were further combined through spatial analyses to produce composite maps that show attributes or “development domains” that serve as indicators of suitability for targeted RWH interventions, grouped as; (i) rooftop RWH, (ii) surface runoff from open surfaces with storage in pans/ponds, (iii) flood-flow harvesting from watercourses with storages in sand/subsurface dams and (iv) in-situ soil water storage systems. The decision of final prioritization is left to the user, after analyses of other factors beyond the GIS database, such as finances, cultural, political and local preferences (Oduor, 2005).

The Multi-criteria evaluation (MCE) technique approach to identify areas for RWH technologies within a GIS context. The approach had been used in some studies in different African countries. That the combination was useful to evaluate multiple criteria and expert opinion in a consistent way in order to obtain suitability maps and tabular data. It was shown that MCE–GIS combination has potentiality to provide a rational, objective and non-biased approach to making decisions in identifying potential sites for RWH technologies (Isioye et al., 2012)

2.8 Dominant Factors for Selection of Potential RWH Sites

Rainwater harvesting has been receiving renewed attention since 1980. Developments in computer technology, geographic in- formation systems (GISs), and remote sensing (RS) have made it possible to develop new procedures to identify suitable sites for RWH and have led to numerous publications focused on the selection of suitable RWH sites (Adham et al., 2016).

The selection of suitable sites for RWH depends on several the most important parameters or criteria (Prinz & Singh, 2000).In 2003, the Food and Agriculture Organization of the United Nations (FAO), as cited by (Adham et al., 2016) listed six main criteria for identifying RWH sites: climate, hydrology, topography, agronomy, soils, and socio-economics. The most common biophysical criteria used in Arid and semi-arid regions (ASARs) to identify suitable sites for RWH were: slope, land use/cover, soil type, and rainfall. The distance to settlements, distance to streams, distance to roads, and cost were the most commonly applied socio-economic criteria.

2.8.1 Slope

The slope of land is important in site selection and implementation of all ground based RWH systems, especially ponds, pans, weirs and in-situ RWH (Oduor, 2005). To ensure high runoff efficiency, the slope of a catchment should be as steep as possible. However, slopes of more than 5% are susceptible to high erosion rates. (Hatibu and Mahoo, 2000) described the catchment that has slopes steeper than this, erosion control measures are a necessity. According to (FAO, 2006) slope classification standard for RWH practices, it can be classified in to five slope classes that represented in table 2.8.1.

Table 2.1: Slope classification (FAO, 2006 cited in Muhmuod et al., 2015)

No.	Slope classes	Slope %
1	Flat	0-2%
2	Undulating	2-8%
3	Rolling	8-15%
4	Hilly	15-30%
5	Mountainous	> 30%

2.8.2 Soil Texture

The suitability of a certain area either as catchment or as cropping area in water harvesting depend strongly on its soils characteristics through (1) surface structure; which influence the rainfall-runoff process, (2) the infiltration and percolation rate; which determine water movement into the soil and within the soil matrix, and (3) the soil depth and texture; which determines the quantity of water which can be stored in the soil (Bakir and Xingnan, 2008). The soils with high percentage of silt and clay particles have higher water-holding capacity. Moreover, the size and spacing of soil particles determine how much water can flow in. Wide pore spacing at the soil surface increases the rate of water infiltration, thus coarse soils have a higher infiltration rate than fine soils (Ball, 2001 cited in Tumbo et al., 2014a). Sandy soils have higher infiltration rates than the loams and clayey soils. Where as clayey soils generally hold more water than sandy soils but have the lowest infiltration rate. Loamy soils actuallyhave more available water for plant use than clayey soils. Water in clay soils is held at a greatertension that reduces its availability to plants. Loamy soils are therefore best suited to water harvesting systems because they are ideally suited for plant growth in terms of nutrient and water holding capacities (Critchleyand Siegert, 1991).

Table 2.2: Infiltration Rate for Soil Textural Classes (FAO, 1979 cited in Akram and Kemper, 1979)

No.	Soil Textural Classes	Infiltration Rate (mm/h)		
		Minimum	Mean	Maximum
1	Sand	25.00	50	250
2	Sandy Loam	13.00	25	76
3	Loam	8.00	13	20
4	Cay loam	2.50	8	15
5	Silty clay	0.30	2.5	5
6	Clayey soil	0.10	0.5	1

2.8.3 Soil depth

The depth of soil is particularly important where WH systems are proposed. Deep soils have the capacity to store the harvested runoff as well as providing a greater amount of total nutrients for plant growth. Soils of less than one metre deep are poorly suited to WH. Two metres depth or more is ideal, though rarely found in practice (Critchley and Siegert, 1991). The deeper the soil the higher is the water storage capacity and vice versa. Sites with deep soils are relatively suitable for location of in-situ RWH technologies than shallow ones as deep soils have higher capacity of storing the harvested runoff as well as providing a greater amount of total nutrients for plant growth (Ibrahim, 2012).Soil depth can be categorized based on (FAO, 1990 cited in Tumbo et al., 2014b) as very shallow (< 30 cm), shallow (30-50 cm), moderately deep (50-100 cm), deep (100-150 cm) and very deep (>150cm).

2.8.4 LULC

Land use and Land cover map is the main parameter for RWH site selection studies. Agriculture land is highly suitable for RWH systems. LULC was used to map in-situ and sites closer to agriculture activities (Javaid et al., 2016). Vegetation cover has several effects on the effective rainfall and runoff. These include: evaporation from canopy, increased surface ponding and slowing down of water which assist infiltration and thus reduce runoff yield and increase hydraulic conductivity due to root channel which also leads to increased infiltration (Hatibu and Mahoo, 2000).

2.9 Evaluation of Existing RWH Structures

A number of studies have been conducted to evaluate the performance of the ambitious plan of the government to develop RWH. The studies were conducted by the government, and/or NGOs. Some studies assessed financial benefit, some technical viability and others focused on assessing past experiences and identifying ways forward in order to facilitate government policies (Girma, 2009).

From results of study on evaluation of the implementation of RWH in Oromiya region, 98% of beneficiaries indicated high seepage losses. The study concluded that the status of the constructed ponds was not good owing to various problems like the unavailability of plastic sheet to reduce seepage losses, lack of coordination and facilitation during implementation (Chala, 2003 cited in Girma, 2009).The evaluation of RWH ponds that was conducted in Tigray Regional State showed that majority of the ponds failed because of insufficient water collection or leakage problems due to poor construction (Segers et al., 2007 cited in Dereje, 2013). In addition, a considerable number of ponds suffered from lack of maintenance contributing to the poor performance. Some RWH ponds were silted up completely. The other reason for failures was that households did not construct or maintain the diversion cannels and inlets that are needed to harvest runoff water.

The evaluation also collected opinions from oromia irrigation developmental authority staff and development agents (DAs) on to the issue "why RWH ponds don't retain or hold water". The answers were pointed: high seepage losses attributed to either poor compaction cracks in tanks, and poor site selection due to lack of experience (Dereje, 2013). Similarly, the low adoption on RWH was occurred at Alaba Wereda due to poor quality of the construction resulting in cracks in the cemented floor and loss of water, improper site selection (insufficient runoff) and fear of malaria spread (Rebeka, 2006 cited in Dereje, 2013)

According to Toronto and Region Conservation Authority (TRCA, 2011) report, typical maintenance activities associated with rainwater harvesting systems include: clean out of sediment from settling chambers, cleaning drain and debris filters, pump maintenance and valve.

The frequency of maintenance and inspection activities will vary depending on the complexity of the system. The RWH systems evaluated by (TRCA, 2011) reported that it requires seasonal cleaning of the inlet debris filter and monthly system checks. Sedimentation tanks should be inspected once a year.

Validation of the existing RWH structures locational was done during a field survey using collected data and the suitability map (Mbilinyi et al., 2007). The validation depends on comparing rainwater harvesting/ recharge dam locations in the generated suitability map and the location of the surveyed RWH structures using proximity analysis tool of ArcGIS software (Mahmoud and Alazba, 2014; Girma, 2009). From the proximity analysis result, most of exiting RWH structures categorized as successful (99 %) was within the good suitable areas. The fact that most of the existing RWH structures are categorized as successful was because most of them were located in the good and excellent suitable areas. The validation results showed that the database and methodology used for developing the suitability model including the suitability levels of the criteria and the criteria's relative importance weights have given great results (Mahmoud and Alazba, 2014).

2.10 SWAT Model

Due to the complexity of the nature of hydrological systems, for instance quantifying the availability of the water resources using water accounting methods, still an imprecise science and as yet there is no universal framework that can be applied to quantify water resources in any location (FAO, 2012) as cited in (Batchelor, 2013). Hydrological modelling can provide insights into the local water balance and how different management decisions and/or climate change impacts patterns of water availability and use. Many model shown incorporate GIS into their structure, primarily because GIS allows a model to explicitly account for the spatial dimension of any problem. GIS is also an effective way of combining many datasets that are often of a spatial nature such as topography, precipitation and land use. Finally, GIS can act both as a relatively intuitive interface for the model and as a tool for producing graphical outputs that are effective at communicating model outputs. One widely-used hydrological model is the Soil and Water Assessment Tool (SWAT (Batchelor, 2013).(Arnold et al.,1998) has developed and proven the SWAT model is an effective tool for assessing water resource and nonpoint-source pollution problems for a wide range of scales and environmental conditions across the globe.

The development of SWAT is a continuation of USDA Agricultural Research Service (ARS) modelling experience that spans a period of roughly 30 years. Applications of SWAT have expanded worldwide over the past decade. Many of the applications have been driven by the needs of various government agencies, particularly in the U.S and the European Union, that require direct assessments of anthropogenic, climate change, and other influences on a wide range of water resources or exploratory assessments of model capabilities for potential future applications (Gassman et al., 2007).

SWAT is a basin or watershed scale, continuous-time model that operates on a daily time step and is designed to predict the impact of management on water, sediment, and agricultural chemical yields in ungauged watersheds. The model is physically based, computationally efficient, and capable of continuous simulation over long time periods. Major model components include weather, hydrology, soil, temperature and properties, plant growth, nutrients, pesticides, bacteria and pathogens and land management. In SWAT, a watershed is divided into multiple subwatersheds, which are then further subdivided into hydrologic response units (HRUs) that consist of homogeneous land use, management, and soil characteristics. The HRUs represent percentages of the sub watershed area and are not identified spatially within a SWAT simulation. Alternatively a watershed can be subdivided into only subwatersheds that are characterized by dominant land use, soil type, and management (Gassman et al., 2007).

The Soil and Water Assessment Tool (SWAT) was selected for the simulation of hydrological processes in arid and semi-arid watersheds for water harvesting practices, because: (1) it simulates all water flows, water balance components and crop yields of different land units at various temporal scales (daily and long-term); (2) it allows easy

representation and use of spatially variable data, processes and results through a GIS interface; and (3) it has a wide development and users' community with open access to the model documentation and source code (Ouessar et al., 2009).
Water balance is the driving force behind everything that happens in the watershed. Simulation of the hydrology of a watershed can be separated into two major divisions. The division is the land phase of hydrologic cycle that controls the amount of water, sediment, nutrient and pesticide loading to the main channel in each sub basin whereas the second one is the water or routing phase of the hydrologic cycle which can be defined as the movement of water, sediments, etc. through the channel network of the watershed to the outlet. Climate of the watershed is one of the inputs data that control the water balance and determine the relative importance of the different components of the hydrologic cycle. The climate variables required by SWAT consist of daily precipitation, maximum and minimum air temperature, solar radiation, and wind speed, relative humidity the model allows their values to be input from records of observed data or generated during the simulation. The daily values for weather are generated from average monthly values using weather generator. The model generates a set of weather data for each sub basin and it also used to fill in missing data in measured data (Neitsch et al., 2009).
SWAT provides two methods for estimating surface runoff volume: the SCS curve number procedure and the Green and Ampt infiltration method. Because of the lack of long-term rainfall intensity data at the watershed level as required by the latter method, the SCS CN method was selected for runoff computation. It calculates the runoff for a given rainfall depth and CN. It is an empirical formula based on several years of rainfall and runoff data obtained from a variety of combinations of soil, land use, topography and climate. The CN is related to the land use and the soil hydrologic group (Neitsch et al., 2009).
SWAT defines percolation as the water that drains through the root zone into the aquifer. Downward flow occurs when the field capacity of a soil layer is exceeded. The downward flow rate is governed by the saturated hydraulic conductivity of the soil layer. Lateral subsurface flow in the soil profile is calculated simultaneously with percolation. A kinematic storage routing method, which is based on slope, slope length, and saturated hydraulic conductivity is used to predict lateral flow in each soil layer. Lateral flow occurs when the storage in any layer exceeds field capacity and is a function of lateral flow travel time (days) and the difference between soil water content and field capacity (Neitsch et al., 2009).The lateral flow and surface runoff of all HRUs are summed for each sub basin and

then routed through the stream network. Return flow or base flow is the volume of stream flow originating from groundwater (Ouessar et al., 2009).

Evapotranspiration is a collective term for all processes by which water in the liquid or solid phase at or near the earth's surface becomes atmospheric water vapour. It includes evaporation from river and lake, bare soil, and vegetation surfaces. Potential evapotranspiration is the rate at which evapotranspiration would occur from a large area completely and uniformly covered with growing vegetation which has access to an unlimited supply of soil water (Neitsch et al., 2009).

Even though the lack of calibration and validation of the SWAT model, which raises questions about how much the model outputs can be trusted, some studies have shown that SWAT can successfully predict water balance components in the absence of calibration (Srinivasan et al., 2010 cited in Batchelor, 2013).

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Study Area

The study area, Adama Subwatersheds, is located in Oromia Region in the Central Rift Valley of Ethiopia (AWRLAEP, 2016). Geographically, the study area lies between 8^{0}13’ 54’’ to 8^{0}43’ 22’’ North latitude and 39^{0} 06’ 22’’ to 39^{0}25’ 17’’ East longitude. It covers an area of about 603.88km^{2}. Awash River is crossing the watershed in East and South (Yusuf and Kiyoshi, 2006). Adama town is the main town of the study area and located about 100km South East of Addis Ababa (AWRLAEP, 2016).

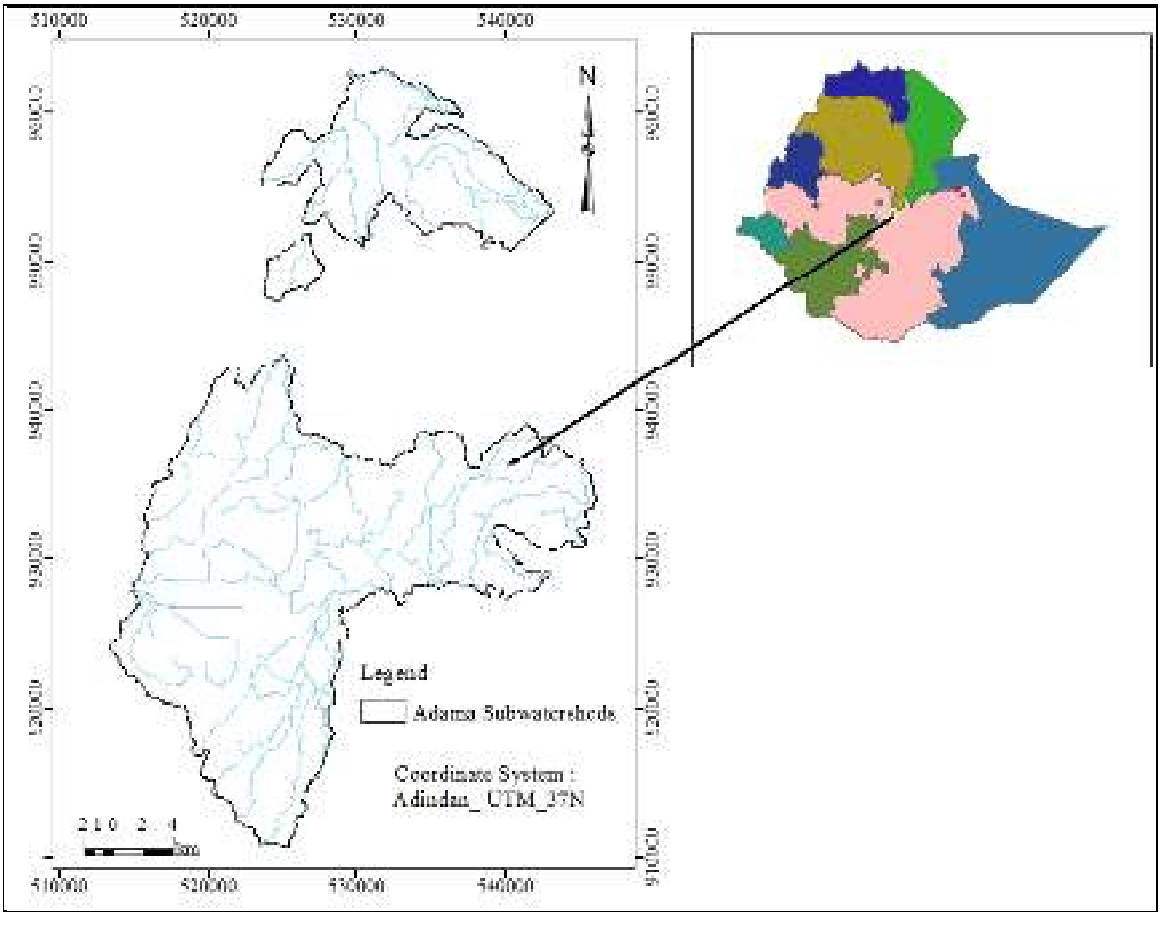


Figure 3.1: Location Map of the study area

3.2 Climate of the study area

The climatic data from 1996 to 2015 of the study area was collected from National Meteorological Agency (NMA) in terms of monthly minimum and maximum temperature and rainfall. Then the monthly mean and annual climatic data was computed for the study area.

3.2.1 Rainfall

The mean annual rainfall of the study area received for the period 1996 to 2015 was 783.94 mm. Its highest mean monthly rainfall during July to September was between 95 and 206 mm. During the rest of the months, the mean monthly rainfall received varied between 8 and 59 mm.

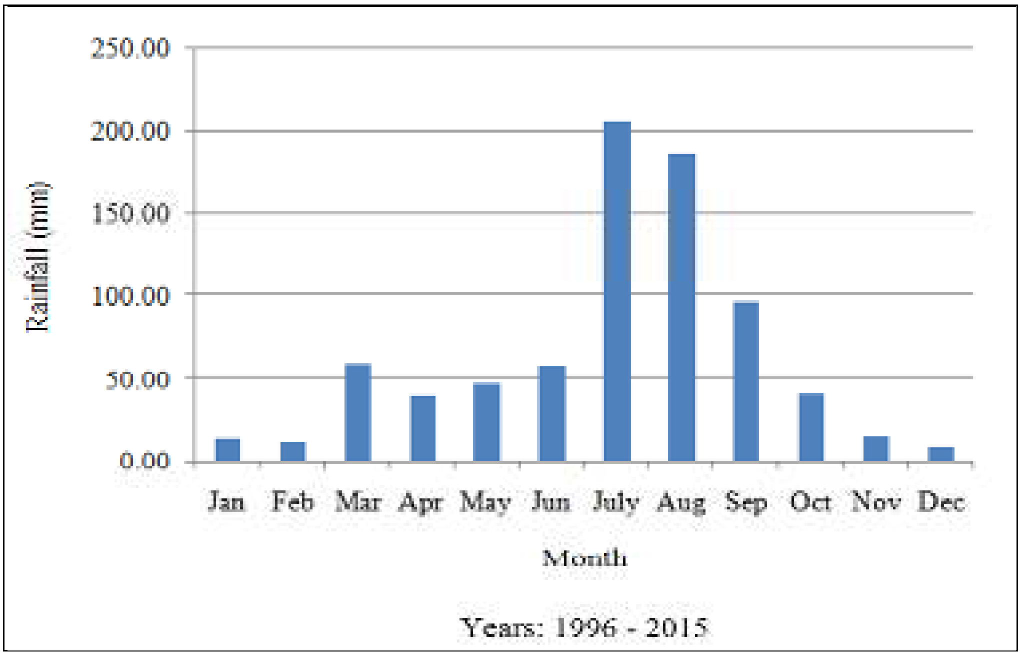


Figure 3.2: Rainfall data of the study area (NMA, 2016).

3.2.2 Temperature

The mean minimum and maximum monthly temperature of the study area, as recorded from 1996 to 2015 was in the ranges between 11.21°C-16.52^{0}C and 27.24^{0}C-30.66^{0}C respectively as shown on figure 3.3.

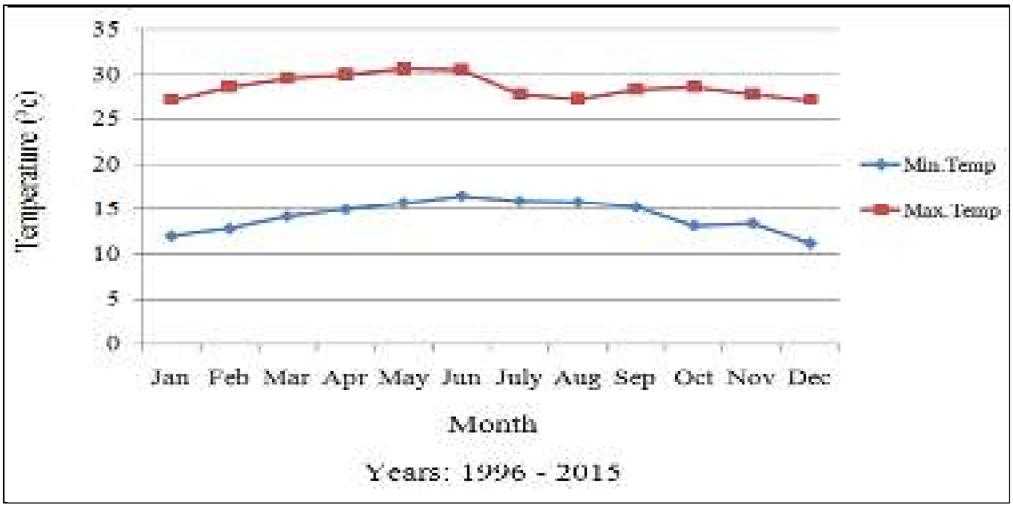


Figure 3.3: Temperature data of the study area (NMA, 2016).

3.2.3 Topography

Most parts of the study areas are covered by low and flat laying areas .The North-West tip part of it is occupied by steep slope landscape. The elevation of the study area ranges from 1327 to 2429 m above m.s.l. Its average altitude is 1878 m above m.s.l.

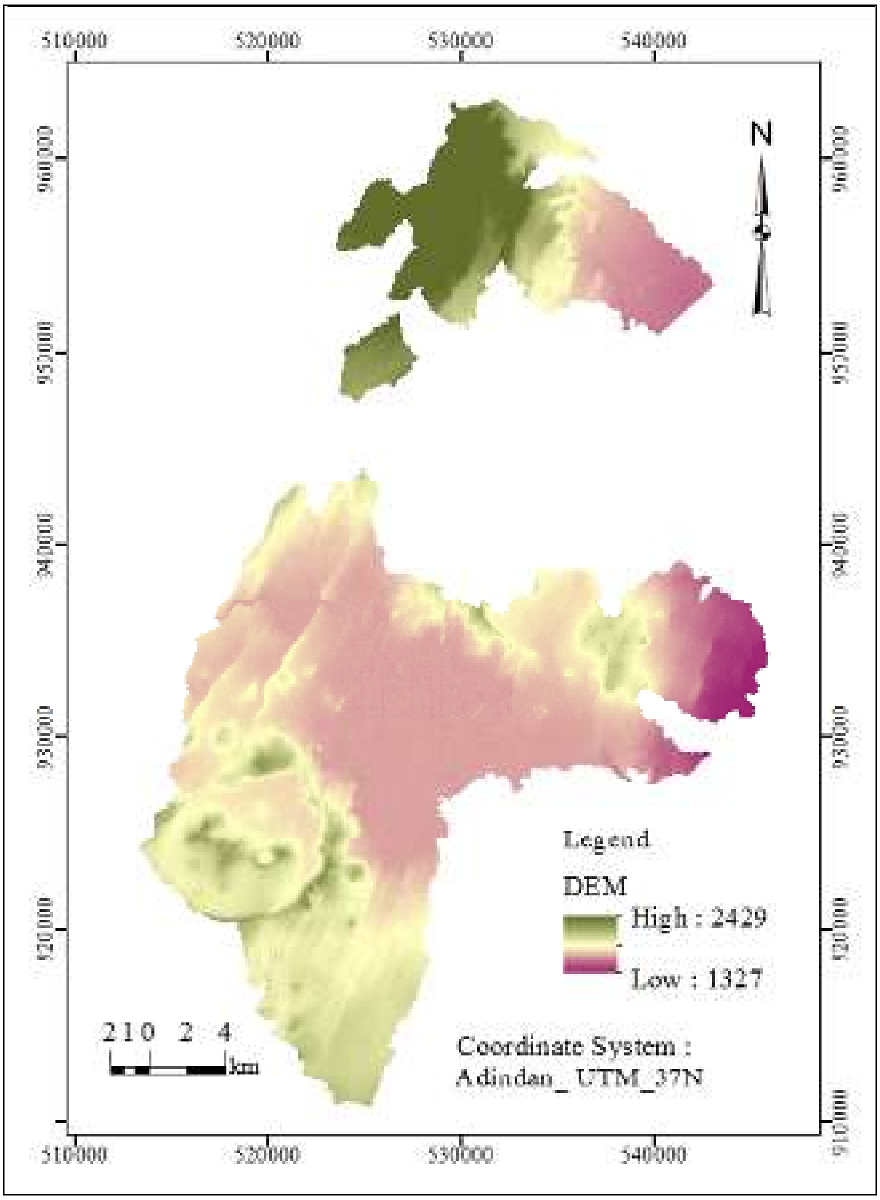


Figure 3.4: DEM map of the study area (EMA, 2016).

3.2.4 Soil

The soil data of the study area was obtained from Awash Basin Authority Upper Awash Branch Office (ABAUABO). The most part of the study area is dominated by Loam textured soils (Chromic Cambisols, Haplic Fluvisols, Mollic Andosols and Umbric Leptosols). The North and South-East parts of the study area is characterized by Clay textured soils (PellicVertisols and Chromic Vertisols).While North- East , South-East and

South-West parts of the study area is covered by Clay Loamy textured soils (Leptic Cambisols and Vitric Andosols).

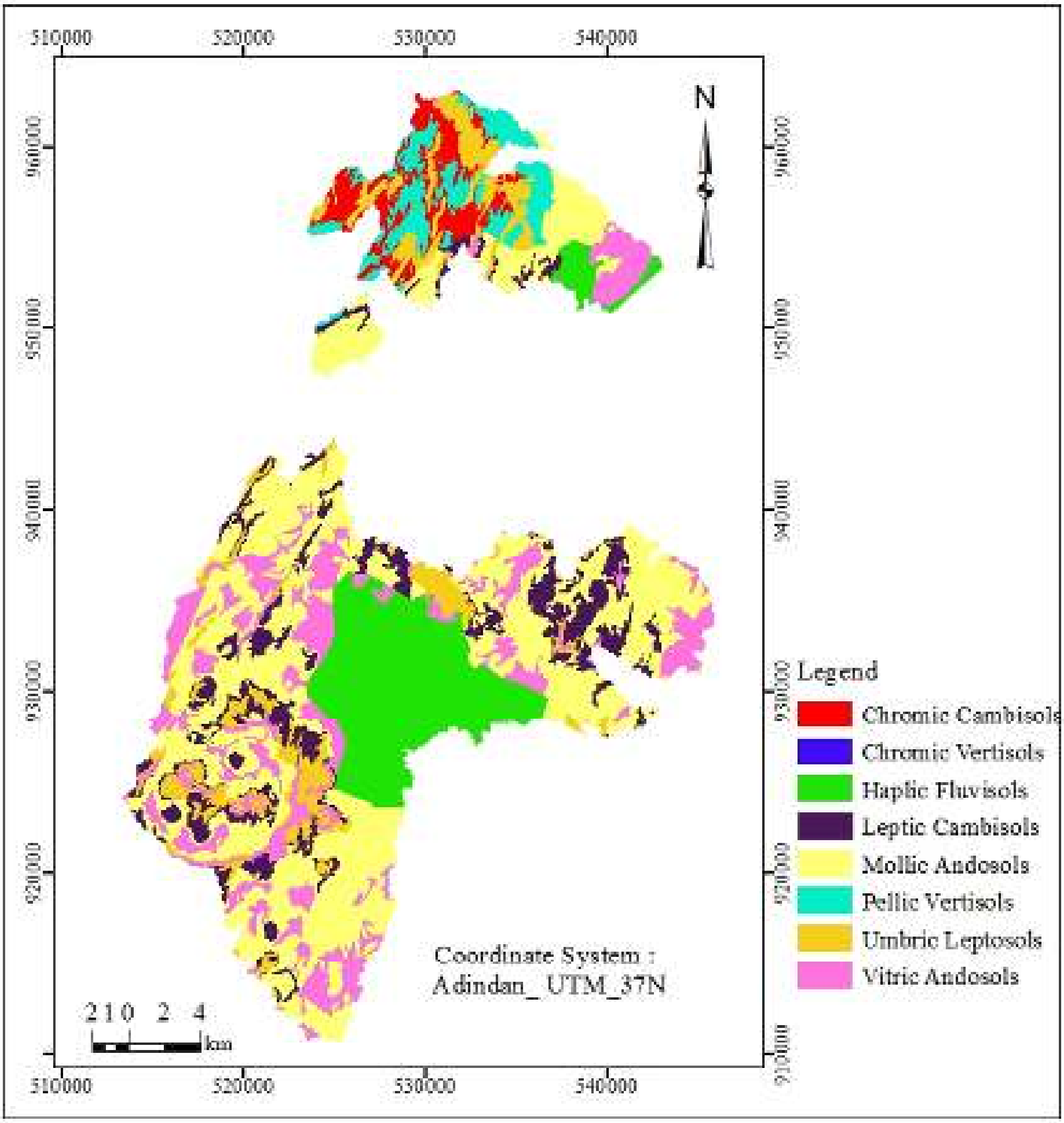


Figure 3.5: Map of Soil types in the study area (ABAUABO, 2016).

3.3 Data types and data Sources

In this study, different types of data were used for the analysis of the research. They were obtained from different sources which are described in the table 3.1.

Table 3.1: Data Types and Data Sources of the study

No.	Types of Data	Scale	Source	Format
1	Satellite imagery LANDSAT 8(OLI)	30m	EMA	Image
2	Digital Elevation Model (DEM)ASTER	30m	EMA	TIFF
3	Meteorological data (Adama Meteorological station Rainfall, Max. & Min. Temperature, Humidity, Solar radiation and Wind speed)	Daily	NMA	Excel
4	Soil map (soil depth and texture) ,2016	1:50,000	ABAUABO	Shape file (polygon)
5	Study area boundary map	-	AWRLAEP	Shape file (polygon)
6	Point data of existing RWH structures collected by hand GPS	-	AWIDA	Excel

3.4 Softwares used

In this study, different softwares have been used to conduct the analysis of the research. Each software was elaborated in detail in the table 3.2 in terms of purpose and version used for the research.

Table 3.2: Softwares used

No.	Material	Version	Purpose
1	ArcGIS	10.3	Factor development, weighted overly analysis
2	ERDAS IMAGIN	2014	To generate LULC map
3	IDRISI Selva	17.0	To derive weightage value of each factor
4	ArcSWAT	2012	To quantify WBCs, delineate watersheds
5	SPAW	6.02.75	To compute available water content, saturated hydraulic conductivity & bulk density of soil
6	Microsoft Excel	2010	Database file creation for event layer generation process for SWAT input

3.5 Methods

The techniques used to analyse and organize the collected data for the current study are briefly explained as follows. Qualitative and quantitative data were prepared for the analysis by following the metadata and analysis specification: coordinate system and datum (i.e. UTM-37N, Adindan), extent (Easting range 511737.875000 m to 546432.812500 m and Northing range 910052.511200 m to 964326.375000 m), rescaling option (i.e. 1 to 5 by 1 where 1, 2, 3, 4 and 5 refers to less suitable, moderate suitable, suitable, very suitable, and very highly suitable).

The suitability analysis for the selection of rainwater harvesting sites in the study area was carried out by developing factors (i.e. slope, soil texture, soil depth, and land use land cover) in ArcGIS environment. The relative importance (i.e. weight) of the developed factors was computed using pair wise comparison technique. The weighted overlay analysis was conducted based on the weight of the developed factors to generate layer of rainwater harvesting suitable sites in the study area.

Based on the field observations, pond rainwater harvesting structure was selected for the evaluation purpose. This is due to the sole existing RWH in the study area is pond structure. Moreover, the potential sites selection carried out for the two RWH (i.e. pond and in-situ structures) from the rainwater harvesting structures harvesting potential, the application cost, and the available local experience point of view for irrigation purpose. These two RWH structures were selected from the reviewed three RWH systems (i.e. in-situ, runoff, and roof catchment). The basic background information about the three rainwater harvesting systems explained in section 2.5.1 to 2.5.3. And the evaluation of the selected structure conducted based on the spatial information (i.e. location of structures in the suitability map of Pond RWH structure in the study area) and the physical performances of pond structures (i.e. construction materials, functional status of the structure, availability of cracks and plastic damages, seepage loss, and siltation status).

The other consideration of the study is to quantify the water balance components (i.e. surface runoff volume and discharge, the potential evapo-transpiration) and annual total sediment loading of the three delineated watersheds (i.e. Northern Watershed, NorthWest Watershed, and Southern Watershed) in ArcSWAT environment.

The overall workflow of the current study is illustrated in Figure 3.6, to accomplish the above mentioned set of activities in the study.

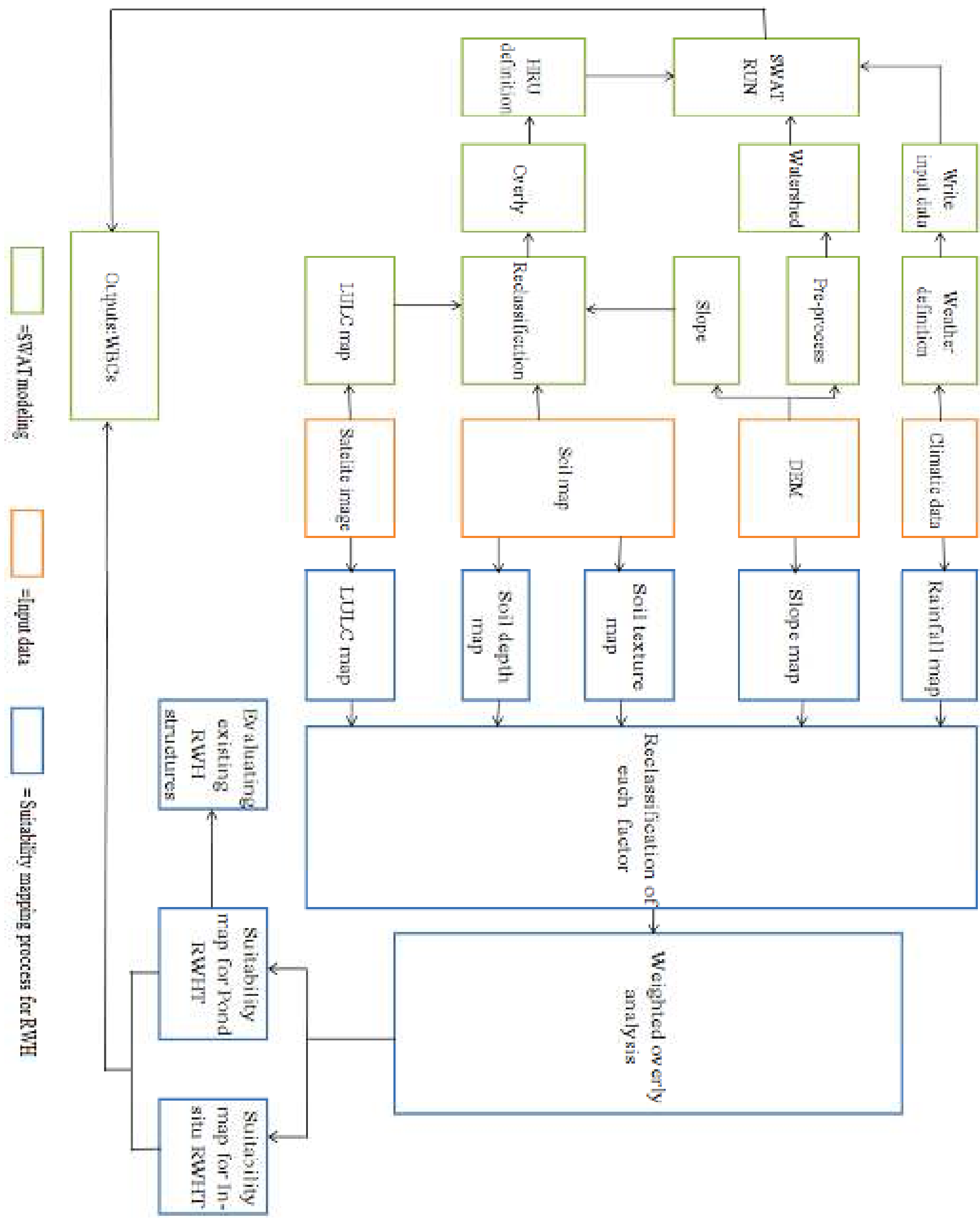


Figure 3.6.: Schematic for general work flow of the study

CHAPTER FOUR

ANALYSIS, RESULT AND DISCUSSION

4.1 Analysis and Results

To meet the specific objectives of the study, the analysis were performed by set specified spatial resolution (30m*30m) and spatial extent was boundary of the study area in GIS environment. The outcomes that obtained from the analysis of the study were represented in the forms of maps, charts, graphs and tables.

Before the analysis of suitable sites selection for RWH, pond and in-situ RWHTs were considered as rainwater harvesting technologies in rural Kebeles within the watershed (study area). This was due to the experience on RWH practice in the study area observed during field study and based on the reviewed literatures about RWHTs in the study area and the country.

4.2 Slope mapping

The slope map was generated from Digital Elevation Model (DEM) data with a spatial resolution of 30 meters using ArcGIS 10.3 spatial analysis tools by masking within the study area. The generated slope map was reclassified into 5 slope classes based on the FAO 2006 slope classification standard described in table 2.1. The suitability ranks were given for each class regarding the importance of the selection of RWH potential sites for pond and in-situ RWH techniques separately as shown in the table 4.1.For pond RWHT, undulating slope class was given the highest rank value to generate convenient runoff from the catchments areas and conveyance to pond structures. In ranking for in-situ RWHT, the highest value 5 was assigned for flat slope class. This is because of larger amount of rain water will be harvested or retained in flat terrain than sloped terrains on which runoff created on the sloped terrains. So, reclassified slope maps were generated for pond and in-situ RWHTs independently that shown on figure 4.1 and annex-2 respectively.

Table 4.1: Suitability rank for slope

No	FAO slope classes	Slope (%)	Pond	In-situ
1	Flat	0-2	3	5
2	Undulating	2-8	5	4
3	Rolling	8-15	4	3
4	Hilly	15-30	2	2
5	Mountainous	>30	1	1

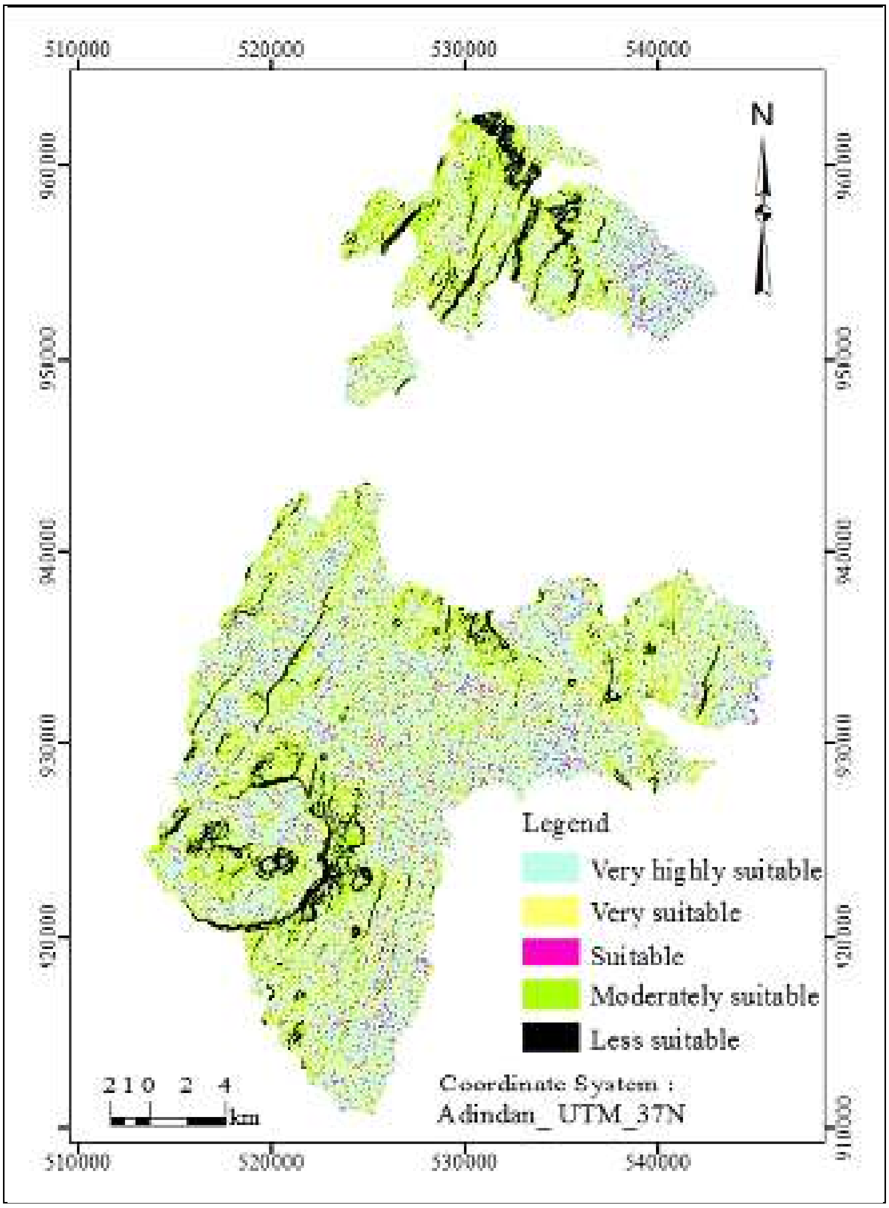


Figure 4.1: Reclassified slope map for Pond RWHT in the study area

The output map of the reclassified slope for Pond RWHT demonstrated in the figure 4.1. The light blue colour is represented a very highly suitable area of 267.36Km^2 (44.27%) within the spatial location of Northeast, Central and Southwest parts while the yellow colour was represented very suitable area of 176.29Km^2 (29.19%) scattered in most parts. The pink one was suitable area that covered by area of 34.17Km^2(5.67%) spread in most parts .Whereas, green colour stands for moderately suitable area of 88.07Km^2 (14.58%) to northwest, southwest and eastern parts of the study area. The black colour is represented for less suitable areas of 37.99 km^2 (6.29%) located similarly in North and Southeast parts of the study area.

The result obtained in slope analysis of the study for in-situ RWHT which is indicated in annex-2, the very highly suitable area is occupied only 34.16 Km^2 (5.66%) in Southwest and scattered in most parts of the study area. While very suitable area was 267.37Km^2 (44.28%) in North, Central, South and Southeast parts, the suitable area was 176.29Km^2 (29.19%) in North, Central and Southwest parts, moderately suitable area was 88.07 Km^2 (14.58 %) and scattered in most parts and the less suitable area was 37.99 Km^2 (6.29 %) in the North and Southwest parts of the study area. Generally, in the slope analysis for in-situ RWHT, the majority of the study area 477.82 Km^2 (79.13%) was found from suitable to very highly suitable status for in-situ RWHT in the study area. In other words, the area suited form 0 to 15% slope ranges and these ranges were suitable for in-situ RWHT accordance with analysis as per classification standard.

4.3 Soil texture mapping

In this study, soil map was created by dissolving similar soil textural classes from input soil shapefile data using dissolving tool in Arc GIS environment. The raster soil texture map was reclassified into four types of existing soil textural classes after conversion its vector format map into raster format. In the analysis, the cell size was 30m by 30m within the extent of the study area in ArcGIS software version 10.3. The suitability ranks for each reclassified soil textural classes was assigned based on the infiltration rate of soil textural classes stated in section 2.8.2 and table 2.2. The reclassification of soil textural classes was conducted based on infiltration rates of soil textures to select the potential sites for each RWHT in the study area and illustrated in the table 4.2.

Loam soil textural class was assigned highest value for in-situ RWHT due to it has the medium infiltration rate that superior water passing and containing desirable nutrients in the soil. The lower infiltration rate of soil was given less value for ranking to identify potential areas for in-situ RWHT. Unlike in-situ RWHT, the lower infiltration rate soil texture class was given highest value for pond RWHT because of the more runoff rather passing down in soil profile and vice versa.

Table 4.2: Suitability rank for soil texture

No	Soil textural class	In-situ	Pond
1	Clay	2	5
2	Clay Loam	3	4
3	Sandy Clay Loamy	4	3
4	Loam	5	2

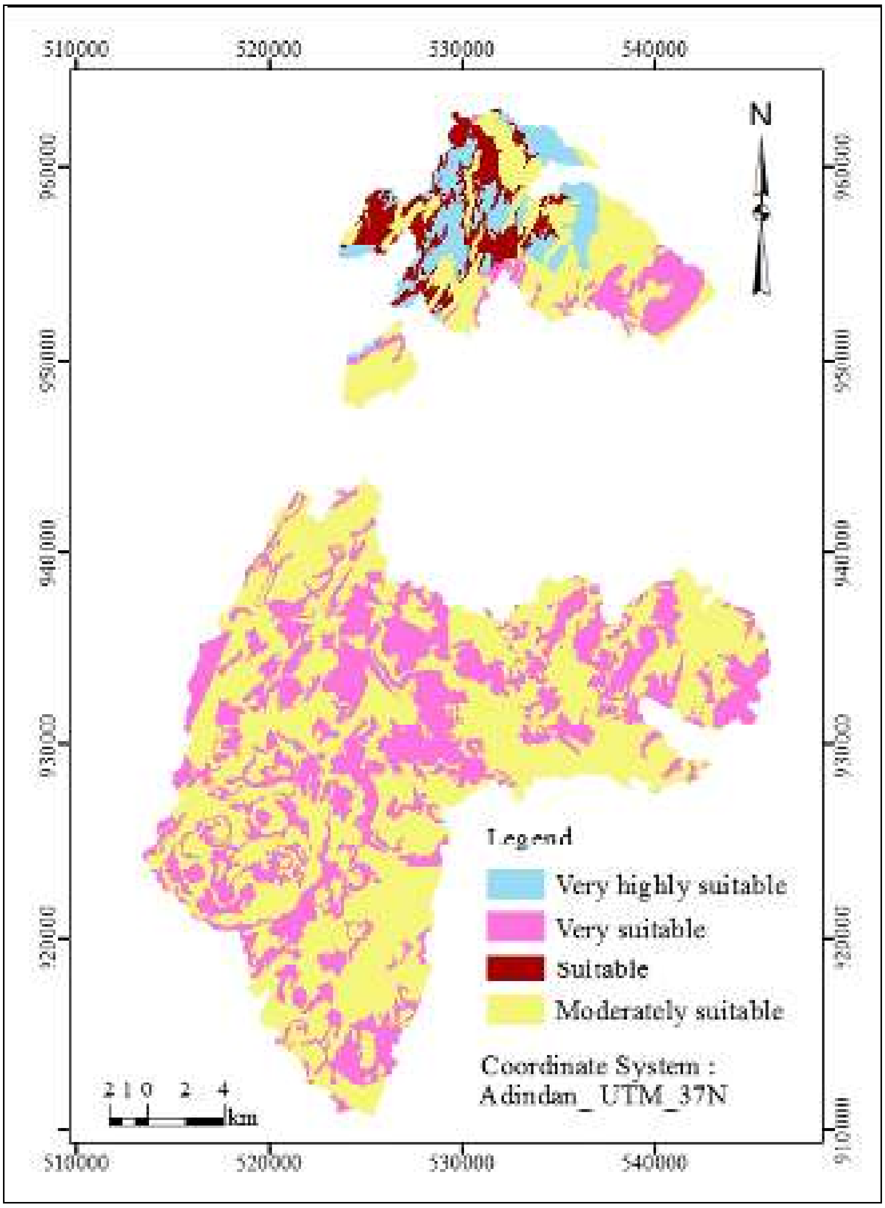


Figure 4.2: Reclassified soil texture map for Pond RWHT in study area.

The reclassified map of soil texture for pond RWHT reported that very highly suitable areas was covered by 30.05 km^2(4.98 %) with clay where located in northern part, the very suitable areas were 193.17 km^2 (31.98 %) with clay loam that located in north east, western, central, eastern and southern parts, suitable area was 24.81 km^2 (4.11 %) with sandy clay spatially located in northern and North east parts, the moderately suitable area was 355.85 km^2 (58.93 %) with loam where found in most parts of the study area which shown in figure 4.2. This indicates only 41.1% of the study area was from very highly suitable to suitable level in terms of soil textural classes of the study area. In contrary, the most parts (95.02%) of the soil textures of the study area were characterized in very highly suitable to suitable levels for in-situ RWHT that depicted in annex-3.

4.4 Soil depth mapping

The soil depth map of the study area was prepared by dissolving similar soil depth classes from the input soil shapefile data using dissolving tool in Arc GIS environment and it was converted into raster and reclassified into existing five soil depth ranges. The reclassification was carried out using the classification standard by (FAO, 1990) listed in section 2.8.3. Suitability ranks were assigned for each depth range regarding the water holding capacity of soil depths to select the potential areas for RWH. The more deep soil was given higher rank value due to it has higher capacity of harvesting runoff than the shallow one to select the potential areas for RWH in the study area indicated in the table below.

Table 4.3: Suitability rank for soil depth

No.	Soil depth class	Depth(cm)	Pond	In-situ
1	Very deep	>150	5	5
2	Deep	100-150	4	4
3	Moderately deep	50-100	3	3
4	Shallow	30-50	2	2
5	Very shallow	<30	1	1

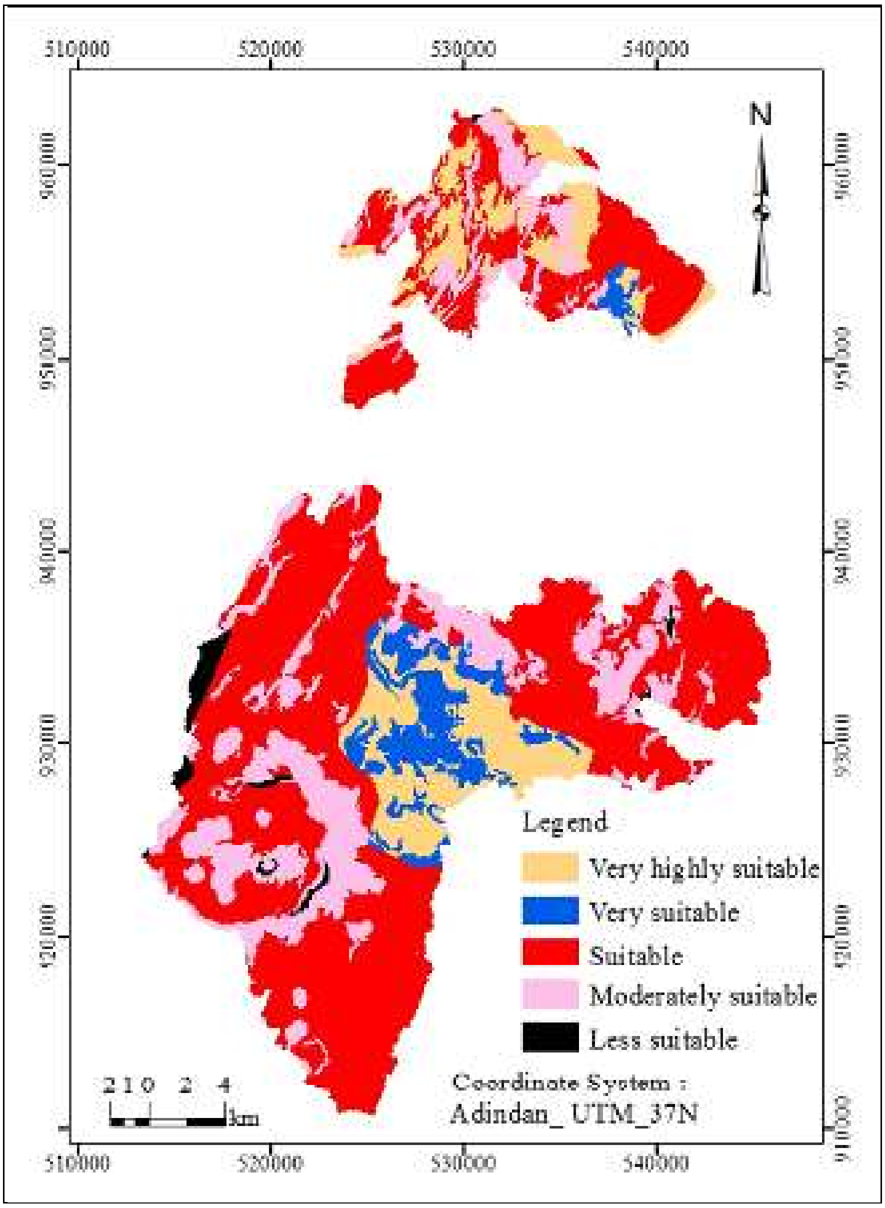


Figure 4.3: Reclassified soil depth map for RWH in the study area.

Figure 4.3 shows reclassified soil depth map for RWH in the study area which was divided into very highly suitable area of 83.5 km^2 (13.83 %)with the spatial location of Northern, Northeast and Southeast, very suitable area of 38.3 km^2 (6.34 %) where located in Northeast and Southeast, suitable area of 342.31 km^2 (56.68 %)in most parts of the study area, moderately suitable area of 131.27 km^2(21.74 %) and less suitable area of 8.5 km^2 (1.41 %) where in Northern, Southwest and Southeast of the study area for both pond and in-situ RWHTs.

Generally, 76.85 % of the soil depth in the study area was categorized from very highly suitable to suitable areas to select RWH potential sites for both pond and in-situ RWHTs.

4.6 Land Use and Land Cover

The Land use/Land cover (LULC) map of the study area was generated from Landsat 8 (OLI) imagery registered August 22/ 2015 with a spatial resolution of 30m through supervised classification technique in Erdas Imagine 2014 software . Combination of three bands as false color composite (RGB: 5, 4, 3) image with Google earth image was used to define training sites. The training site characterization was used to create signatures for each information class. The maximum likelihood algorithm was used to classify LULC using the mean, variances and covariance data from the signature. Four types of LULC were found in the study area: cultivated land, bush land, sugarcane plantation and settlement. The LULC map was reclassified based on the importance to select potential areas of RWH for agriculture purposes. Therefore, the highest value was given for cultivated land due to its accessibility for agriculture activities with respect to RWH potential sites. The suitability levels of LULC were ranked as very highly suitable, high suitable, moderately suitable and restricted (for settlement).

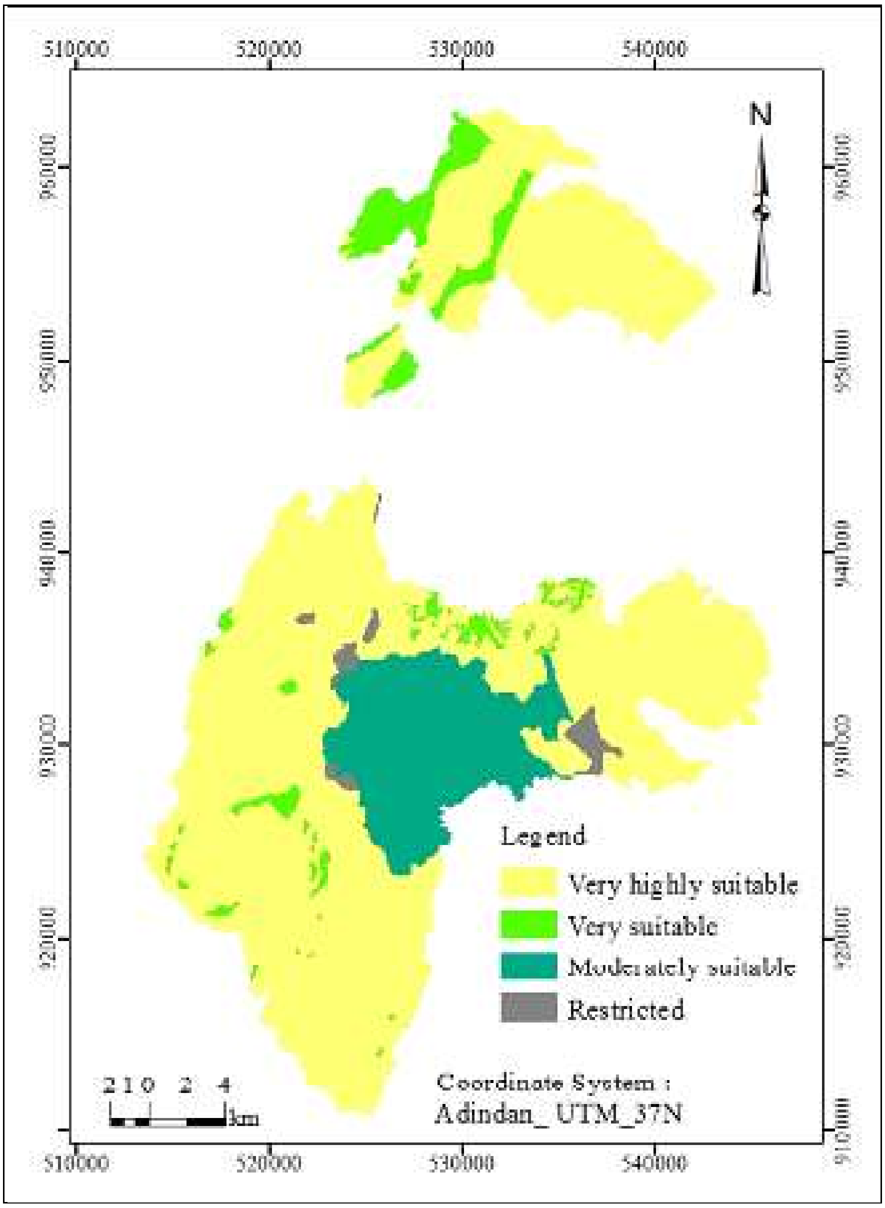


Figure 4.4: Reclassified LULC map for pond and in-situ RWHTs in study area

The reclassified map of LULC in figure 4.4 demonstrated: very highly suitable area was 468.89 km^2 (77.65 %) in most parts, very suitable area was 39.95 km^2 (6.62 %) in Northwest, Southwest and Central parts, moderately suitable area was 86.15 km^2 (14.26 %) where found in Southeast, restricted area was 8.89 km^2 (1.47 %) in Central and Southwest parts of the study area. The majority of the study area (98.53%) was occupied by very suitable to very highly suitable level of LULC to select potential sites of RWH for pond and in-situ RWHTs.

4.7 Weight Derivation

To identify suitable areas for both pond and in-situ RWH techniques in the study area, multi criteria decision making (MCDM) technique was used. The criteria which were taken into account for MCDM are soil texture, slope, soil depth and land use/cover. The Pair wise comparison method was developed based on an analytic hierarchy process (AHP) (Saaty, 1980) to estimate the weight for each criterion by creating a ratio matrix using Idrisi selva17.0 software. As input, it takes the pair wise comparison of the parameters and produces their relative weights as output. If the consistency ratio is less than or equal to 0.1, it shows acceptable reciprocal matrix (Lawal et al., 2011).Hence, the consistency ratio weight calculation for this study is accepted with 0.04.

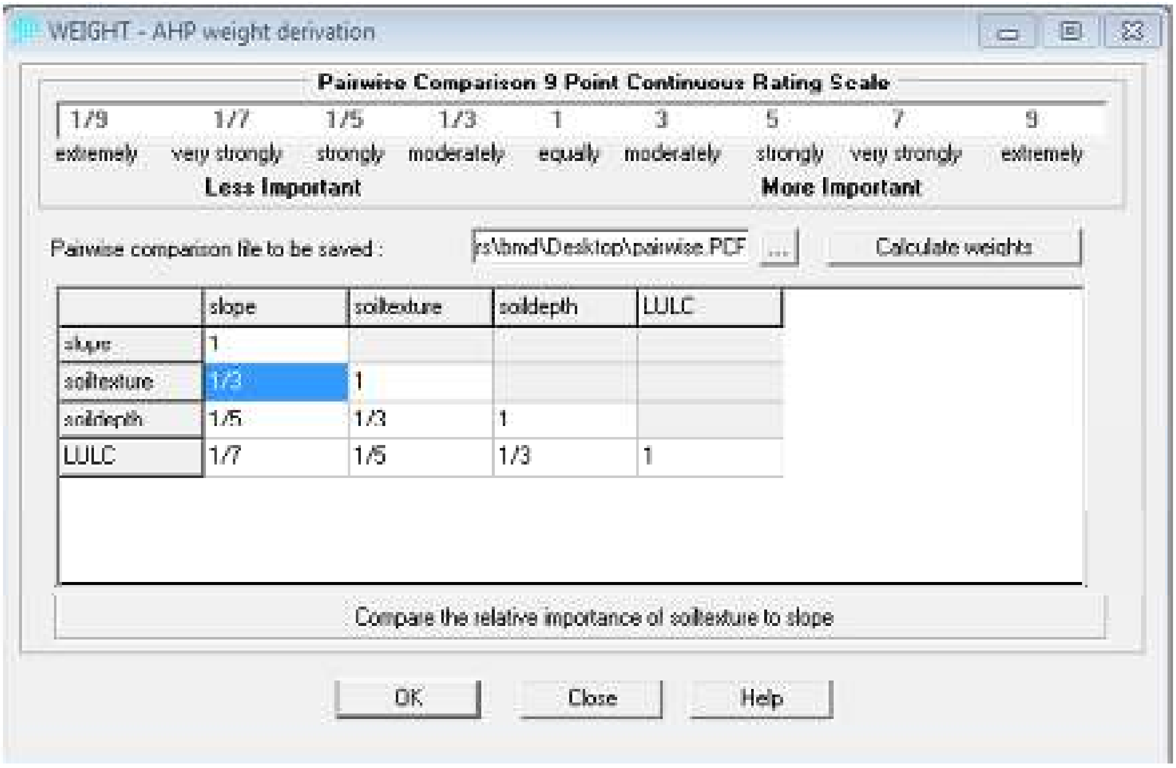


Figure 4.5: AHP Weight Derivation of criteria to select potential sites for both pond and in-situ RWHTs

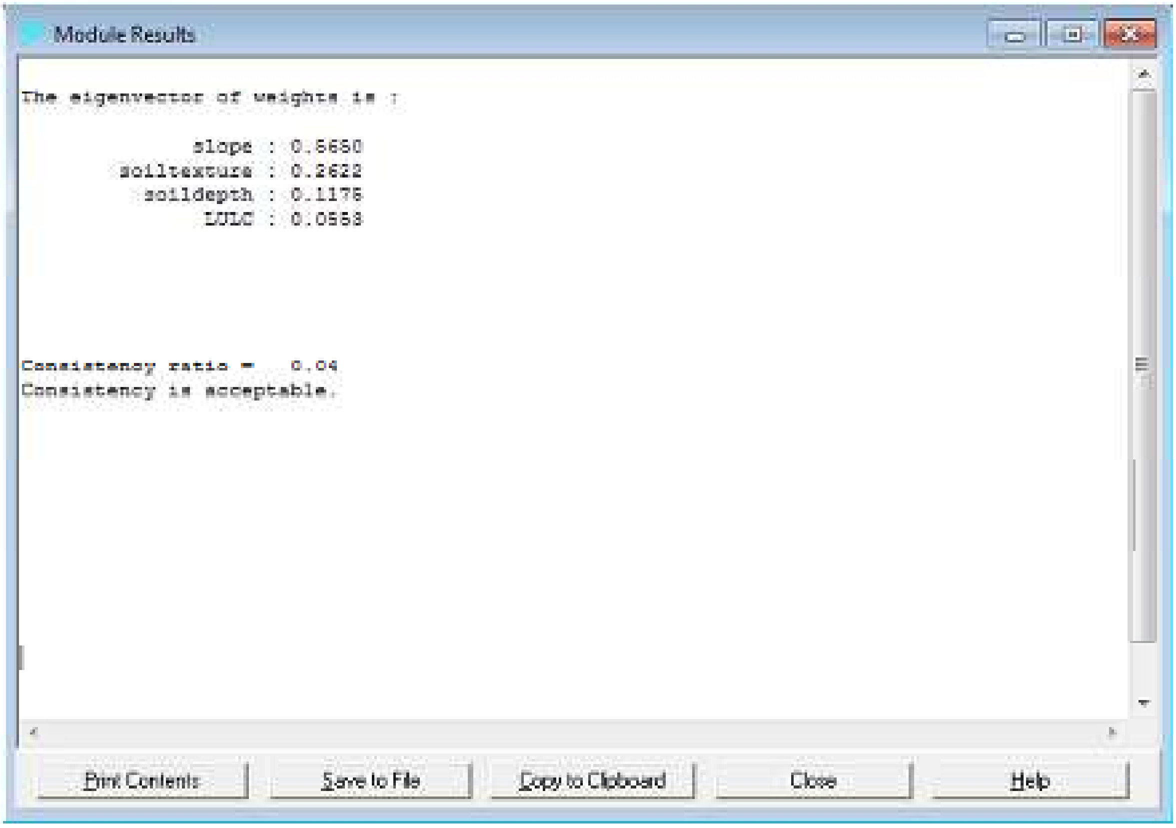


Figure 4.6: Module Result for Weight Derivation of each factor for both pond and in-situ RWHTs

4.8 Site suitability mapping for RWH

Weighted overlay analysis was done by combing each reclassified raster maps for both pond and in-situ RWHTs factors with their corresponding weights developed in Idrisi selva software for each parameter of pond and in-situ RWHTs using ArcGIS weighted overlay spatial analysis tools. The resultant polygons of homogeneous areas or the site suitability maps for RWH were produced separately.

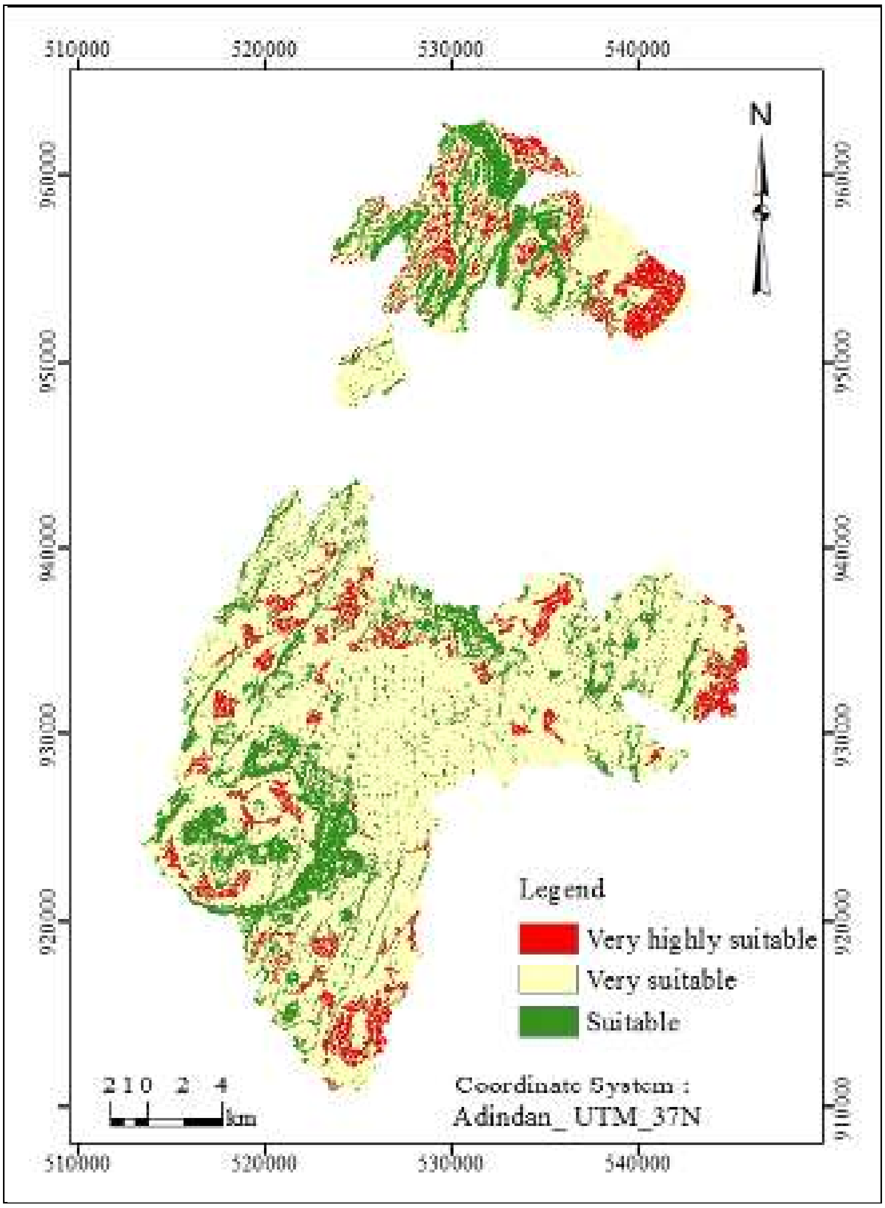


Figure 4.7: Suitability map for Pond RWHT in the study area.

The output site suitability map of the pond RWHT was displayed in figure 4.7.The map depicted the suitability status with the corresponding area coverage and their direction as followed: the very highly suitable area was 58.14 km^2 (9.63 %) and located in the Northern, East and South parts of the study area, very suitable area was 423.92 km^2 (70.2 %) in the Northwest, East and Southern parts. The 121.82 km^2 (20.17 %) area was occupied by suitable area in the Northwest, Southwest and Central parts of the study area.

Totally, the 603.88 km^2 (100%) of the study area was covered by the suitability levels from very highly suitable to suitable area that had the potential sites for pond RWHT.

In this study, the suitability map for in-situ RWHT was also generated in the study area. The output map shown that the very highly suitable areas was covered by 20.06 km^2 (3.32

%) and followed by the area 458.07 km^2 (75.86 %) with very suitable level that geographically located in the majority parts of the study area. The suitable area was 125.75 km^2 (20.82 %) and located in Northern, Southwest and Central parts of the study area which depicted in annex-5. It was generalized as 100% of the study area was from suitable to vey highly suitable levels for in-situ RWHT and it was an alternative RWHT in the study area.

4.9 Evaluation of the existing RWH structures

Evaluation of existing RWH structures in the study area was conducted by considering the engineering and locational aspects of the structures. In the engineering aspects, the physical performances of pond structures which depend on construction materials, silt condition in pond, functional status of the structure, availability of cracks and plastic damages, and seepage loss were evaluated based on related literatures (section 2.9) and field observations. Geographical locations of ponds were collected with the hand-held Global Positioning System (GPS) instrument during field observation. Accordingly, the collected locational information of the existing pond structures in the study area were evaluated by overlaying the collected waypoints on the developed suitability map of pond rainwater harvesting technique in ArcGIS environment. So the evaluation focuses on the location of pond structures in the suitable to the very highly suitable domain in the study area. Accordingly, the 44 ponds are available in only 12 rural kebeles from the 37 rural kebeles of the Adama watershed and these 44 ponds are found to be located in the suitability domain, see annex-6 for distribution existing pond structures in the study kebele domains.

Among these, 5 ponds (Adulala Hate 2 ponds, Geidiya Mukiye Egu 1 pond, Merebe Mermersa 1 pond & Roge Balewold 1 pond) only with corrugate iron sheet cover to reduce the harvested water form evaporation and protect breeding of mosquito, 24 ponds (Beqoji Dewaro 8 ponds, Chuka Hurufa 5 ponds, Ejersa Mersa 8 pond, Mukiye Haro 1 pond and Qechema 2 ponds) were plastic lined and 18 concrete lined ponds(Adulala Hate 5 ponds, Awash Melkasa 1 pond, Geidiya Mukiye Egu 2 ponds, Merebe Mermersa 5 ponds & Roge Balewold 5 ponds) were found out of 44 ponds in the study area. All most all ponds were exposed for silting problems due to lack of continuous site clearing surrounding the ponds and drainage forwards to the ponds. According to the field observation data, only 4 (9 %) existing pond structures were functioning for RWH which were concrete lined with corrugated iron sheet roof covered in the study area but the rest 40 (91%) existing RWH structures were found not functioning due to seepage problem for unlined ponds and cracking defects on concrete lined ponds as well as plastic damage for plastic lined ponds that causes for water drains to soil or ground that recorded in Annex-6. Moreover, evaporation was a potential problem which may cause the dysfunctional of the existing pond structures in the study area.

The results of the locational evaluation generally indicates that 13 ponds (29.5%) were located in very highly suitability level based on the proposed suitability map of pond RWHT within the Adama Watershed Kebeles: Bokoji Dewaro, Ejersa Mersa, Geidiya Mukiye Egu and Merebe Mermersa while the 27 ponds or (61.4%) of the total number of ponds were found in very suitable level in the listed kebeles namely: Adulala Hate, Bokoji Dewaro, Bubisa kusaye Chuka Hurufa, Ejersa Mersa, Geidiya Mukiye Egu, Qechema, Mukiye Haro, Roge Balewold and followed by 4 ponds (9 %) suitable status which were found in the kebeles: Adulala Hate, Awash Melekasa, Roge Balewold and Waqemiya Tiyo as shown in figure 4.8.

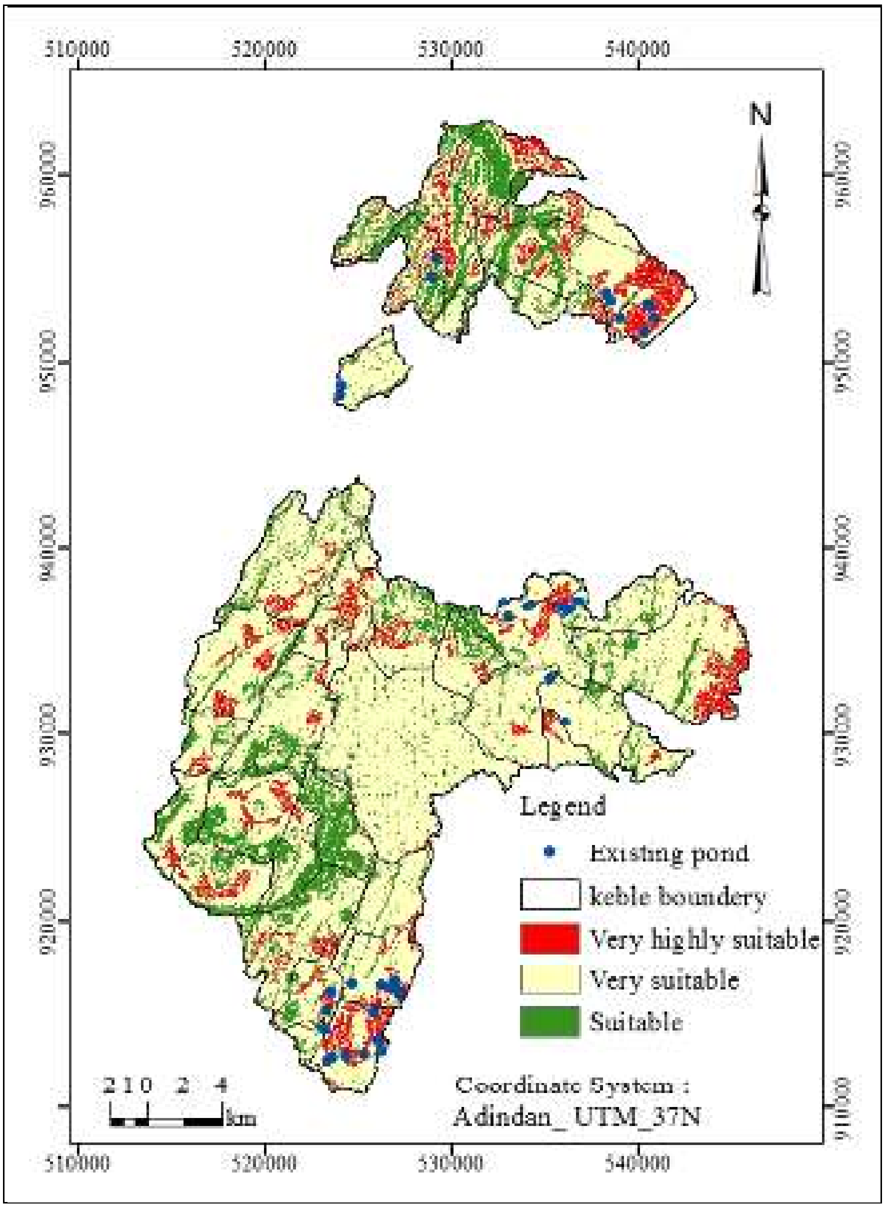


Figure 4.8: Existing pond structures in the study area.

4.10 SWAT modelling

In this study, input parameters for SWAT modelling were used: DEM, climate, soil characteristics and land cover for simulating the water balance components: surface runoff and discharge, potential evapotranspiration and annual total sediment loading in the study area.

To delineate the watershed a 30m by 30m resolution DEM was used as input data in the ArcSWAT model that used to calculate the slope and contours of the watershed. Then after, flow direction and accumulation were established and the stream network was generated by the model. In the stream network, each individual reach drains a subbasin and each reach has a node or outlet that was selected. The selected outlets set the lower bound for the watershed, which was then delineated based on the location of that outlet and the stream network. In the analysis of watershed, the study area was divided into three subwatersheds based on generalized outlets' directions as shown in figure 4.9. The subwatersheds were located and named as Northern watershed, Northwest watershed and Southern watershed

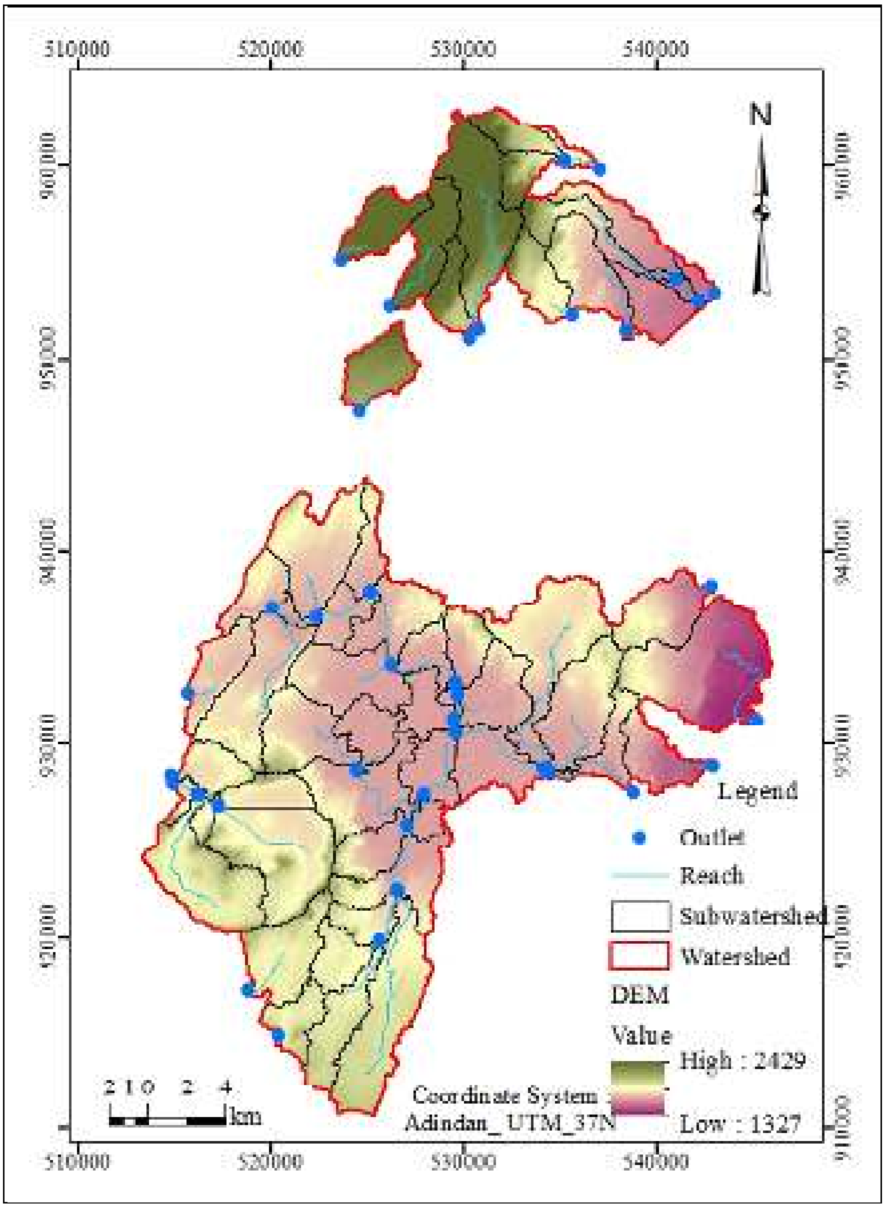


Figure 4.9: Watershed delineation of the study area.

In order to define hydrologic response units (HRUs) in ArcSWAT model, land use map, soil map and slope were used as input data for HRU analysis in the study area. The land use types: cultivated land, bush, sugarcane plantation and settlements that were coded as AGRL, HAY, SUGC and URMD respectively according to ArcSWAT input coding system (annex-12) to define land use and then reclassified into SWAT land use classes.

The input soil parameters for SWAT were defined in terms of FAO soil type classification in the watersheds. Basic physical properties of the soil (percentage sand, clay, and silt; soil texture class; the percentage of carbon and profile thickness), derived soil properties such as hydraulic conductivity, bulk density and available water capacity were obtained by analysis in Soil Plant Atmosphere Water field and pond hydrology (SPAW) software using soil texture class and soil organic matter content as input data.

The slope was one of the parameters for HRU analysis that defined and reclassified in percentage FAO slope classification for each watershed in ArcSWAT HRU analysis. After the reclassification of the parameters, they were combined in ArcSWAT HRU analysis and the reports of defined HRUs were created as output that represented in annex-13 for each watershed of the study area.

Based on the output reports on annex-13.1, the Northern watershed contained 14 subbasins and 342 HRUs with total area of 119.26km2 (15.5%) of the study area. This watershed was characterized by land use of HAY (bush) and Agricultural Land Generic (cultivated land) with area of 22.78km2 or 19.1% and 96.48km2 or 80.9% of the area watershed respectively while the slope of 0 – 2%, 2 - 8%, 8-15%, 15-30%, >30% were covered by 4.62%,36.14%, 28.41%, 19.70% and 11.14% of the total area of the northern watershed. The soil types within the watershed were: Calcarice Cambisols (20.80%), Umbric Leptosols (18.93%), Pellic Vertisols (24.80%), Vitric Andosols (7.93%), Mollic Andosols (18.51%), Haplic Fluvisols (6.14%) and Leptic Cambisols (2.90%) of the area of the watershed.

In the North-west watershed of the study area, one subbasin and 28 HRUs were covered by area of 3.48km2(33.16%) with HAY (bush) and 7.01km2 (66.84%) with Agricultural Land Generic (cultivated land) land use. The slope of this watershed were: 0 – 2%, 2 - 8%, 8-15%, 15-30%, >30% and the distribution of soil types in the watershed were found Leptic Cambisols (11.23%), Mollic Andosols(84.49%) and Pellic Vertisols(4.29%) of the area watershed that presented in annex-13.2.

The SWAT model simulation outcome of Southern watershed reported on annex-13.3was characterized by: 43 subbasins and 1122 RHUs. The distribution of land use in the watershed were 365.39km2 (77.07%) area for Agricultural Land Generic (cultivated), 13.69(2.89%) for HAY (bush), 8.89 (1.88%) for Residential-Medium Density (settlement), and 86.14 (18.17%) for Sugarcane in the watershed while distribution of slope were: 0 -2 %, 2 - 8%, 8-15%, 15-30%, >30% that covered by the area of 5.92%,46.20%, 29.29%, 13.41% and 5.18% respectively with in total the southern watershed area but the distribution of soil types in the watershed were Leptic Cambisols (12.10%), Mollic Andosols (45.32%), Umbric Leptosols(7.18%), Vitric Andosols (17.59%) and Haplic Fluvisols(17.81%) area of watershed.

In this study, measured meteorological data were used and the weather generator model was set up to estimate any missing data in SWAT model to generate hydrologic flow patterns in the subbasin. The Daily precipitation, maximum and minimum air temperature, solar radiation, wind speed, and relative humidity data were used from the year 2006 to 2015 for SWAT modelling. The SWAT model was built in weather generator that can be used to fill gaps in data and predicts daily weather variables for specific geographic locations.

The hydrological modelling outputs that were generated by the ArcSWAT model simulation of the research were: detailed water balance components, sedimentation and spatially distributed output. Output generated by SWAT model can be largely depending on the selected output options. One can select output to be written per day, month or year. Output files can include results for the entire watersheds, for each subbasin or for each HRU of the three watersheds in the study area.

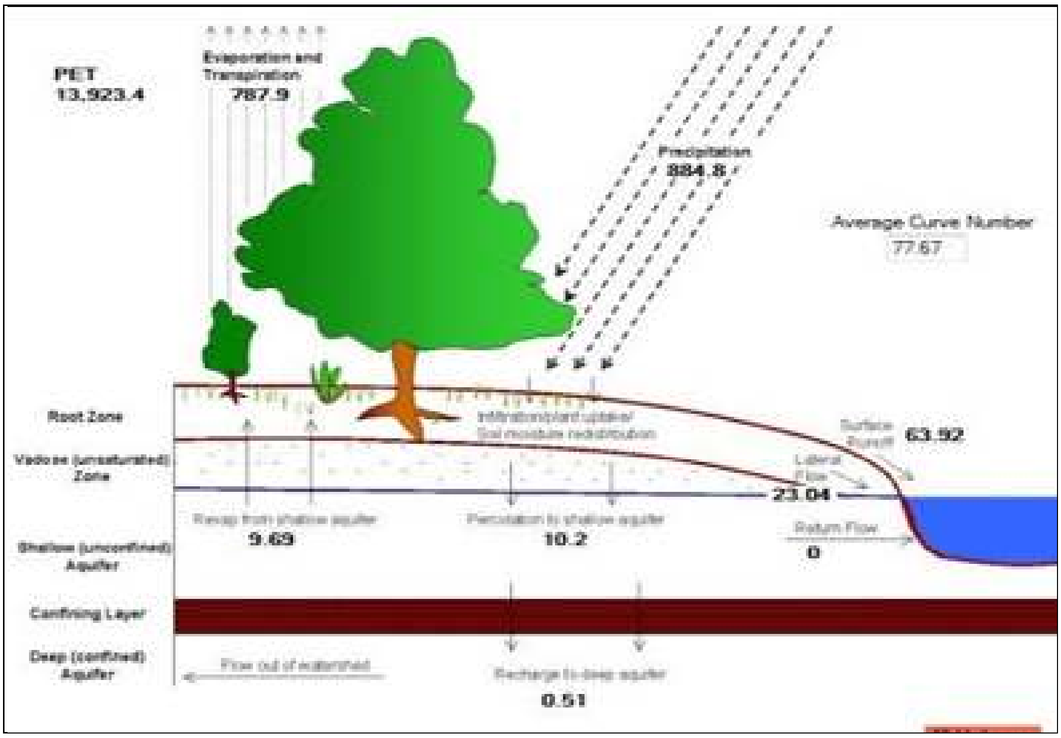


Figure 4.10: Average annual WBCs from year 2006 to 2015 for Northern watershed.

The outcomes that illustrated on figure 4.10 were summarized as: precipitation was 884.8 mm and evapotranspiration amounted to 787.9 mm. This indicated that 96.7mm amount of water was remained and was redistributed in to water balance components such as: 63.92mm runoff, 23.04mm for lateral flow, 10.2mm percolation to shallow aquifer, 0.51mm to deep aquifer in the watershed. The potential evapotranspiration was as high as 13923.4mm.

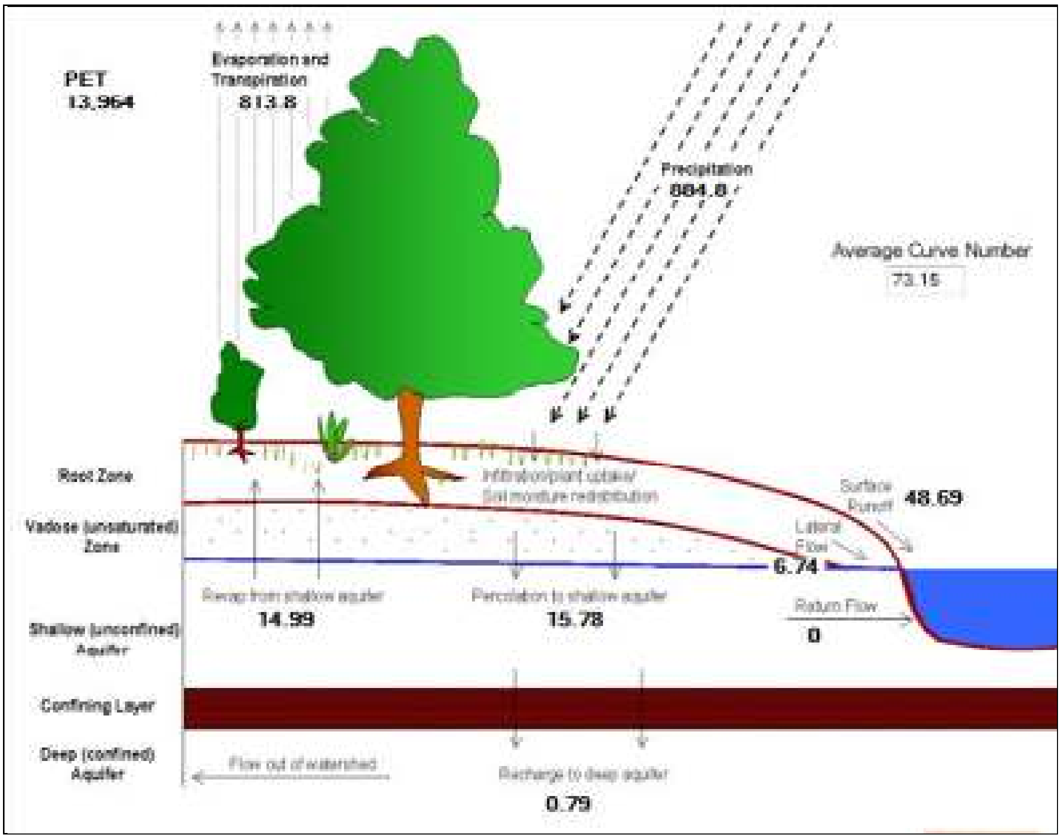


Figure4.11: Average annual WBCs from year 2006 to 2015 for North-west watershed.

From the outputs of the hydrological modelling for the Northwest watershed, 48.69mm runoff and 23.31mm recharge were generated as described in figure 4.11. The amount of runoff in the watershed was less than that of the Northern watershed due to smaller area coverage that can be influenced on the amount of runoff generation when compared with Northern watershed (the larger catchment area, the more runoff).

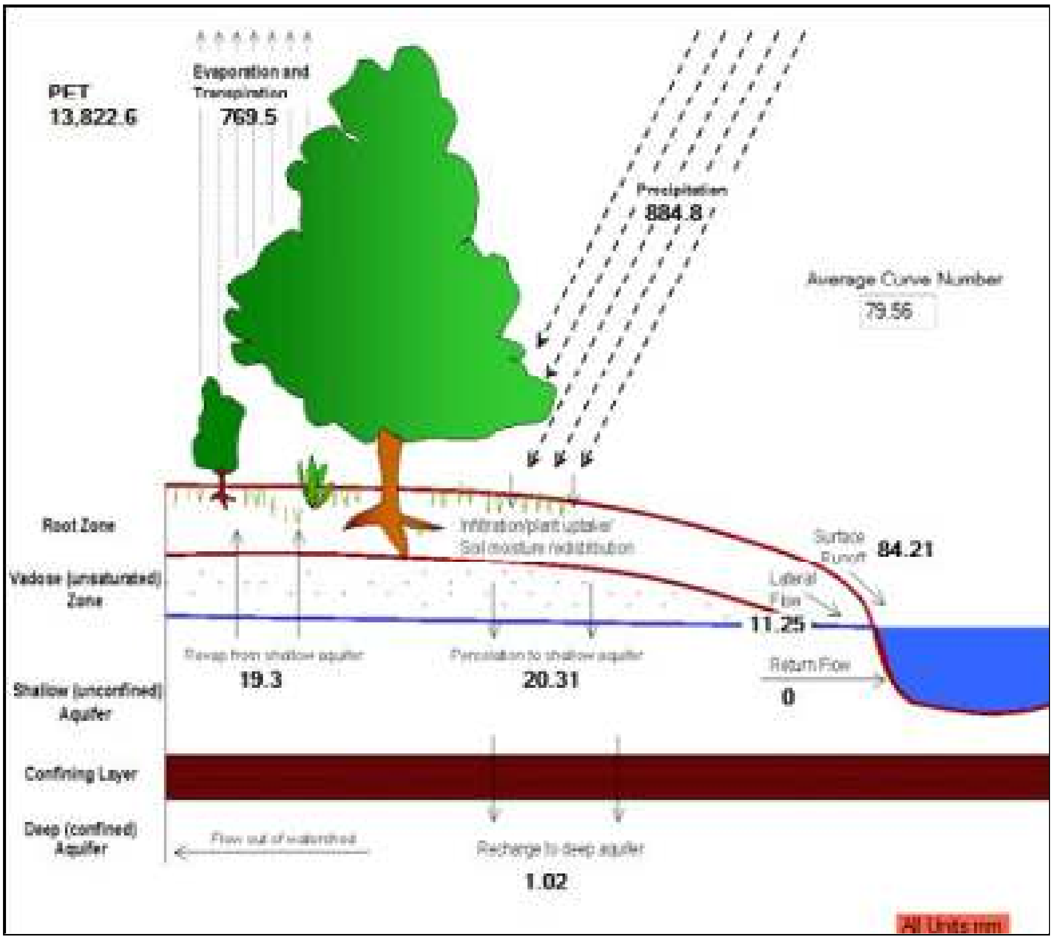


Figure 4.12: Average annual WBC from year 2006 to 2015 for Southern watershed

Figure 4.12 shows water balance components that generated for Southern watershed in SWAT model were: 84.21mm of runoff and 32.58mm of recharge from 884.8 mm of annual precipitation. The runoff amount in the southern watershed was found the largest in amount due to larger coverage area and settlement land use type existence in the watershed than other watersheds.

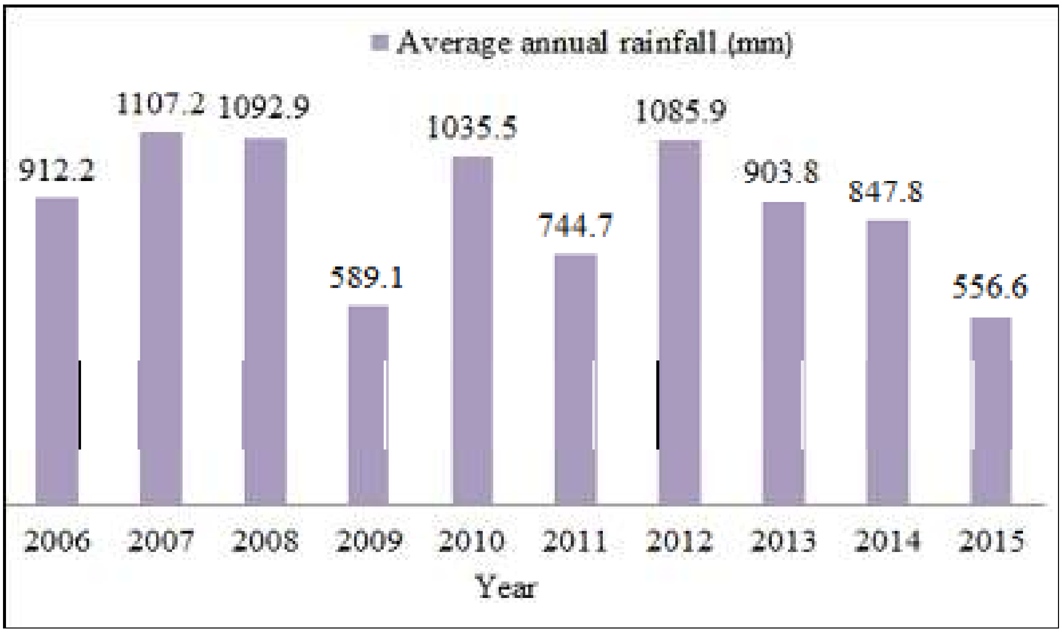


Figure 4.13: Average annual rainfall from 2006 to 2015 of the watersheds

The result of SWAT simulation in figure 4.13 and annex-14 the three watersheds (i.e. Northern, Northwest and Southern) referred that the annual rainfall in 2006 and 2015 were 912.2mm and 556.5 mm respectively and the average annual rainfall (884.8mm). The variation of the annual rainfall was 24.21%.Furthermore, the annual potential evapotranspiration of the Northern, Northwest and Southern watersheds in 2006 and 2015 were (13752.81mm and 14721.72mm),(13793.31mm and14762.87mm) and (13651.92mm and 14619.72mm) respectively for three watersheds. While, the variation of annual potential evaptranspiration in the Northern, Northwest and Southern watersheds were 3.4%, 3.4% and3.46% respectively. The increment of annual potential evapotranspiration compared to rainfall that demonstrated water shortage varied from year to year in the study area.

From annex-15, the SWAT outputs reported that the lowest runoff was occurred in the year of 2015 amounted to 6.58mm, 3.98mm and 10.72mm for Northern, Northwest and Southern watersheds while the highest runoff occurred in the year of 2012 amounted to 159.25mm, 124.91mm and 197.69mm respectively for each watershed in the study area. In those years of low runoff, the water shortage became more severe and it was likely to have greater food insecurity impacts.

Between the year 2006 and 2015, the highest rainfall was occurred in the year 2007 but the highest runoff was generated in the year of 2012. In other words, the amount of runoff in the watershed not only affected by the amount of rainfall but also affected by evapotranspiration and vegetation cover in the same study area.

The total sediment loading for the Northern, Northwest and Southern watersheds of the study area were quantified in ArcSWAT model from year 2006 to 2015 were: 4.389 T/HA, 2.716 T/HA and 4.938 T/HA respectively as shown in annex-16.

4.11 Discussion

Based on the results of the analysis of the current study, the discussion focused on the methodologies of suitability analysis, evaluation of RWH structures and quantification of water balance components.

Firstly based on the methodology considerations, the potential areas for RWH in the study area were selected based on rainfall, slope, soil textural classes, soil depth and LULC were selected as dominant criteria for RWH in the study area. This was agreed with findings of different researchers Tumbo et al. (2014a), Girma (2009) and Mbilinyi et al. (2007) these criteria were used to select the potential areas for RWH practices.

The spatial distribution and coverage of the suitability levels of the suitability maps for RWH were confirmed that the study area had the potential areas for both ponds and in-situ RWHTs. The results were agreed with findings by Girma (2009) that indicated pond and in-situ RWHTs are RWH interventions where the areas with food insecurity due to water shortage. So Girma (2009) and the current study are in agreement with the finding of the higher level of suitability for pond and in-situ rainwater harvesting techniques in the area of water shortage but the scale is different from the current study which is wereda level and Girma (2009) concluded at zonal scale.

Secondly based on the evaluation of RWH structure, the majority or 91% of existing pond structures were found to be non-functioning during evaluation and the problems that were identified were seepage loss due to cracked concrete lined ponds and unlined ponds as damage plastic lined ponds, evaporation for unroofed ponds and silting due to lack of surrounding and ponds clearance. These findings were substantiated with the study by Yusuf and Kiyoshi (2006) stated that crack was observed at the middle of the pond due to using poor quality sand for plastering the tank sand Girma (2009) also proved that the unlined ponds were attributed to the improper sitting of the ponds which led to poor runoff harvest.

Thirdly based on the quantification of water balance components, the result of SWAT simulation in figure 4.14 and annex-14 the three watersheds (i.e. Northern, Northwest and Southern) referred that the annual rainfall in 2006 and 2015 were 912.2mm and 556.5 mm respectively and the average annual rainfall (884.8mm). The variation of the annual rainfall was 24.21%.Furthermore,the annual potential evapotranspiration of the Northern, Northwest and Southern watersheds in 2006 and 2015 were (13752.81mm and 14721.72mm), (13793.31mm and 14762.87mm) and (13651.92mm and 14619.72mm) respectively .While, the variation of annual potential evaptranspiration in the Northern, Northwest and Southern watersheds were 3.4%, 3.4% and 3.46% respectively. The increment of annual potential evapotranspiration compared to rainfall that demonstrated water shortage varied from year to year in the study area. This finding was met with the shortage of water during growing season would follow from a decrease in precipitation and an increase in potential evapotranspiration that was proved by Haurie and Viguier (2005).

The amount of rainfall and runoff within 2006 to 2015 were reached in the highest peak in the years 2007 and 2012 respectively, see annex-15. That is to say, the amount of runoff in the watershed not only affected by the amount of rainfall but also affected by evapo-transpiration and vegetation cover in the study area. It was supported by the finding that was conducted by Biruk (2009) and stated as: the surface runoff is produced when the soil is saturated and there is a delay in the lateral flow. Additionally, Critchley and Siegert (1991) concluded that an area densely covered with vegetation, yields less runoff than bare ground.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The study on selection of the potential areas for evaluation of RWH using GIS techniques integrated with ArcSWAT hydrological model was conducted in Adama Wereda and the results of analysis of the research were concluded as follow:

The study area has the potential for pond and in-situ RWH. This is justified by the area coverage of suitable to very highly suitable domains in the study area is 100% for both pond and in-situ RWHTs. This condition implies that there is vast potential for the development of pond and in-situ rainwater harvesting structures in the area.

From pond engineering consideration point of view, the study concludes that there is the majority of the observed pond RWH Structures are faced with mal-functioning problem. This is justified by the field observations that indicates only 4 (9 %) of the existing pond structures were functioning for RWH which were concrete lined with corrugated iron sheet roof covered in the study area but the rest 40 (91%) of the existing RWH structures were found not functioning according to the field observation data of 12 Kebeles in the study area.

From locational evaluation of existing pond structure point of view, the whole observed pond RWH Structures are found to be located in the suitable sites for rainwater harvesting technique. Accordingly, the spatial information generated in the study area indicates that almost all existing pond structures (i.e. 44 ponds) were located from very suitable to suitable levels based on the proposed suitability map of pond using GIS techniques.

Finally, the study concludes that there is water shortage in Adama Wereda. Accordingly, ArcSWAT computations of annual precipitation and evapotranspiration results indicate that the increment of annual evapotranspiration compared to annual precipitation. This implies that there very high level water shortage that cannot meet the requirement of growing season period definitions for plant growth.

5.2 Recommendations

The recommendations of the study that forward to select the potential RWH sites in the study area were summarized as follow:

Selection of the potential RWH areas using GIS techniques should be encouraged to harvest rainwater for reducing food insecurity in the study area and the areas faced similar problem in the country, Ethiopia.

Further factors, socio economic data, such as population density, population income, proximity, and demographic data should be included in the analysis of selection of the potential RWH sites by other researchers, in addition to the dominant factors that used the study.

The generated suitability maps of in-situ RWHT of the study should be implemented in addition to pond RWHT for water management practices like irrigation and flood control programs by concerned bodies in the study area.

The construction of pond structures should be done properly as per design and the cracked ones needs proper maintenance work to reuse the pond for RWH. Moreover, plastering in side unlined ponds or utilizing plastic lining for unlined ponds, replacing of the damaged plastic for damaged plastic lined ponds, preparing the roof with corrugated iron sheet or concrete for unroofed ponds and site clearing surrounding the ponds and inside ponds to reduce silting problem for the first or starting rain runoff should be blocked rather than harvested in to the ponds (preparing shallow hole before the pond to reduce silt).

Application of SWAT model simulation integrated with ArcGIS should be applied to quantify the water balance components to improve the hydrology analysis and utilize outputs for further related analysis in the watersheds of the study area and the country.

Other SWAT model simulations such as agriculture management practices, plant nutrition and water quality should be simulated the using the model in the future studies.

REFERENCES

Adham,A.,Riksen,M.,Ouessar,M.,Ritsema, C., 20016.Identification of suitable sites for rainwater harvesting structures in arid and semi-arid region.

Adama Wereda Disaster Protection and Preparedness Office, 2016.Report on Food Aid program for Rural Kebel Population in Adama Wereda, unpublished. Adama: ADPPO.

Adama Wereda Irrigation Developmental Authority, 2016.Adama: AWIDA.

Adama Wereda Rural Land Administration and Environmental Protection, 2016. Map of study boundary. Adama:AWIDA.

Akram, M. and W.D. Kemper. 1979. Infiltration of soils as affected by the pressure and water content at the time of compaction. Soil Sci. Am. J. 43: 1080-1086.

Al-Adamat,R.,Diabat,A.& Shatnawi,G.(2010).Combing GIS with multi criteria Decision making for sitting water harvesting ponds in Northern Jordan.

Alemu, Y. and Kidane A., 2015.Rainwater Harvesting: An option for dry land agriculture in arid and sem-arid areas Ethiopia, Vol.7(2), pp.17-28,February, 2015. Available through: http://www.academicjournals.org/IJWREE [Accessed 25 December 2016]

Ali, A., 2009. GIS Applications in Water RecourseEngineering: Term Paper.

Awulachew, S. B.; Merrey, D. J.; Kamara, A. B.; Van Koppen, B.; Penning de Vries, F.; Boelee,E.; Makombe, G. 2005. Experiences and opportunities for promoting small–scale/micro-irrigation and rainwater harvesting for food security in Ethiopia. Colombo, Sri Lanka: IWMI. v. 86p. (Working paper 98)

Bakir, M. and Xingnan, Z., 2008.GisAnd Remote Sensing Applications For Rainwater Harvesting In The Syrian Desert (Al-Badia): Twelfth International Water Technology Conference, IWTC12 2008 Alexandria, Egypt.

Batchelor, J., 2013.Using GIS and SWAT analysis to assess water scarcity and WASH services levels in rural Andhra Pradesh: Working Paper 10.

Biazin, T., 2012.Rainwater harvesting for drylandagriculturein the Rift Valley of Ethiopia.Ph. DWageningen University.

Biruk, A., 2009 SWAT to Identify Watershed Management Options: Anjeni Watershed, Blue Nile Basin, Ethiopia. Msc. Cornell University

Calfoforo, S.nd. Rainwater Harvesting and Utilization: An Environmentally Sound Approach for Sustainable Urban Water Management: An Introductory Guide for Decision-Maker, International Rainwater Catchment Systems Association (IRCSA). Available through: <http://www.ircsa.org/> [Accessed 5 September 2016].

Critchley, W. and Siegert, K., 1991. A manual for the design and construction of water harvesting schemes for plant production, with contributions from: Chapman, C. and Finkel, M., FAO, Rome.

Dereje, M., 2013. Performance Evaluation of Rainwater Harvesting Ponds in Yilmana Densa Woreda, West Gojam Zone. Msc.Haramaya University.

Disaster Prevention and Preparedness Agency, 2006.Food Supply Prospect. Addis Ababa:DPPA. Available through: <Website: www.dppc.gov.et> [Accessed 17 September 2016].

FAO ,1990. Guidelines for soil description. 3rd edition. FAO, Rome. 70 pp.

Gassman, P. W., Reyes, M. R., Green, C. H., Arnold J. G. 2007. The Soil and Water Assessment Tool: Historical Development, Applications, and Future Research Directions. Vol. 50(4): 1211-1250.

Girma, M.K., 2009. Identification of potential rain water harvesting areas in the Central Rift Valley of Ethiopia using a GIS based approach. Msc. Wageningen University.

Hatibu, N. and Mahoo, H., 1999. Rainwater harvesting technologies for agricultural production: A case for Dodoma, Tanzaniain Sokoine University of Agriculture

Department of Agricultural Engineering and Land

Hatibu, N. and Mahoo, H. F., 2000. Rainwater harvesting for natural resources management.A planning guide for Tanzania. Nairobi: RELMA (Regional Land Management Unit)

Haurie,A. and Viguier,L.,2005. The Coupling of Climate and Economic Dynamics, 341-353.Printed in the Netherlands. Available through :<*https: // books.google.co.uk /books ?isbn=1402034253* > [Accessed 28 January 2017].

Ibrahim, A., 2012. Investigation of Rainwater Harvesting Techniques in Yatta District, Kenya.Msc.Jomo Kenyatta University of Agriculture and Technology

Isioye, O.A., Shebe, M. W.2 ,Momoh, U.O. and Bako, C. N., 2012. A Multi Criteria Decision Support System (MCDSS) for Identifying Rainwater Harvesting Sites In Zaria, Kaduna State, Nigeria: February – 2012Volume – 1, Issue – 1

Javaid,A.Ghauri,B.M.K. and Nasar-u-Minallah,M.,2016.Criteria Maps for Rainwater Harvesting in Potohar Region

Lawl, D. U., Martori, A. N. and Balogun, A. L. ,2011. Geographic Information System and Multi-criteria decision analysis in proposing new recreation park sites in university Technology Malaysia.

Mahmoud, S.H and Alazba, A. A., 2014. The potential of in situ rainwater harvesting in arid regions:developing a methodology to identify suitable areas usingGIS-based decision support system. Arab J Geosci (2015) 8:5167–5179

Mahmoud, S.H., Alazba, A. A., Adamowski, J., and El-Gindy, A. M., 2015. GIS methods for sustainable stormwater harvestingand storage using remote sensing for land cover datalocationassessment: Springer International Publishing Switzerland 2015.

Mbilinyi B.P.,Tumbo,S.D.,Mahoo,H.F.,Senkondo, E.M. and Hatibu,N.(2005).Indigenous Knowledge as Decision Support Tool in Rainwater Harvesting.

Mbilinyi, B.P., Tumbo, S.D., Mahoo, H. F., and Mkiramwinyi, F.O.,2007.GIS-Based Decision Support System for Identifying Potential Sites for Rainwater Harvesting.

Mekdaschi,R.S. and Liniger, H., 2013. Water Harvesting Guidelines to Good practice: Centre for Development and Environment (CDE) and Institute of Geography, University of Bern; Rainwater Harvesting Implementation Network (RAIN), Amsterdam; Meta Meta, Wageningen; The International Fund for Agricultural Development(IFAD), Rome

Meselech, S., 2003.Overview of the Ethiopian Rainwater Harvesting Association (ERHA): Addis Ababa, Ethiopia.

Millennium Development Goals, 2007.An Assessment of Rainwater harvesting Potential in Zanzibar. Zanzibar: MDG.

Mohammed, H., 2013. Detection of suitable sites using Geographic Information System and Remote Sensing: Water harvesting in Erbil Governorate, Kurdistan region, Iraq. Msc. Lund University, Sweden.

Neitsch, S.L., Arnold, J.G., Kiniry, J.R., Williams, J.R., 2009. Soil and Water Assessment Tool Theoretical Document Version 2009: Agriculture Research Service Black land Research Center – Texas Agri life Research.

Ngigi, S.N., 2003. What is the limit of up-scaling rainwater harvesting in a river basin: Physics and Chemistry of the Earth 28 (2003) 943–956, Nairobi, Kenya.2016.

Oduor, A., 2005. Potential for Rainwater Harvesting in Africa: A GIS Overview Volume I.

Oduor, A. and Gadain, H., 2007. Potential of Rainwater Harvesting in Somalia: *A Planning, Design, Implementation and Monitoring Framework.* Technical Report NoW-09, 2007, FAO-SWALIM, Nairobi, Kenya

Ouessar, MBruggeman, A.Abdelli, F. Mohtar, R. H. Gabriels, D. and Cornelis W. M. 2009.Modelling water-harvesting systems in the arid south of Tunisia using

SWAT,Hydrol. Earth Syst. Sci., 13, 2003–2021, 2009. Available through: <www.hydrol-earth-syst-sci.net> [Accessed 12 October 2016].

Tesfaye,K., Walker, S.,2004.Matching of crop and environment for optimal water use: The case of Ethiopia Phys.& chem. Earth 29,1061-1067.

Oweis, T. and Hachum, A., 2009.Water Harvesting for Improved RainfedAgriculture in the Dry Environments:*Integrated Water and Land Management Program*. International Center for Agricultural Research in the Dry Areas (ICARDA), Aleppo, Syria.

Oyewumi, O., 2013.A Multi-Criteria Decision Analysis Framework for Sustainable Rainwater Harvesting Systems: In Ibadan, Nigeria.Ph. D. Wolverhampton University

Prinz, D., Oweis, T. and Oberle, A. (1998). Water Harvesting for Dry Land Agriculture Developing a Methodology Based on Remote Sensing and GIS.

Prinz, D. and Singh, A. K., 2000. Technological Potential for Improvements of WaterHarvestingStudy for the World Commission on Dams, Cape Town, South Africa.(Report: Dams and Development)

Rift Valley Maize and Haricot Bean Livelihood Zone, 2008.Oromiya livelihood Zone Report: RVMLZ.

Saaty , T.L. ,1980. The analytical hierarchy process, Mc Graw -Hill, New York.

Toronto and Region Conservation Authority, 2011. Performance Evaluation of Rainwater Harvesting Systems Toronto, Ontario:TRCA

Tumbo S.D., B. P. Mbilinyi, H. F. Mahoo1 and F.O. Mkilamwinyi, 2014a. Identification of Suitable Indices for Identification of Potential Sites for Rainwater Harvesting: Tanzania Journal of Agricultural Sciences (2014) Vol. 12 No. 2, 35-46

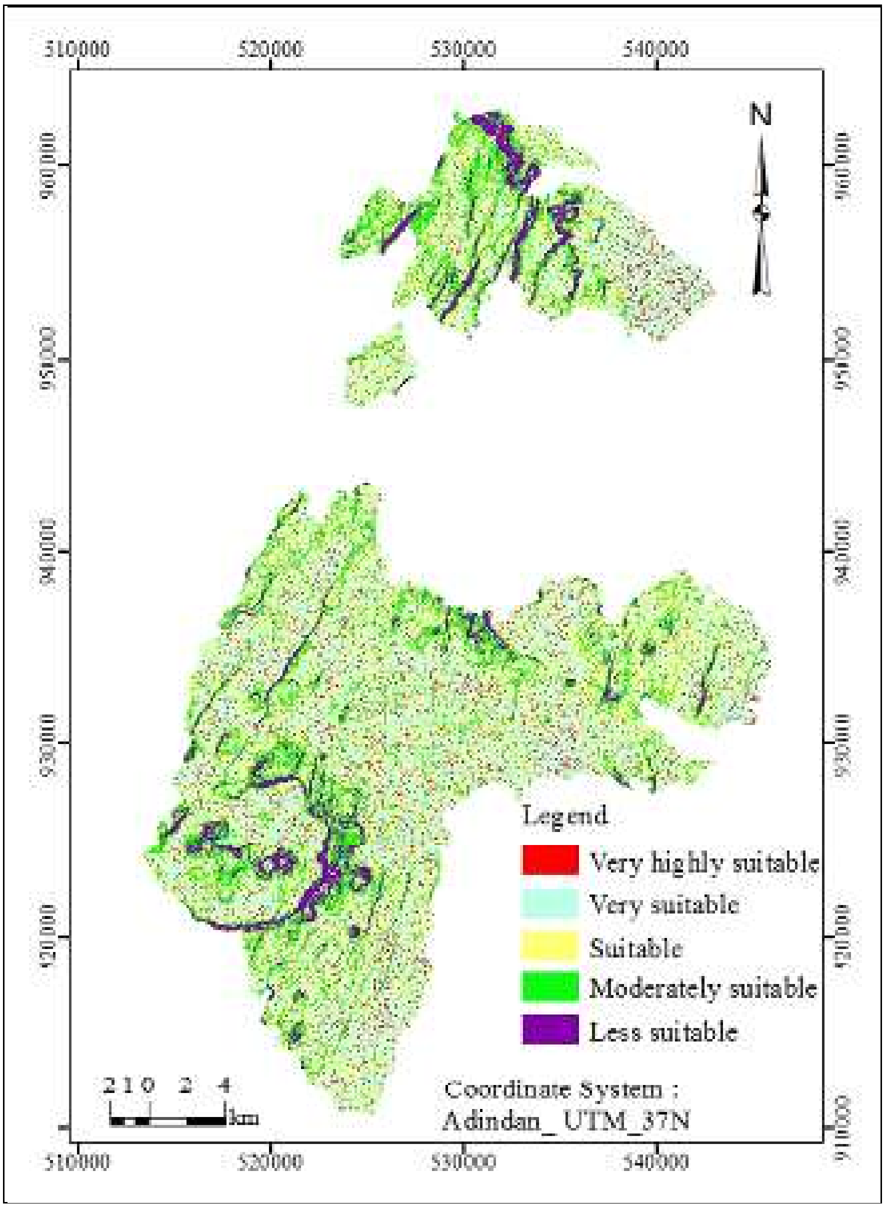
Tumbo, S.D., Mbilinyi, B.P., Mahoo, H. F.andMkiramwinyi, F.O., 2014b.Determination of Suitability Levels for Important Factors for Identification of potentialSites for Rainwater Harvesting.

UNEP/IETC (United Nations Environment Programme/International Environmental Technology Centre).1998a.Sourcebookof alternative technologies for freshwater augmentation in Africa. UNEP,Nairobi, Kenya. 182 pp.

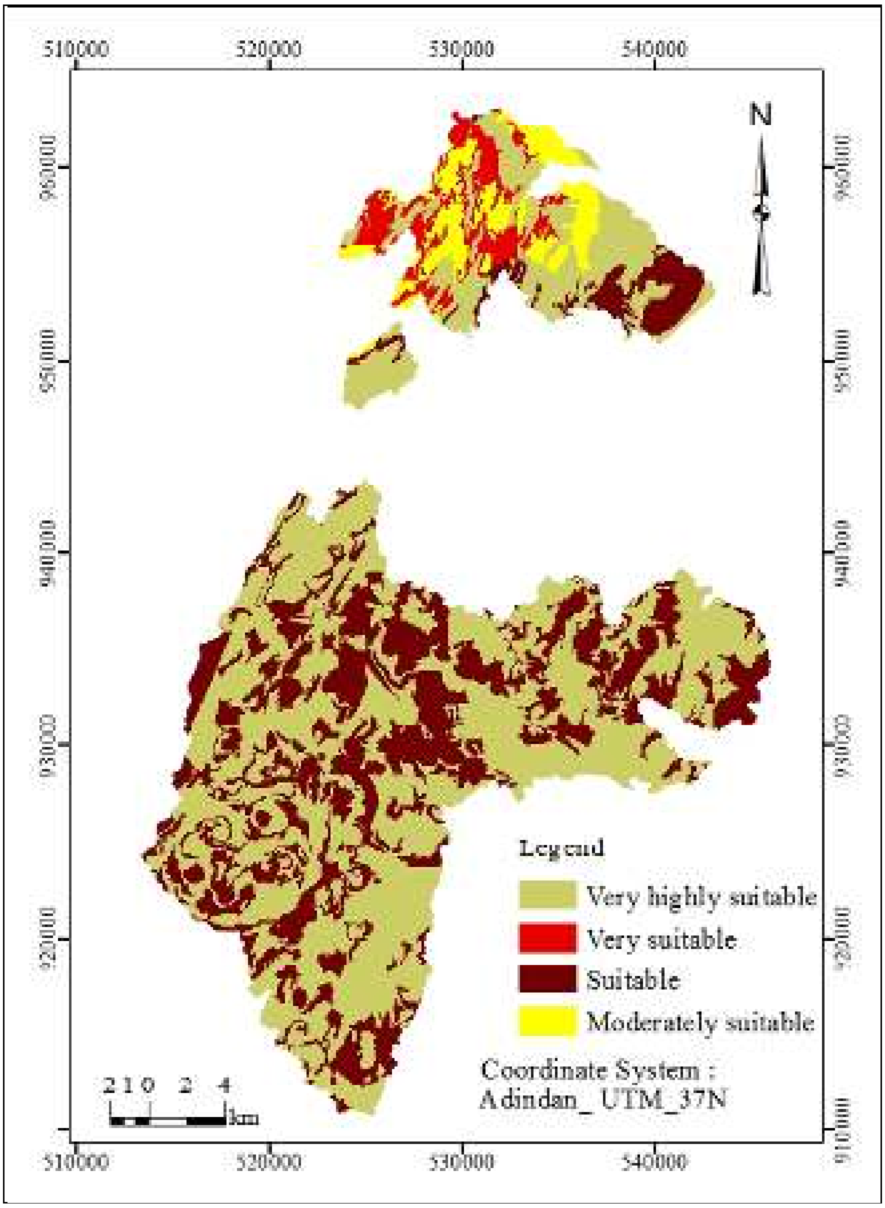
Yosef, A.B. and Asmamaw, K.D., 2015.Rainwater harvesting: An option for dry land agriculture in arid and semi-arid Ethiopia.

Yusuf, K. and Kiyoshi, S., 2006. Workshop on the Experience of Water Harvesting Technology in East Shewa and Arsi Zones: Proceedings of a Workshop, Melkassa Agricultural Research Centre.

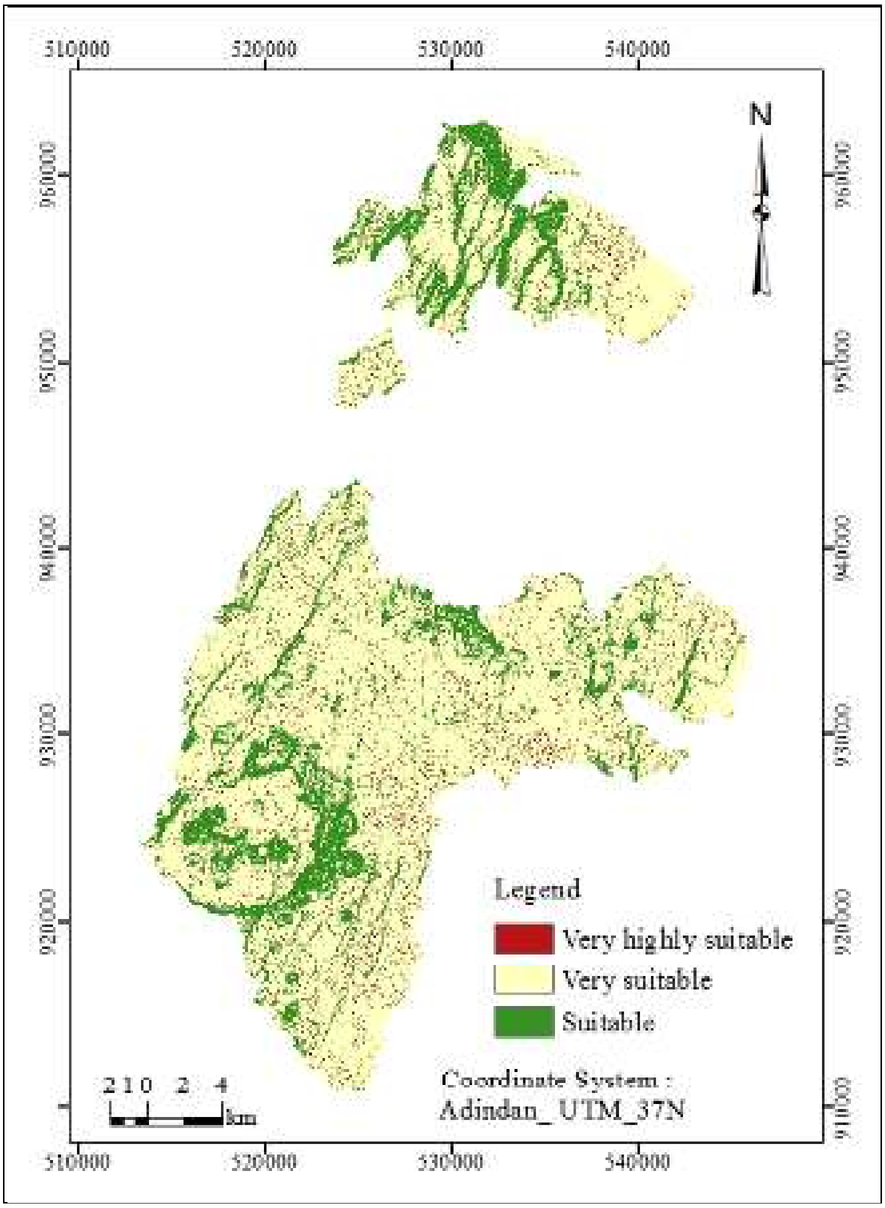
Annex-2: Reclassified slope map for in-situ RWHT in the study area



Annex-3: Reclassified Soil texture map for in-situ RWHT in study area.



Annex-5: Suitability map for in-situ RWHT in the study area.



Annex-6: Field observed data for evaluating existing pond structures in the study area.

Keble Name	Number of ponds	Silting problem	Roof cover	Material of construction	Functioning	Not Functioning	Status of ponds	Seepage problem
Adulala Hate	5	yes	2	Concrete	2	3	3ponds cracked	3
Awash Melkasa	1	yes	no roof	Concrete	-	1	cracked	1
Beqoji Dewaro	8	yes	no roof	Plastic lined	-	8	damaged	8
Bubisa kusaye	1	yes	no roof	Unlined	-	1	-	1
Chuka Hurufa	5	yes	no roof	Plastic lined	-	5	damaged	5
Ejersa Mersa	8	yes	no roof	Plastic lined	-	8	damaged	8
Geidiya Mukiye Egu	2	yes	1	Concrete	-	2	cracked	-
Merebe Mermersa	5	yes	1	Concrete	1	4	4 ponds cracked	4
Mukiye Haro	1	yes	no roof	Plastic lined	-	1	damaged	1
Qechema	2	yes	no roof	Plastic lined	-	2	damaged	2
Roge Balewold	5	yes	1	Concrete	1	4	4 ponds cracked	4
Waqemiya Tiyo	1	yes	no roof	Unlined	-	1	-	1

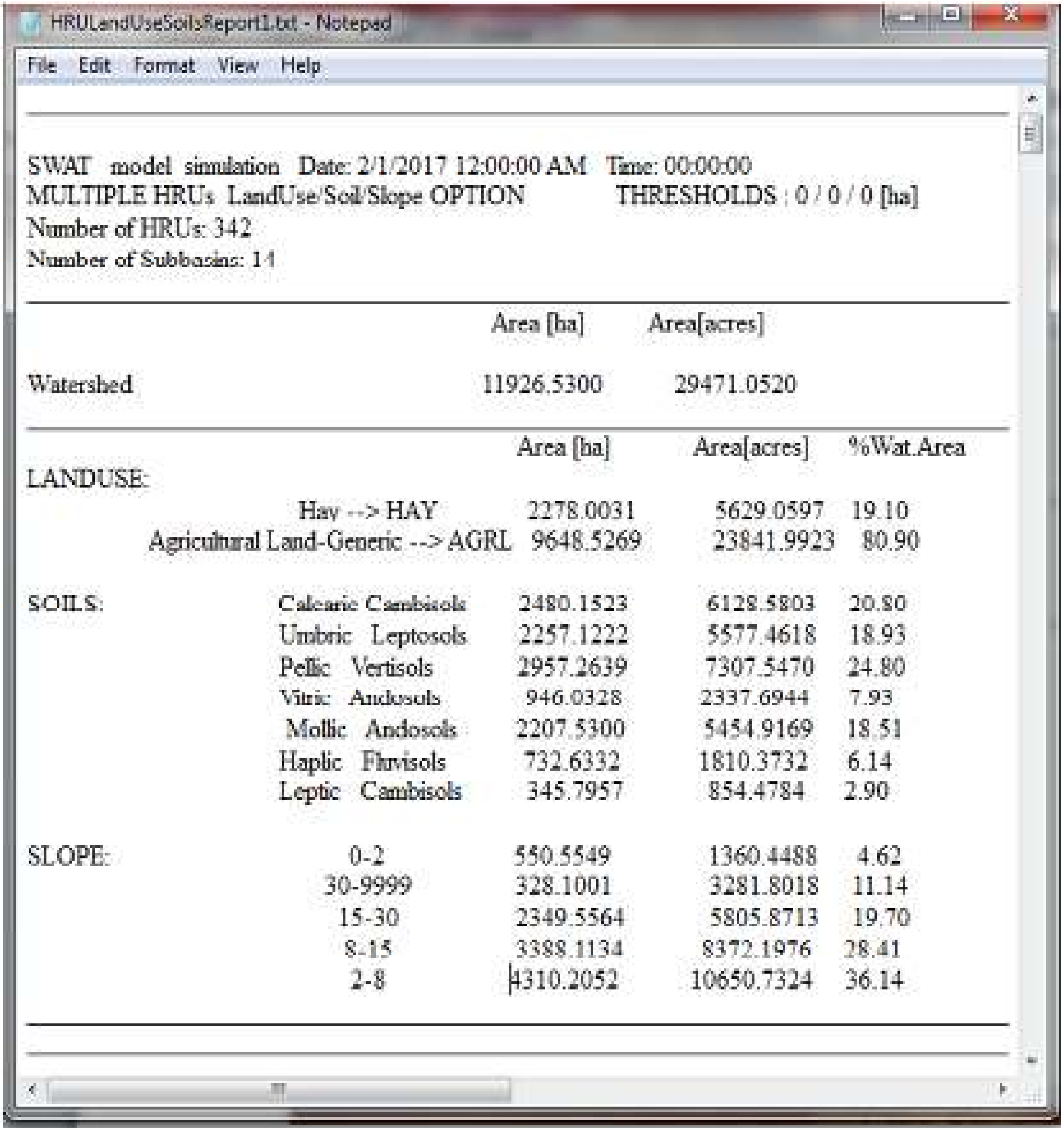
Annex-7: Sample Photos of existing ponds in the study area

Annex-12: SWAT Land use classes and codes

No	Study land use	SWAT Land use	SWAT Land use Code
1	Cultivated land	Agricultural Land-Generic	AGRL
2	Bush	Hay	HAY
3	Sugarcane Plantation	Sugarcane	SUGAR
4	Settlement	Residential-Medium Density	URMD

Annex-13: HRU Reports of SWAT model simulation for watersheds of the study area

Annex-13.1: HRU Report for Northern watershed of the study area


HRULandUseSoilsReport1.txt - Notepad

File Edit Format View Help

SWAT model simulation Date: 2/1/2017 12:00:00 AM Time: 00:00:00
MULTIPLE HRUs LandUse/Soil/Slope OPTION THRESHOLDS : 0 / 0 / 0 [ha]
Number of HRUs: 342
Number of Subbasins: 14

	Area [ha]	Area[acres]
Watershed	11926.5300	29471.0520

		Area [ha]	Area[acres]	%Wat.Area
LANDUSE:				
	Hay --> HAY	2278.0031	5629.0597	19.10
	Agricultural Land-Generic --> AGRL	9648.5269	23841.9923	80.90
SOILS:	Calcaric Cambisols	2480.1523	6128.5803	20.80
	Umbric Leptosols	2257.1222	5577.4618	18.93
	Pellic Vertisols	2957.2639	7307.5470	24.80
	Vitric Andosols	946.0328	2337.6944	7.93
	Mollic Andosols	2207.5300	5454.9169	18.51
	Haplic Fluvisols	732.6332	1810.3732	6.14
	Leptic Cambisols	345.7957	854.4784	2.90
SLOPE:	0-2	550.5549	1360.4488	4.62
	30-9999	328.1001	3281.8018	11.14
	15-30	2349.5564	5805.8713	19.70
	8-15	3388.1134	8372.1976	28.41
	2-8	4310.2052	10650.7324	36.14

Annex-13.2: HRU Report for North-west watershed of the study area

hru2.txt - Notepad

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SWAT model simulation Date: 2/2/2017 12.00.00 AM Time: 00.00.00
MULTIPLE HRUs LandUse/Soil/Slope OPTION THRESHOLDS : 0 / 0 / 0 [ha]
Number of HRUs: 28
Number of Subbasins: 1

	Area [ha]	Area[acres]
Watershed	1049.4000	2593.1199

		Area [ha]	Area[acres]	%Wat.Area
LANDUSE:				
	Hay --> HAY	347.9400	859.7771	33.16
	Agricultural Land-Generic --> AGRL	701.4600	1733.3427	66.84
SOILS:				
	Leptic Cambisols	117.8100	291.1144	11.23
	Mollic Andosols	886.5900	2190.8082	84.49
	Pellic Vertisols	45.0000	111.1973	4.29
SLOPE:				
	8-15	355.1400	877.5687	33.84
	2-8	520.5600	1286.3298	49.61
	0-2	58.4100	144.3340	5.57
	15-30	100.6200	248.6371	9.59
	30-9999	14.6700	36.2503	1.40

Annex-13.3:HRU Report for Southern watershed of the study area

HRULandUseSoilsReport3.txt - Notepad

File Edit Format View Help

SWAT model simulation Date: 2/2/2017 12:00:00 AM Time: 00:00:00
MULTIPLE HRUs LandUse/Soil/Slope OPTION THRESHOLDS : 0 / 0 / 0 [ha]
Number of HRUs: 1122
Number of Subbasins: 43

	Area [ha]	Area[acres]
Watershed	47412.0000	117157.4226

		Area [ha]	Area[acres]	%Wat.Area
LANDUSE:				
	Agricultural Land-Generic --> AGRL	36539.1480	90290.0617	77.07
	Hay --> HAY	1369.3900	3383.8311	2.89
	Residential-Medium Density --> URMD	889.4644	2197.9111	1.88
	Sugarcane --> SUGC	8613.9976	21285.6187	18.17
SOILS:	Leptic Cambisols	5734.0842	14169.2089	12.09
	Mollic Andosols	21489.0896	53100.6148	45.32
	Umbric Leptosols	3402.8630	8408.6446	7.18
	Vitric Andosols	8339.2915	20606.8063	17.59
	Haplic Fluvisols	8443.3414	20863.9187	17.81
	Chromic Cambisols	3.3303	8.2294	0.01
SLOPE:	2-8	21904.7490	54127.7301	46.20
	30-9999	2456.5132	6070.1668	5.18
	8-15	13885.7079	34312.2786	29.29
	15-30	6358.0235	15710.9939	13.41
	0-2	2807.0064	6936.2532	5.92

Annex-14: Annual potential evapotranspiration of SWAT output from year 2006 to 2015 for watersheds

Year	Annual potential evapotranspiration (mm)		
	Northern Watershed	Northwest Watershed	Southern Watershed
2006	13752.81	13793.31	13651.92
2007	13488.52	13528.66	13388.81
2008	13748.58	13790.00	13645.26
2009	14623.76	14665.80	14518.71
2010	13601.25	13641.74	13500.46
2011	13795.87	13836.19	13695.80
2012	13640.87	13680.42	13543.04
2013	13404.51	13443.21	13308.52
2014	14285.95	14327.06	14183.41
2015	14721.72	14762.87	14619.72

Annex-15: Annual runoff of SWAT output from year 2006 to 2015 for watersheds

Year	Annual runoff (mm)		
	Northern Watershed	Northwest Watershed	Southern Watershed
2006	39.11	28.84	54.16
2007	103.88	78.32	132.03
2008	101.05	75.76	131.86
2009	18.19	12.23	24.27
2010	57.42	45.01	81.6
2011	24.33	18.84	40.18
2012	159.25	124.91	197.69
2013	86.9	68.58	113.49
2014	17.66	10.54	26.03
2015	6.58	3.98	10.72

Annex-16: Average annual Sediment loading from 2006 to 2015 for watersheds of the study area

Annex-16.1: Average annual Sediment loading from 2006 to 2015 for Northern watershed

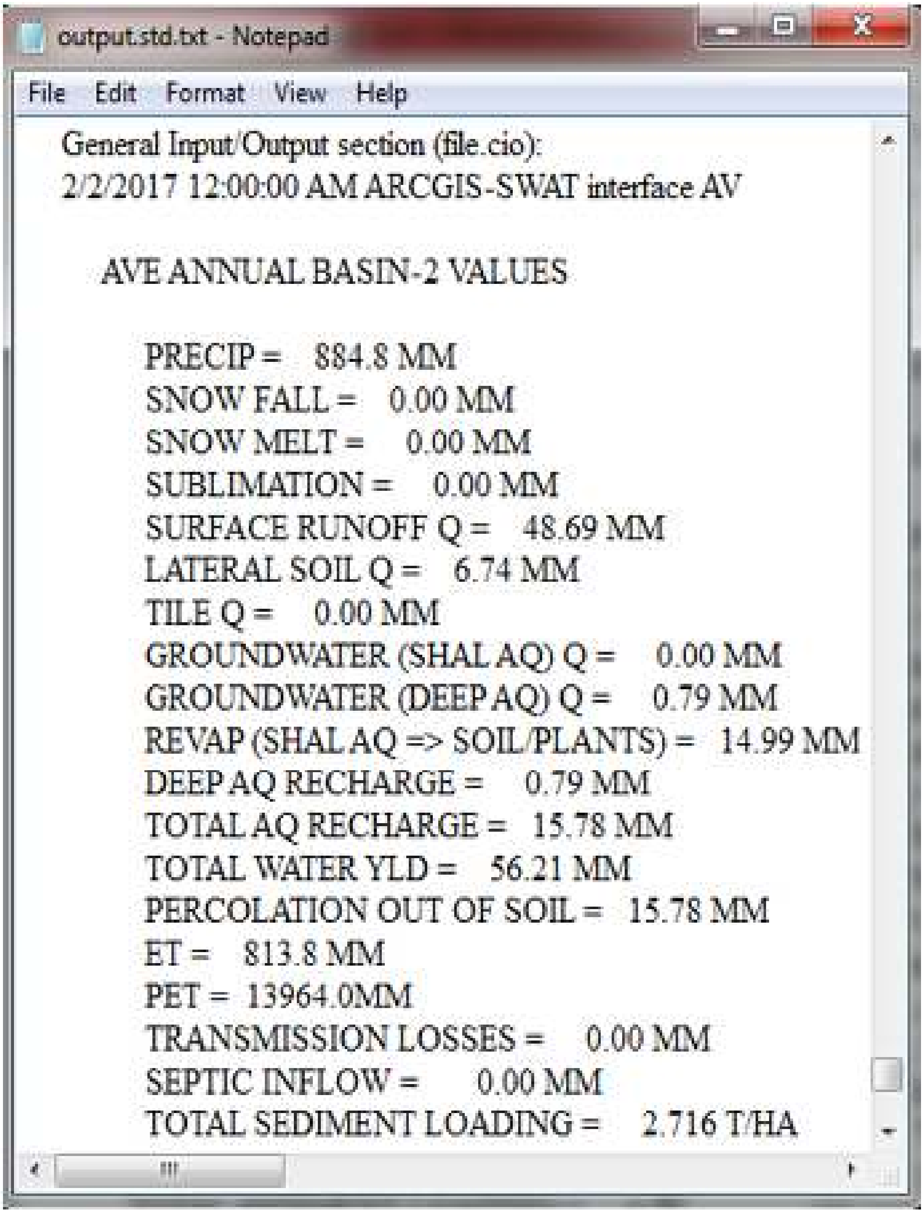
```
output.std_1.txt - Notepad
File  Edit  Format  View  Help
SWAT Jun 11 2014    VER 2012/Rev 627

General Input/Output section (file.cio):
2/1/2017 12.00.00 AM ARCGIS-SWAT interface AV

   AVE ANNUAL BASIN-1 VALUES

      PRECIP =    884.8 MM
      SNOW FALL =    0.00 MM
      SNOW MELT =     0.00 MM
      SUBLIMATION =     0.00 MM
      SURFACE RUNOFF Q =    63.92 MM
      LATERAL SOIL Q =   23.04 MM
      TILE Q =     0.00 MM
      GROUNDWATER (SHAL AQ) Q =     0.00 MM
      GROUNDWATER (DEEP AQ) Q =     0.51 MM
      REVAP (SHAL AQ => SOIL/PLANTS) =    9.69 MM
      DEEP AQ RECHARGE =     0.51 MM
      TOTAL AQ RECHARGE =   10.20 MM
      TOTAL WATER YLD =    87.47 MM
      PERCOLATION OUT OF SOIL =   10.20 MM
      ET =    787.9 MM
      PET =  13923.4MM
      TRANSMISSION LOSSES =     0.00 MM
      SEPTIC INFLOW =      0.00 MM
      TOTAL SEDIMENT LOADING =     4.389 T/HA
```

Annex-16.2: Average annual Sediment loading from 2006 to 2015 for North-west watershed



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General Input/Output section (file.cio):
2/2/2017 12:00:00 AM ARCGIS-SWAT interface AV

   AVE ANNUAL BASIN-2 VALUES

      PRECIP =    884.8 MM
      SNOW FALL =    0.00 MM
      SNOW MELT =    0.00 MM
      SUBLIMATION =    0.00 MM
      SURFACE RUNOFF Q =    48.69 MM
      LATERAL SOIL Q =    6.74 MM
      TILE Q =    0.00 MM
      GROUNDWATER (SHAL AQ) Q =    0.00 MM
      GROUNDWATER (DEEP AQ) Q =    0.79 MM
      REVAP (SHAL AQ => SOIL/PLANTS) =   14.99 MM
      DEEP AQ RECHARGE =    0.79 MM
      TOTAL AQ RECHARGE =   15.78 MM
      TOTAL WATER YLD =    56.21 MM
      PERCOLATION OUT OF SOIL =   15.78 MM
      ET =    813.8 MM
      PET =  13964.0MM
      TRANSMISSION LOSSES =    0.00 MM
      SEPTIC INFLOW =    0.00 MM
      TOTAL SEDIMENT LOADING =    2.716 T/HA
```

Annex-16.3: Average annual Sediment loading from 2006 to 2015 for Southern watershed

output.std.txt - Notepad

File Edit Format View Help

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SWAT Jun 11 2014    VER 2012/Rev 627

General Input/Output section (file.cio):
2/2/2017 12:00:00 AM ARCGIS-SWAT interface AV

   AVE ANNUAL BASIN-3 VALUES

      PRECIP =    884.8 MM
      SNOW FALL =    0.00 MM
      SNOW MELT =    0.00 MM
      SUBLIMATION =    0.00 MM
      SURFACE RUNOFF Q =    84.21 MM
      LATERAL SOIL Q =   11.25 MM
      TILE Q =    0.00 MM
      GROUNDWATER (SHAL AQ) Q =    0.00 MM
      GROUNDWATER (DEEP AQ) Q =    1.02 MM
      REVAP (SHAL AQ => SOIL/PLANTS) =   19.30 MM
      DEEP AQ RECHARGE =    1.02 MM
      TOTAL AQ RECHARGE =   20.31 MM
      TOTAL WATER YLD =    96.48 MM
      PERCOLATION OUT OF SOIL =   20.30 MM
      ET =    769.5 MM
      PET =  13822.6MM
      TRANSMISSION LOSSES =    0.00 MM
      SEPTIC INFLOW =     0.00 MM
      TOTAL SEDIMENT LOADING =     4.938 T/HA
```