



ADDIS ABABA UNIVERSITY

**COLLEGE OF NATURAL AND COMPUTATIONAL
SCIENCES SCHOOL OF EARTH SCIENCES**

**MODELING APPROACH FOR IDENTIFICATION OF POTENTIAL
RAINWATER HARVESTING SITES IN ARSI ZONE, EASTERN ETHIOPIA**

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GSR/0472/08

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A Thesis submitted to

**School of graduate studies of Addis Ababa University in partial
Fulfillment of the requirements for the Degree of Masters of Science in
Remote Sensing and Geo-informatics**

Addis Ababa, Ethiopia

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This is to certify that thesis prepared by **GETACHEW HAILE WONDIMU**, entitled: “*Modeling Approach for Identification of Potential Rainwater Harvesting Sites in Arsi Zone, Eastern Ethiopia*” and submitted in partial fulfillment of the requirements for the degree of Masters of Science in Remote sensing and Geo-informatics complies with the regulations of the University and meets the accepted standards with respect to the originality and quality.

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Acronyms

AHP	Analytical Hierarchical Process
ARC	Antecedent Runoff Condition
CN	Curve Number
CSA	Central Statistics Agency
DEM	Digital Elevation Model
DSS	Decision Support System
ERHA	The Ethiopian Rainwater Harvesting Association
FAHP	Fuzzy Analytical Hierarchical Process
FCR	Fuzzy Consistency Ratio
FAO	Food and Agriculture Organization
FEA	Fuzzy Extent Analysis
GIS	Geographical Information Science
GPS	Global Positioning System
HSG	Hydrological Soil Groups
IDW	Inverse Distance Weight
LU/LC	Land-use/land-cover
MCDA	Multiple Criteria Decision Analysis
MoA	Ministry of Agriculture
NMA	National Metrological Agency
NRCS	Natural Resources Conservation Service
OLI	Operational Land Imager
RWH	Rain Water Harvesting
RS	Remote Sensing
SCS-CN	Soil Conservation Service Model
SRTM	Shuttle Radar Topography Mission
TFN	Triangular Fuzzy Number
WLC	Weighted Linear Combination

Abstract

Modeling Approach for Identification of Potential Rainwater Harvesting Sites in Arsi Zone, Eastern Ethiopia.

Getachew Haile, Msc. Thesis

Addis Ababa University, May 2017

Water plays a crucial role in fulfilling basic human needs, for socio-economic developments and for ecosystem services. Absence of this vital resource for extended periods, make severe drought in the affected areas. Ethiopia is currently experiencing growing pressure on water resources caused by increasing water demand mostly for agricultural and domestic uses. This has been brought due to the effects of climate change and country development in agro-industrialization sector. This study was conducted in Arsi Zone, which is located in eastern Ethiopia. Arsi Zone frequently faces drought, crop failure and lack of permanent sources of water. Rain Water Harvesting (RWH) has been considered as the most encouraging among others with endeavors, to provide water to meet the increasing necessity. The objective of this study is to develop a model for the identification of potential RWH sites in Arsi Zone, Eastern Ethiopia, integrating Multi Criteria Decision Analysis (MCDA), which uses Analytical Hierarchy Processes (AHP) with a Fuzzy logic approach and Geographical Information System (GIS). Eleven physical characteristics of the study area layers were adopted for the analysis. The soil conservation service (SCS) model was used to estimate the runoff depth layer of the study area. Weighting was made based on environmental, socio-economical and hydro-geological characteristics of the study area, and reviewed literature. Fuzzification and Weighted Linear Combination (WLC) aggregation was made in order to get the result. In addition to aggregation, the analysis used Boolean Intersection of MCDA methodology to identify and exclude restricted environmental and geological constraints. The result of this research shows that, each potential suitability class coverage was: not suitable 5769.8 km² (27.88%), less suitable 3104.34 km² (15%), suitable 5695.42 km² (27.52%), very suitable 4097 km² (19.8%) and extremely suitable 2027.38 km² (9.8%). The area coverage of constraints were 4,540.37 km² (21.94%) of study area. The outcome of this study emphasized the importance of geospatial modeling in assessing RWH potential sites, proposed to assist in planning water facility and to address the water scarcity problem in Arsi Zone. In addition, the model developed in this research can be used in other areas to determine the potential of RWH and integrate rainwater as an alternative water source to ensure sustainable development. Detail ground validation and survey; using high-resolution data in modeling and study on environmental impact assessment before implementation are among the recommendations.

Keywords: Arsi Zone, RWH, Fuzzy logic, MCDA, Boolean Intersection, AHP, FAHP, WLC

CHAPTER ONE

1. INTRODUCTION

1.1 Background of the Study

Water is one of the vital resources required by every living organism, yet a large percentage of the earth's people do not have access to an adequate and constant supply of water. In the developing world, many rural communities are located in water scarce areas, where there is uneven distribution of hydrological resources and economic and/or political barriers to pipe and distribute water from the ground or surface (UN, 2014). People living in developing and under developed countries live with unsanitary conditions where their everyday survival is the main concern. They are exposed to drought, famine and death as a result of water-borne diseases come from unclean water sources and food shortage as a result of inability of land to grow crops. The problem of accessing fresh water will be more costly and difficult and it has become more wide even in developed countries (Rosegrant *et al.*, 2002). Climate change and a developing water resource interest for agricultural and urban development are increasing the pressure on water resources and variability of the hydrological regime. By the year 2020 between 75 and 250 million people will be exposed to highly increased water stress in Africa, in some regions of the continent, 50% of yield and agricultural production will become more severely compromised as a result of food shortage (Ammar *et al.*, 2016).

Natural disaster, climate change and dramatic increase of human population, effect on food security, human and animal health, water resource and all over on ecosystems. The UN (2014) report states water is an essential medium through which climate change influences the earth's ecosystem. Such stressors can bring an impact on the hydrological balance, disrupting historical patterns and causing phenomena such as heavy precipitation events and droughts (Bates *et al.*, 2008). According to the World Health Organization (WHO) semi-arid and rural areas are more vulnerable and exposed to the difficulties of accessing water supply (WHO, 2012). Worldwide comprehensive studies indicate that an average of 96% of the urban population is able to access water supply, but only 81% of the rural population has it (WHO, 2012). A consistent water supply is crucial for rural populations to be productive, particularly to rely on economic services (water supply, agriculture, fisheries, forest, and livestock management) for their economic development (Barron, 2009). Populations in semi-arid and arid rural areas are more prone to

water scarcity as compared to urban areas, as a result of little rainfall input and technological barriers. Thus, there is a requirement for alternative water supply in order to facilitate development without compromising human health. From those water supply alternatives rainwater harvesting is crucial for a country like Ethiopia, which has high rainfall intensity, on the other hand water shortage and drought affecting millions of people every year.

Food insecurity is widespread in Ethiopia. Severe food shortages and high levels of famine continue to affect a large number of people in different parts of the country. On the other hand, Ethiopia is known as the water rich country in eastern Africa, having big rivers and basins. The country is currently economically unable to potentially utilize its large rivers for different wellbeing of the community integrates with national, regional and local interests at required level. Ethiopia constitutes diversified agro-ecological zones which enable the country to produce many types of agricultural products of both crops and livestock's. The annual average rainfall of Ethiopia ranges between 400 and 1300 mm, and rainfed agriculture is predominantly practiced agricultural system in the country. Even though, 3.5 million hectare of land is suitable for potential irrigated agriculture practice, in terms of the water resources for water supply and agricultural purposes, only 0.2 million hectare of land is currently under irrigation. In this case, only about 25 percent of the people have access to clean water of some kind. The present water requirement of the land to produce a one season crop will require around 3 % of the total runoff (Getachew, 1999; Fitsum *et al.*, 2014). The most source of water resource available is rainfall as a local source, and that is why rainwater harvesting is extremely necessary.

Rainwater harvesting (RWH) has been distinguished and practiced in many areas as an economically practical solution for reducing water shortage, and to maximize water quality. In addition, it is seen as measure to address climate change effects on precipitation variability (Ndiritu *et al.*, 2011). To overcome the problem of water shortage, it is believed that rainwater harvesting is one of the best options.

Rainwater harvesting refers to the collection, storage and use of rainwater for household or agricultural purposes. The term water harvesting refers to collection and storage of natural precipitation and also other activities aimed at harvesting surface and groundwater, prevention of losses through evaporation and seepage and all other hydrological studies and engineering

interventions (IFAD, 2013). Rainwater harvesting has been an alternative for rural populations, especially where a permanent water supply system is not viable (Barron, 2009). There are numerous RWH studies that demonstrate the effectiveness to reduce users' vulnerabilities to water supply shortage and improve their day to day life (Mutekwa and Kusangaya, 2006; Barron, 2009). Run-off irrigation, flood spreading, in-situ water harvesting and roof water harvesting are common RWH techniques mostly practiced in Ethiopia.

Geographical Information System (GIS) and Remote Sensing (RS) are playing significant role in hydrological modeling in view of its capacity to handle enormous amount of spatial and attribute data. Some of its features, such as map overlay and analysis help to derive and aggregate hydrologic parameters from different sources like soil, land-cover and rainfall data (Ramakrishnan *et al.*, 2009). In this recent years, integrated studies of RS, GIS and run-off modeling has gained significance in targeting suitable sites for water recharging/harvesting structures (Ramakrishnan *et al.*, 2009). This research mainly aims at identification and prioritizing the area suitable for water harvesting by taking into consideration factors such as hydrological, physiography, environmental and socio-economic conditions. Analysts and decision-makers work at different scales of interest to deal with different types of environmental problems seeking solutions putting into their considerations the complexity of natural and human impacts that cause these problems. Remote sensing data have been attractive sources in the determination of land-cover thematic mapping, providing valuable information for delineating the extent of land-cover classes, as well as driving and analyzing hydrological data at various scales. Today application of RS and geoinformatics for environmental assessment, natural resource conservation and geo-spatial data handling and their potential to prepare valid spatial models are in high demand. The Weighted Linear Combination (WLC) and the Boolean technique are the two major techniques used in GIS environment to select potential sites for development of projects. Common technical steps the WLC follows are: preparing layers, standardizing the suitability layers, assigning weights of relative importance to the suitability layers, combining the weights and standardizing suitability layers and obtaining an overall suitability score (Baban and Wan-Yusof, 2003; Malczewski, 2004; Ayalew and Yamagishi, 2005). This technique provides site selection of a project based on using either the OR (*UNION*) or the AND (*INTERSECTION*) operations (Tabor and Hutchinson, 1994; Chenini *et al.*, 2010).

Arsi Zone has promising, sensitive and complex geological systems. Geospatial data handling and analysis techniques bring out significant attention for locating potential RWH sites selection. The goal of this thesis was to develop spatial GIS modeling using Fuzzy modeling approach and Analytical Hierarchical Process (AHP) for potential suitable sites selection for RWH and supply in the Arsi Zone Eastern Ethiopia based on integration of RS and GIS techniques.

1.2 Statement of the Problem

Altitude of the Arsi Zone ranges from 862 to 4,098 m a.s.l. and the area is characterized by erratic and poor distribution of rainfall over the year. The Zone faces frequent drought, crop failure, and lack of permanent sources of water, which brings low crops yield and sometime it completely fails due to shortage of water during the flowering or maturation stage. Hence, there is a need additional water supply for dry season drought mitigation by improving water supply options.

In the rainy season that extends from June to September in which food crops are grown in this area, the occurrence of rainfall is unreliable. Late or early occurrence, uneven distribution, interruption and insufficiency of the rainfall are common in the area. Inadequate showers that fall during the short raining season that extends from December to February can only support some grass for livestock. The Millennium Development Goals (MDGs) of the county is obliged to ensure that the inhabitants have access to clean safe drinking water and irrigation for sustainable agricultural development. There is, therefore, need for an alternative water source to ensure the country and specifically drought-prone area like Arsi Zone for sustainable development.

Arsi Zone is reputed as a surplus area but faced 2002 drought and long-run deterioration in the food security situation. Out of the 22 Woredas of Arsi Zone, 19 Woredas were affected by the prolonged drought conditions. Especially areas in the lowlands suffered greatest drought condition: It was estimated that in 2001 farmers lost 95% of their total agricultural production, especially in Merti and Gololcha woreda agricultural production decline with 80% and Seru 70% failure. In addition, water and pasture stress, low agriculture performances and overgrazing occurred mostly in the lowlands. This disaster is still affecting some potential production areas in this Zone (Piguet, 2002).

The survey of Goal Ethiopia and concern worldwide indicate that in the Arsi Zone, deteriorating food security situation was prevailed. The affected and vulnerable Woredas of Arsi Zone were Jeju, Diksis, Sude, Robe, Bilbilo, Sire and Guna. Due to poor performance of the Autumn (last September to February first) seasonal rains led to shortage of pasture and water and poor development of planted crops (UNICEF, 2014). Rainwater harvesting is one of the best alternatives to mitigate the disaster harnessing as the water source to address the water scarcity problem. For relatively small areas, a field survey carried out by experienced people will be the best technique to select the appropriate sites and to determine the suitable methods for RWH. But, for larger areas, the application of GIS and RS could be the most relevant means (Prinz *et al.*, 1998; Kumar and Jhariya, 2016). Geospatial technology provides tools that can be used to better determine the potential of RWH to ensure sustainable development.

Nevertheless, selecting sites for potential RWH is a complex process, which needs technical, physical, economic, social and environmental requirements. Such complexities demand different influential factors consideration with several decision support tools such as GIS and multi-factor analysis system.

In order to fill this research gap and solve the problem, an attempt was made in this research to determine the rainfall-runoff depth and other determinant factors integrating Fuzzy-modeling approach and analytical hierarchy process (AHP) with GIS has implemented to determine the potential sites for RWH. The fuzzy AHP modeling approach method using GIS and RS data were used in order to identify the potential RWH sites of the study area.

1.3 Objectives of the Study

1.3.1 General Objective

The general objective of this study was to demonstrate the use of geo-information technology by identifying the suitability of land units for rainwater harvesting in the study area, based on RS application, participatory GIS and fuzzy modeling approach.

1.3.2 Specific Objectives

The specific objectives of the present study was:

- To determine the effectiveness of RS and GIS with fuzzy modeling approach in identifying RWH potential sites in the Arsi Zone.
- To apply a model for estimation of potential RWH sites in the study area using GIS and fuzzy modeling approach.
- To prepare RWH potential maps for the study area
- To validate the suitability of fuzzy modeling and AHP approach for potential RWH structure sites selection in the study area.

1.4 Research Questions

The following questions have been formulated to achieve the above mentioned objectives.

- What are the factors in the hydrogeology of the study area will influence the effectiveness of RWH? In addition, what are the main determinant factors for potential RWH site selection modeling?
- How to develop a model using GIS, fuzzy and AHP integrated modeling approach, for potential RWH sites selection?
- What are the advantages of GIS integrated fuzzy model and AHP approach for potential RWH sites selection?
- How can integrating GIS, RS and hydrological modeling be used to identify potential RWH sites selection?

1.5 Significance of the study

In spite of the problems that the Arsi Zone is facing with water scarcity and flooding, required amount of analysis has not been done to quantify the runoff on impervious surfaces and other hydrogeological parameters using Geo-spatial techniques. The purpose of this study is to model the extent of potential sites for RWH in the Zone.

Detail problem analysis was done by Oromia Irrigation Development Authority (OIDA) and Irrigation Farming Improvement Project (IFI) in selected woredas of study area on existing water harvesting technologies (Noruoka and Yohannes, 2006) (see Annex VI for Problem analysis on Water Harvesting technologies), based on the identified problems this research is important by providing solutions for the following assessed problems:-

- Water infiltrate from the Pond into the ground.
- Water is not gathered by the water catchments.
- Farmers think that Ponds was located in unsuitable area.
- Mosquito, which is the carrier of Malaria, reproduce in Tank and Pond.
- Farmers think that children and livestock fall down in Tank and Pond.

Generally, this research is significant for the following reasons:

- i) In sighting major factors that affect RWH sites selection, for successive research communities, who are doing on potential RWH.
- ii) Agricultural research institutes working on natural resource conservation and management could use the model for decision making on RWH.
- iii) By providing necessary input data the model could also use for other areas, where water resource is inadequate.

1.6 Limitation of the Study

The study was done with all possible efforts in collecting required inputs for both primary and secondary data with clear and procedural analysis and technical interpretations. However, the following limitations were encountered in this study:

- Required geo-spatial information and performance about current and past RWH practice and status of the structures are not available at required level.
- Most soil data and some soil physical properties that are not included in this research are not available with a required resolution to use for this research to improve the accuracy of the result.

1.7 Scope of the Study

This study focused on the use of Geospatial Technology in modeling potential RWH site selection. The scope of the study was limited to the Arsi Zone, Ethiopia.

1.8 Organization of the Thesis

This thesis is organized into six (6) chapters as follows:

Chapter one contains the background of the study and provides a brief overview the overall study undertaken. It also provides information on the study and gives a highlight of the significance of the study as well as the goals and scope of the study. Chapter two gives a detailed description of RWH and explores the history and different methods of RWH. It also highlights previous works, which have been used in RWH modeling and describe the model used in the study. Chapter three explains the datasets available as well as the actual implementation of the models. Chapter four provides information on the results. Chapter five contain discussion on the results of the models. Chapter six gives conclusion and recommendations.

CHAPTER TWO

2 LITERATURE REVIEW

2.1 An Overview of Water Harvesting

Rainwater harvesting is broadly defined as storing, inducing and concentrating local surface rainfall runoff for the purpose of agricultural production, such as crop production, tree production, fodder, livestock and domestic water supply in arid and semi-arid regions (Oweis *et al.*, 1999; Prienz and Singh, 2000; Alamerew *et al.*, 2002). Other literatures defined RWH as rainwater collection from runoff and catchment areas such as urban structures or roofs to meet demands for domestic, industrial, agricultural and environmental purposes when water sources are becoming scarce or low quality (Worm and van Hattum, 2006; Aladenola and Adeboye, 2010). Mzirai and Tumbo (2010), define RWH as the process reusing the collected and stored rainwater from surface runoff or roof. The process of rainfall harvesting and reusing has been used for agricultural irrigation and as a source of drinking water.

Critchley and Reij (as cited in Pachpute *et al.*, 2009) define RWH in their water harvesting manual as, a technology that used for collecting and storing rainwater from surface runoff (surface or catchment) and rooftops, using different methods such as jars and pots as well as more complex techniques such as ponds and underground check dams. The technology usually found in Africa and Asia arise from practices of ancient civilizations within these regions and still serve as a major source of water for agricultural inputs and supply both in rural and urban areas. The catchment area, the collection device, and the conveyance system are commonly used principal components of the system.

Collecting and using rainwater would help to save municipal and groundwater sources. Since the rainwater collected from roofs is much better cleaner than the rainwater collected from other impermeable surfaces, in urban area, roofs are the main impervious surface in especially in residential areas to be used as catchment areas and allow harvest of water that would otherwise enter into the rainwater drainage system. This may decrease rainwater runoff and the necessity for downstream rainwater management and treatment. Rainwater is much clean as it rains, but the surface may contains pollutants, Therefore adjustment and necessary treatment and filtration

are needed before harvesting and storing rainwater. Harvested rainwater is used mainly for irrigation and domestic usage (Ling and Benham, 2014).

According to Nordin and Hamid (2011), there are six components of any RWH system:

- Catchment area
- Gutters and downspouts
- Filtration system
- Storage system
- Delivery system
- Treatment system

2.2 Rainwater Harvesting in Ancient History

Water management infrastructure is an essential component of the built environment. For thousands of years, quality of life was directly correlated to flood control because floods would destroy both food crops and livestock. So, even very ancient societies have had some technique or strategy to manage and control the flow of rainwater (Koutsoyiannis *et al.*, 2008).

According to Oweis *et al.* (2001), water harvesting is as ancient as people lived and practiced agriculture in the dry lands. An inclusive literature review made by Prinz (1996) concerning on the history of water harvesting worldwide, with emphasis on Africa, Asia, and America discussed numerous water harvesting systems and their applications in agriculture production that was practiced in the past and developed since the middle of the last century was discussed. In Africa, water harvesting was practiced since the Roman Empire in Northern Africa: as well as runoff irrigation in Libya, various traditional systems in Morocco, lacscollinaires in Algeria and Tunisia, Wadi terraces in Egypt, various traditional systems in Chad, Caag and Gawan in Somalis, Hafier in Sudan and rock bunds in Niger. Brush weirs were used in America among other traditional systems to spread floodwater in the desert lands of Southwest USA and North Mexico (Prinz, 1996; Oweis *et al.*, 2004).

In Asia, water harvesting practices were archived to exhibit since long time in the Central and eastern Asia, China, Saudi Arabia, Pakistan and India. For the Middle East, archeologists

examine about old mankind's exercises demonstrated the existence of water storage structures in Iraq, Syria, Jordan, the Negev and the Arabian Peninsula, particularly in Yemen. Those structures were dated back to 1000 years BC in North Yemen; 10th century BC in Negev with only 100 mm and 9000 years in Jordan. Those systems practiced were mainly collecting floodwater (Yemen), flood irrigation for agriculture (Saudi Arabia), runoff farming (Negev), water bunds (Pakistan), Tanks, (Khadin), and Ahar (India), and flood diversion in China (Warping) for capturing water and sediments (Prinz, 1996).

2.3 Importance of Water

According to Scheierling (as cited in Mekdaschi and Liniger, 2013) currently, of the 1.5 billion hectares of cropland worldwide, more than 80 percent depend on rainfall alone, contributing to at least two-thirds of global food production. While the coverage of rainfed agriculture varies regionally (Table 1), in developing regions including Latin America and Sub-Saharan Africa, more than 90 percent of cropland is rainfed.

Table 1: Approximate percent of world rainfed cropland.

Region	Area (%)
Latin America	90
Middle East and North Africa	75
East Asia	65
South Asia	60
Sub-Saharan Africa	95

Source: (Mekdaschi and Liniger, 2013).

2.4 Rainwater Harvesting and Climate Change

Climate change is an additional risk that puts increased pressure on the already stressed hydrological systems and water resources. The impacts of climate change are already visible given that temperature and rainfall variability have increased and intensified over the last two decades (Kahinda *et al.*, 2010 as cited in Faramarzi *et al.*, 2013). As stated by Intergovernmental Panel on Climate Change (IPCC), climate of the world is changing; rain-fed agriculture is one of the most vulnerable sectors to the climate change effect, as the available water and land

resources are limited where day-to-day livelihood of millions of the world's poorest people will be more insecure (Raneesh, 2014). Consequently, the effect of climate change has greatly been affected in other sectors including the water sector. Other than the impacts on water for irrigation, the impact also additionally felt in water for household use, where economies and livelihoods of the inhabitants has been affected, as taps remain dry while wells, boreholes and streams also dry up.

2.4.1 Ethiopian Water Resource and Challenges

Ethiopia has a generous endowment of water, but this water is distributed erratically in space and time. Unmitigated hydrological variability, compounded by climate change, has been estimated to cost the country roughly 35 percentage of its growth potential. The 2006 World Bank report shows that the best and worst case scenarios for climate change effects over the coming decades predict a reduction of gross domestic product (GDP) growth by 2% and 10% per year, respectively (Margulis *et al.*, 2010). The agricultural sector, which is the backbone of Ethiopia's economy, will likely generate 30% less income in agricultural productivity due to the problem (Gebreegziabher *et al.*, 2011). According to Mosello *et al.* (2015), Ethiopia has always been characterized by high hydrological variability, compounded by the almost total absence of water storage and highly vulnerable watershed. Climate change is expected to worsen such variability (Conway and Schipper, 2011). The stunning economic growth and population increase that the country has been experiencing for the last two decades also demand a lot of good quality water resources. Home to several international rivers, of which the Nile is the most important, Ethiopia needs to plan the development of its water resources with careful consideration of how its neighbors might react.

2.4.2 Climate Change Effect in Ethiopia

Ethiopia faced five major climate change triggered severe droughts and local dozen of drought since 1980. Repetitive droughts generate poverty traps for many households, constantly thwarting efforts to build up assets and increase income. As the survey of World Bank indicates, more than half of all households in Ethiopia faced at least one major drought disaster, resulting poverty. Agro-pastoralists and pastoral households are suffering severe property losses during droughts, as their livelihood is dependent on livestock production as shown in (Table 2).

Table 2: The impact of drought shocks in Ethiopia

	People in poverty (%)
Observed poverty	47.3
Predicted poverty with no drought shocks	33.1
Predicted poverty with no shocks of any kind	29.4

Source: (UNDP, 2008 as cited in Gebrehiwot *et al.*, 2011).

2.5 Ethiopian Agriculture

Agriculture in Ethiopia is primarily rain-fed and highly sensitive to fluctuations in rainfall, forms the basis of the economy providing approximately 46% of GDP and jobs for 80% of the working population (Demeke and Zeller, 2010). Droughts can result in enormous reductions in agricultural production development and related productive activity and employment, with multiplier effects on the monetary economy. According to Ethiopian MoA (2015) report, in the Oromia regional state August 2015 Targeted Supplementary Feeding Program requirement was dramatically increased by 67.5 percent from 16,667 in July 2015 to 27,929 in August 2015 and about 63 percent of these cases were reported from Arsi, West Hararghe, and East Hararghe Zones of the Oromia region.

Floods also regularly cause crop and infrastructure damage and widespread suffering and hardship. As the millennium development goal the country has set ambitious targets for the development of the agricultural sector, there is a strong requirement to diversify the sources of water for agricultural use, including harnessing Ethiopia's groundwater potential and increasing irrigation coverage, as recognized in the GTP. In relation to the existing El Nino phenomenon occasional fall is anticipated over some parts of the study area. As a result, flash flood and overflow of rivers are likely in some areas the aforementioned areas, thus the concerned personnel should take appropriate measures ahead of time in order to mitigate the effect of flood hazard (MoA, 2015).

2.6 Rainwater Harvesting Practice in Ethiopia and its Benefit

Ethiopia has the history of water harvesting even before 560 BC, when rainwater harvested and stored in ponds for agriculture and other water supply services (Habtamu, 1999). There are still

some recorded anthropological evidences of remains of ponds that were used for irrigation purposes before the Axumite period. A roof rainwater harvesting structure remain is still available in one of the oldest Queen Sheba Axume Palace. Another anthropological evidence show that there is still the remains of water harvesting setups and pools constructed in the 15-16th century in one of the oldest Gonder Castle that was used for religious services (Fattovich, 1990).

According Hailemichael (2011), the Konso people (lived southern part of Ethiopia) had a long and well established tradition of building rainwater harvesting structure in level terrace practiced with each farmer to produce good yield of sorghum under extreme unsuitable climatic conditions. Much works has been done during the last two decade to promote water harvesting to produce good results especially in micro watershed management of sustainable land management and drought mitigation (Yohannes and Haile, 2010). According to Awulachew and Merrey (2007), Ethiopian agriculture is mainly practiced rainfed agricultural system with approximately 3.5 million hectare of land is suitable for irrigated agriculture. Over 90% of the food supply comes from rain-fed small holder agriculture.

The primary goal of the Ethiopian government water policy is developing water resources for economic and social benefits of the people on a sustainable basis. Rainwater harvesting has been one of the prominent water security strategies from other optional strategies. Even if RWH strategy is not new in Ethiopia, it has widely preferred among development agencies, research institutes, policy makers and agents. The country has a vast potential for benefiting from rainwater for rainfed agriculture even in arid and drought-prone areas. Using multiple water harvesting technologies such as ponds, dug-wells, sand-dams, sub-surface dams, in-situ and roof catchment among others, rainwater can be harvested and stored in flash floods, surface runoff and the ephemeral rivers. Among many parameters and factors the geographical analysis is important, as these are some of the driest regions in Ethiopia, with frequent and prolonged droughts. The primary strategy of the country on RWH is to explore, enhance and optimize local rainwater harvesting technologies and to strengthen local capacities to sustainably manage the productive assets.

2.7 Methods of Rainwater Harvesting

Rainwater harvesting method can be categorized into two broad classes, namely: Surface runoff harvesting and Rooftop harvesting (Figure 1).

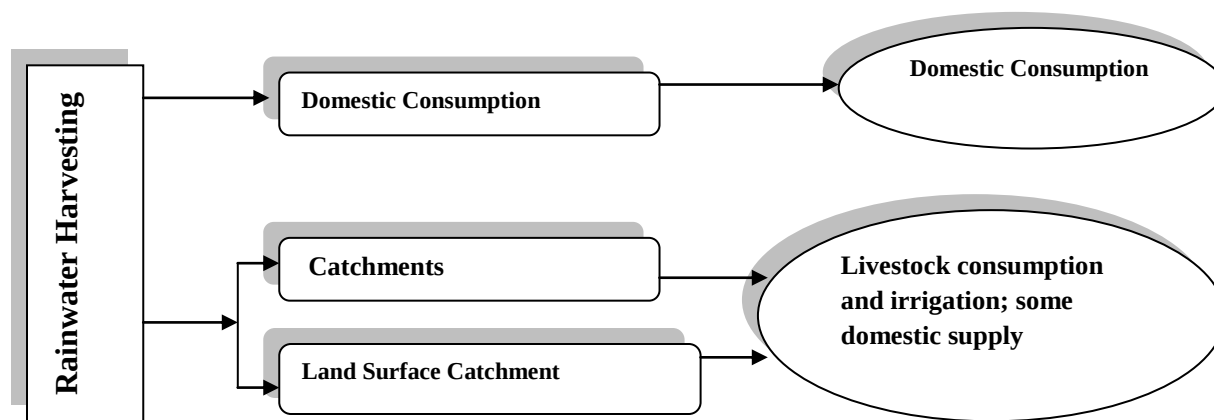


Figure 1: Rainwater harvesting systems and uses (Wafler, 2010).

Rooftop rainwater harvesting: In this method, rainwater is collected from the roof catchments and stored in reservoirs. Rain does not reach the surface of the earth and therefore, the water collected by this method is less contaminated as compared to the rainwater collected from the surface runoff (Thomas and Martinson, 2007).

Surface runoff harvesting: Here, runoff refers to rainwater that flows off a surface other than roof (Awulachew *et al.*, 2009). The surface may be a rock, pavements, fields or roads. Some surfaces are permeable while others are impermeable.

Rain that falls on the surface can be collected and used either for irrigation or domestic purposes. In some cases, depending on the quality, it has been used for flushing toilets and cleaning activities in households. It could even be used to recharge aquifers. This method is also very common in urban areas in many parts of the world, where the surfaces are less permeable and therefore the seepage is minimal (Nthuni *et al.*, 2014). The amount of water collected by this method depends on the amount of the rainfall, the permeability of the surface, the area of the surface and the slope of the surface among other factors. This research is done on this type of RWH method.

Rainwater harvesting technologies could significantly enhance the productivity of rainfed agriculture in semi-arid areas, where the rainfall is usually unsatisfactory to meet crop water

requirements throughout the crop-growing season. Rain-fed agricultural production contributes 60% of the world's food supply (Bot *et al.*, 2000). The traditional practice of cultivating conventional tillage (the land under dry land conditions) planting, involves the use of plowing and several tasks done for soil conservation. Farmers typically practice these mechanical operations with the point of increasing the soil water holding capacity through increased porosity, which boosts infiltration rates, and therefore decreases surface runoff, allowing the crop to have improved soil water availability. However, crop production yields using conventional tillage are usually very little, especially in semi-arid areas. One of the major causes for this is the fact that huge amounts of water are lost through runoff, which triggers increase of water scarcity for crop production, as well as soil nutrient deficiency. Therefore, an optimization of potential rainfall utilization through the practice of rainwater harvesting techniques in dry areas would reduce the risk of crop failure due to enhanced water availability to plants.

Rainwater harvesting technologies have the following characteristics. Firstly, it is mainly practiced in arid and semi-arid regions, where surface rainfall-runoff often has low and an irregular character. Secondly, it is based on the consumption of runoff and requires a runoff utilizing area and a runoff getting area. Finally, due to the irregular nature of runoff events, water storage is an integral part of the system and it can be done directly in the soil profile or in small reservoirs, tanks and aquifers (Oweis *et al.*, 1999).

According to Kahinda *et al.* (2008), six significant factors to be considered when identifying RWH sites selection are: rainfall-runoff, slope, agronomical activity, soils property especially texture, structure and depth and socioeconomic criteria. A study conducted by Durga rao and Bhaumik (2003) identified drainage density, runoff potential, land-use, soil, slope, proximity and geology, as criteria to identify suitable sites for RWH. In addition to that, physical properties like land-use, soil texture and soil depth, ecological factors mainly ecological importance and sensitivity category and socio-economic factors are important.

2.8 Major Problems found on Rainwater Harvesting Technology

Even though, Arsi Zone has received some support for RWH from international NGOs mostly with Medical Emergency Relief International (MERLIN) and World Vision (WV) and some indigenous organizations such as Oromo Self Help Organization (OSHO), Community

Development Association (CDA) and Oromia Irrigation Development Authority (OIDA), but targeted goal was not achieved.

Assessments held by Oromia Irrigation Development Authority (OIDA) and Irrigation Farming Improvement Project on sampled woredas (Sire and Merti) of Arsi Zone, Major problem found on implementation of Rainwater harvesting technologies were: 1) Water harvesting structure facilities were not working properly. 2) Farmers motivation to utilize and accept water harvesting declined (Noruoka and Yohannes, 2006).

2.9 Application of Remote Sensing and GIS in Rainwater Harvesting

Water harvesting is an ancient long aged practice and it has been used for long period of time in most water-stressed area of the world, and many different methodologies have been developed. Nevertheless, sometimes the same methodology has different terms in different parts of the world and others have similar terms but practically they are completely different methodologies (Oweis, 2004). Remote Sensing and GIS can help in the identification areas of potential water harvesting site selection (Prinz *et al.*, 1998). For the purpose of RWH sites selection decision making analytical process and GIS is suggested as a problem-solving tool. Numerous technical approaches have been implemented to identify potential RWH sites in remote area and in an area where sufficient data is not available. In most of these techniques, thematic layer data are derived from RS imageries and integrated in GIS environment to identify potential sites for RWH (Munyao, 2010).

In another study conducted in Tanzania RS was used for field survey for the identification of potential RWH production area. The factor layers used in this model was slope, soil texture, rainfall, drainage density, LU/LC and soil depth. The output of this model was potential sites for different water harvesting structures such as bench terraces, stone borders and terraces. This model was developed using Model Builder in the Arc View platform for the Decision Support System (DSS). Testing and validation done from the results of two sites were the DSS indicates suitable areas for RHW (Mbilinyi *et al.*, 2007). Munyao (2010) used GIS and RS with selected primary layers of data sets for input factor, which are runoff coefficient, soil type, slope, LU/LC, rainfall and the socio-economic data. Using ILWIS and ArcGIS software to derive all the fundamental spatial layers that were used for different analysis and weighted overlay. Finally,

weighted overlay was done to produce map of potential RWH sites (Munyao *et al.*, 2010). These studies shows that, GIS and RS is a crucial science for the identification of RWH site. Since RWH is a geographical or spatial requirement and can be done by manipulating GIS and RS as a decision support tool based on site selection and criteria and as an alternative form of data capture for analysis. Hence, the main objective of this research was the Modeling identification of potential rainwater harvesting sites and techniques suitable for each site for Agricultural development using GIS and RS.

2.10 Fuzzy and Boolean Logic Modeling System

Boolean Logic Theory

Boolean logic has been mostly used on attribute that can only be one of two distinct possibilities and the boundaries between these possibilities or classes clearly defined. Boolean logic mostly applied and it is preferable when parameter maps have classified into Boolean suitability (1) or Boolean unsuitable (0). Boolean algebra has three basic operators: Intersection (the logical term AND), Union (the logical term OR) and Inverse (the logical term NOT). These Boolean operators use integers or terms such as (True and False) as input raster on a cell-by-cell basis. Output values of True are (1) and those of False are (0). This logic represents a real world reality in completely discrete ways, but in a reality few elements are completely discrete and others continuous. All the above-mentioned Boolean operators are integrated in ArcGIS software.

Fuzzy Logic Theory

Fuzzy logic was originally proposed by Zadeh in 1965, he defined as “a class of objects with continuum of grades of memberships”. The fuzzy logic theory was presented as alternative approach to deal with uncertain and imprecise data. It's preferable for conditions where zones of gradual transition are used to divide classes instead of the conventional crisp boundaries (Zimmermann, 2010). The membership function values assigned to each object are ranging between 0 and 1, the higher the value of membership the closest class value to 1. Some advantages of fuzzy logics that make preferable than other logics are: Fuzzy logic is manipulated based on natural language built on the structures of qualitative description used in everyday language, Fuzzy logic permits decision making with estimated values under incomplete or uncertain information, it is logic is flexible. With any given system, it is easy to use more

functions without starting again from scratch. Since each stage of the system is processed individually and it can model nonlinear functions of arbitrary complexity and can be generated to match any set of input-output data.

2.10.1.1 Fuzzy Sets

Fuzzy logic starts with the concept of a fuzzy set. A fuzzy set characterizes classes without a crisp, clearly defined boundary in which the transition from one set to another is gradual rather than abrupt. It can contain elements with a partial degree of membership that range in value between 0 and 1. In contrast to Boolean sets theory, the membership of sets is defined as 1 or 0. However, membership of a fuzzy set are defined by the membership functions (MFs) in which represent a continuous increase from non-membership 0 to complete membership 1 (Zadeh, 2008). A fuzzy set is characterized by its membership function, allocating a membership grade to any element of the referential domain, and the unit interval is usually taken as the range of these membership grades. As the Boolean and fuzzy set represented in Figure (2), while with Boolean logic the boundary between sets is sharply defined (0 or 1), with fuzzy logic there is a transition Zone where each set has membership grade less than 1 (Zadeh, 2008).

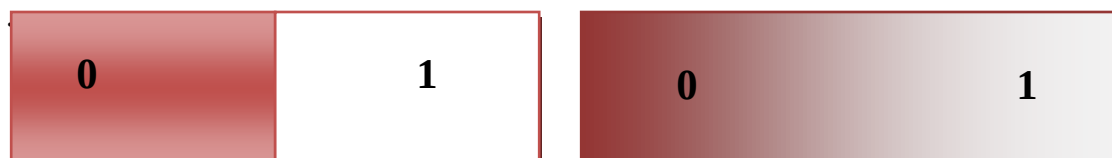


Figure 2: Representation of Boolean (left) and Fuzzy sets (right).

2.11 Fuzzy AHP Modeling

The fuzzy Analytical Hierarchical Process (FAHP) has the same core as the conventional AHP. Both are based on hierarchical structure and use pairwise comparison decision to estimate the preference of the criteria and their alternatives. Similar to AHP, FAHP uses pairwise comparisons of criteria and alternatives in order to form a reciprocal decision matrix, but it transforms data to fuzzy ratios. The eigenvector is also used to solve the reciprocal matrix and to determine the importance of criteria and the performance of alternatives with respect to each criterion (Saaty, 2005).

CHAPTER THREE

3 MATERIALS AND METHODS

3.1 Description of the Study Area

3.1.1 Location

Arsi Zone is one of the Zones of the Oromia Regional State in Ethiopia bordered with the north by the Adama Special Zone, on the northwest by East Shewa Zone, on the south by Bale Zone, on the southwest by the West Arsi Zone and on the east by West Hararghe. The administrative center of the Zone is Asella town located at 175 km southeast of Addis Ababa. Abomsa, Assasa, Bokoji, Sagure, Kersa, Dhera, Etaya, Arsi Robe and Huruta are other major towns in this Zone. Arsi Zone is located in the eastern part of Ethiopia bounded by latitude $7^{\circ}10'34''$ – $8^{\circ}42'46''$ N and longitude $38^{\circ}41'14''$ – $40^{\circ}43'58''$ E covering a total area of 20,694.41 km² (Figure 3).

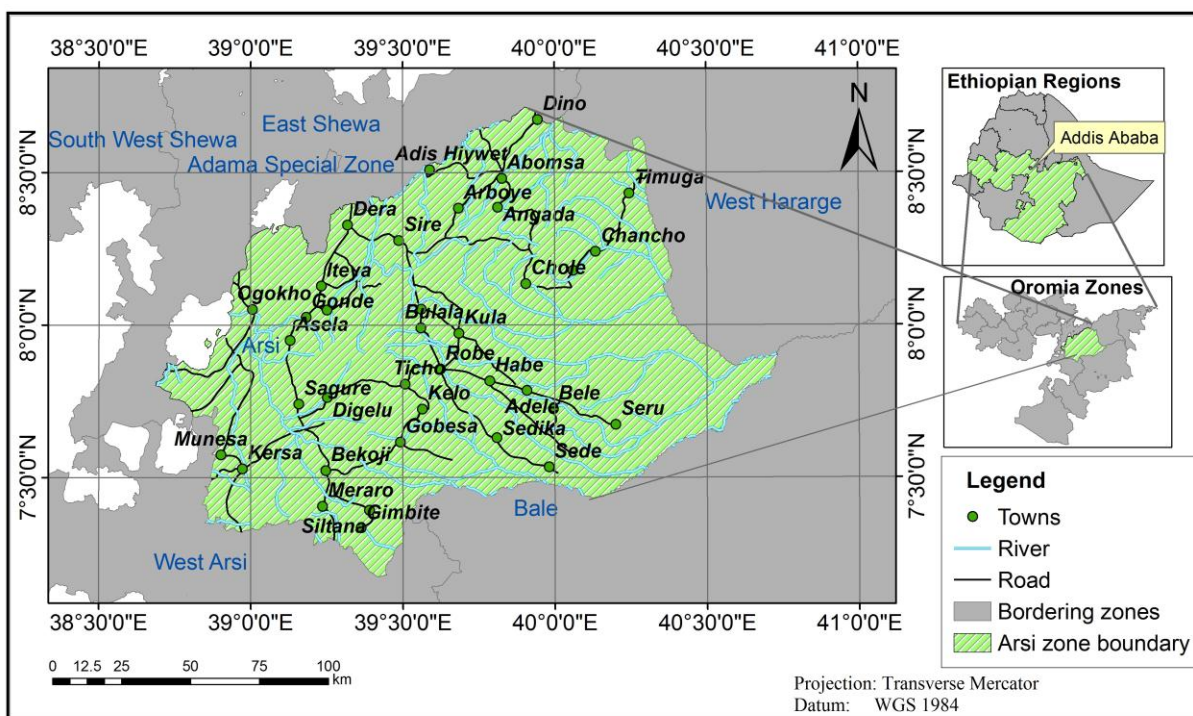


Figure 3: Location map of the study area.

3.1.2 Population and Economic Activities

According to Central Statistics Agency (1994) national census report, the total population of Arsi Zone was 2,217,245 in 438,561 households, of whom 1,105,439 were men and 1,111,806

were women; 216,403 (90.24%) of its population were urban dwellers at that time (CSA, 1994). Later in 2007 national census conducted by the CSA, the Zone has a total population of 2,637,657 of whom 1,323,424 were men and 1,314,233 women; with the population density of 127.45 per km². Projected population value of 2014 for all woredas of Arsi Zone shows that, 90.09% of Zonal population was rural residents (CSA, 2008) (Figure 4).

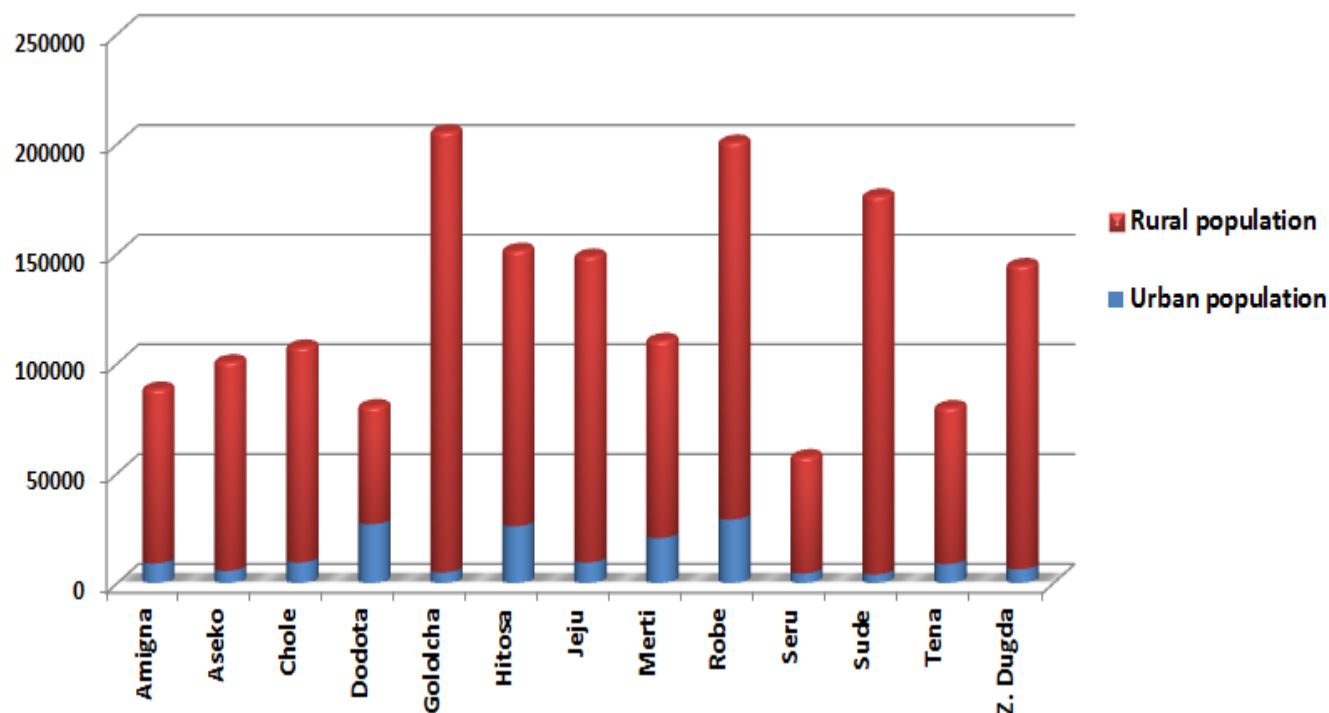


Figure 4: Population projection values of 2014 for Arsi Zone at Woreda level.

With regard to some socio-economics activities, World Bank 2004 memorandum reported that, only 4% of the total population has access to electricity facility, within a road density of 45 km per 1000 km². Averagely 1.2 hectare of land owned by a single rural household with equivalent of 1.1 heads of livestock and the Zone had 83.5% of Zonal population was participated in agricultural related jobs. Concerning literacy and education, from all eligible children, 84% of them attended primary school, and 22% attended secondary schools. From the total population 17% of the population was exposed to malaria, and prone to Tsetse fly. The World Bank memorandum ranked this Zone as a drought risk rating of 364 (World Bank, 2004).

3.1.3 Climate

According to the National Metrological Agency (NMA), the average minimum and maximum temperature of Arsi Zone is 10°C and 24°C respectively. The rainfall of the Zone is characterized by bimodal pattern. The annual average rainfall in the Arsi Zone is 1000 mm with a seasonal distribution. The main rainy season, which accounts for approximately 60% of the annual precipitation, covers the period between the beginning of June and end of September, while the short rainy season is during March to May.

3.1.4 Land-use/Land-cover

The land-use types of the study area were classified into eight major classes (Figure 5). These are bareland, forest, farmland, grassland, settlement, shrubland, water body and wetland. Farm land and shrubland types have the higher proportion in the study area as shown in Table 3.

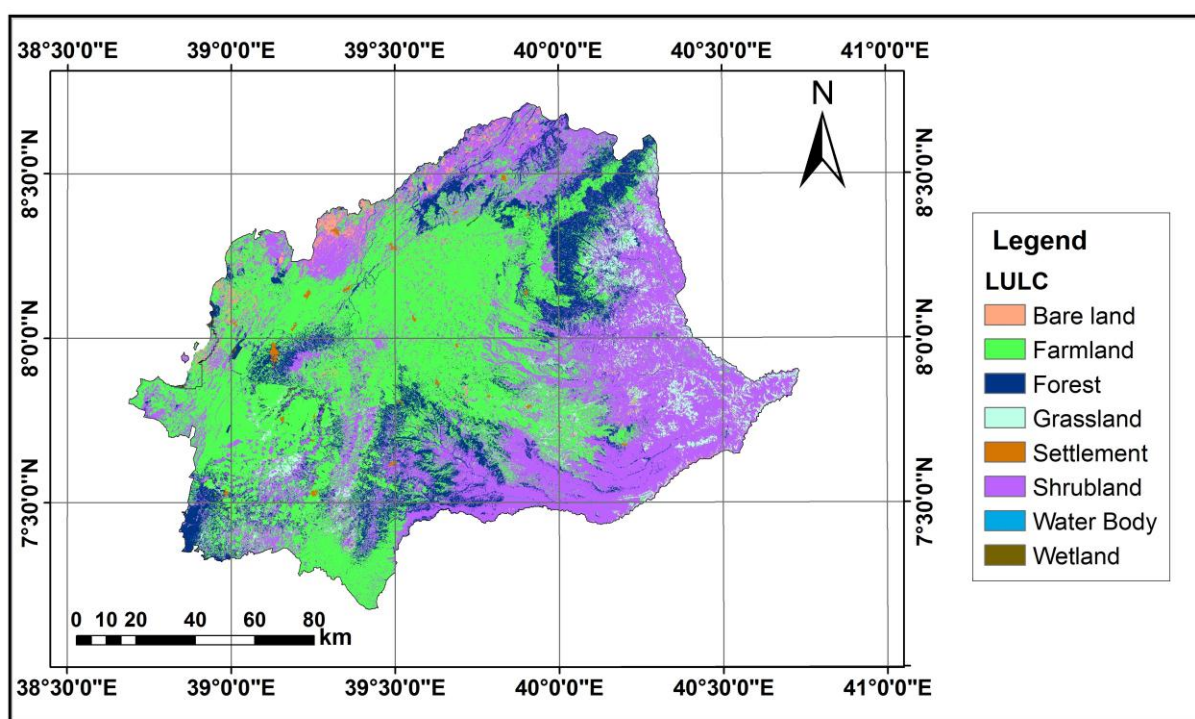


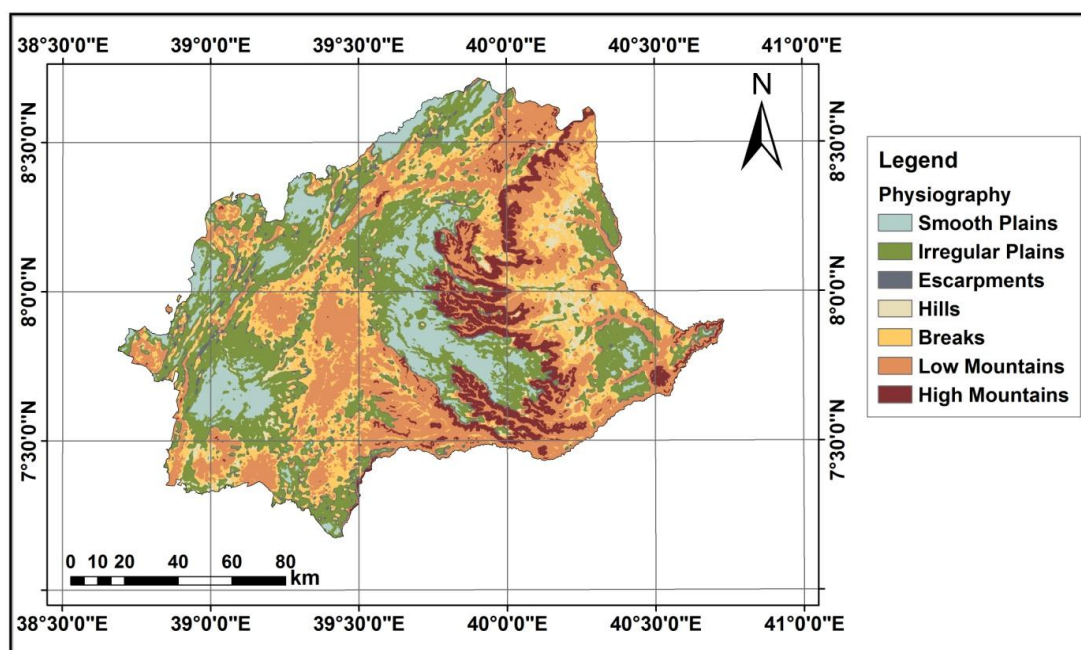
Figure 5: Land-use/land-cover map of the study area.

Table 3: Land-use/land-cover types and coverage of study area.

LU/LC	Area (km ²)	Area (%)
Farmland	8,961.04	43.30
Shrubland	7,639.60	36.91
Forest	2,684.02	12.97
Grassland	935.21	4.52
Bareland	293.90	1.43
Settlement	117.00	0.57
Wetland	51.68	0.25
Water body	11.98	0.06
Total	20694.41	100

3.1.5 Physiographic Classes

The altitude variation of Arsi Zone ranges from 881 to 4287 m a.s.l. From the total land size of the Zone, the landform types in the study area were classified into seven major physiographic classes (Figure 6). These are smooth plain, irregular plain, escarpments, hills, breaks, low mountain and high mountain (Deep Canyons) classes.

**Figure 6:** Physiographic map of the study area.

3.6 Geology

According to Geological Survey of Ethiopia (Getahun, 1987; Workineh *et al.*, 2014), Geology of Arsi Zone is mainly volcanic plateau belonging to the southeastern Ethiopia and associated lowlands and minor areas occurring to the northwestern part belong to the Main Ethiopia Rift (MER). This contains faulted volcanic plateau, which are mainly pyroclasts. Volcanic rock of ignimbrite, tuff and quaternary basalt cover a large part of the study area.

The main rock types encountered in the area begins with Mesozoic marine and continental sediments followed by Cenozoic basic and Felsic volcanics and younger Quaternary alluvial sediments. The volcanic include early to late Tertiary volcanic rocks and Quaternary volcanic and alluvial sediments (Figure 7). Lithology of Arsi Zone composes upper sandstone (Ka), upper limestone (Mulst), sedimentary (Musst), Alaji basalt(N1a), Arba_gugu basalt (N1g), Bofa basalt (N2Qb), Ignimbrite ,tuff (Nn, Tv3(1)), Quaternary basalt (Q1), Basalt flow (Tv4), Late (Tv6) and Pliocene trachyte (Tv7). See Appendix (Annex V: Lithological description of study area) for lithology description of study area.

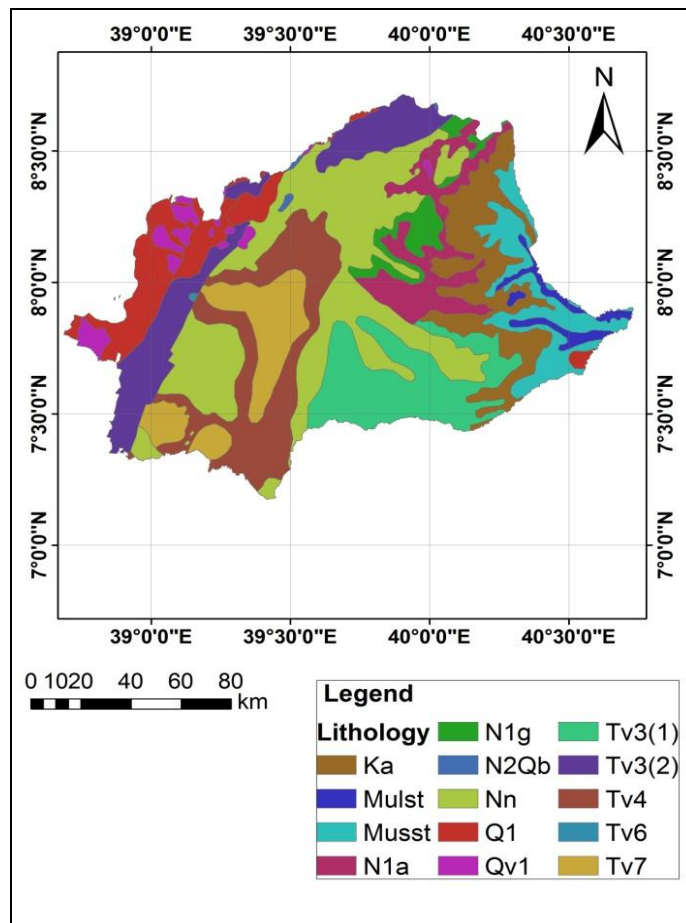


Figure 7: Geological map of the study area.

3.2 Data Description and Software

3.2.1 Data Description

The primary and secondary data for both factors and constraints that were identified as criteria and constraint factors for analysis were collected from different sources (Table 4). The primary data includes cloud free Landsat 8 image (spatial resolution of 30 m) and Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM, 30 m $\times$ 30 m and DEM, 1 km $\times$ 1 km) was downloaded from United States Geological Survey Global Visualization Viewer Website (<https://earthexplorer.usgs.gov>).

Table 4: Data sources

GIS data layer	Description	Data Source
Vector (polygon)	Zonal Boundary	CSA(2008)
Vector(Line)	Roads	CSA(2008)
Vector(Polygon)	Settlements (Town & Villages) boundary	CSA(2008)
Raster Shuttle	Elevation	Radar Topography Mission (SRTM)
Attribute table	Zonal metrological Station records	National Metrological Agency
Vector (polygon)	Geology/Lithology	Geological survey of Ethiopia (1978)
Vector (line)	Fault	Geological survey of Ethiopia (1978)
Raster	Satellite Image	Landsat OLI (2017)
Raster	Soil Profile	World Soil Information(ISRIC, 1988)
Raster	Slope, Aspect, Drainage	DEM 30m SRTM

The secondary data used were from published and unpublished documents from different organizations. Interpolated rainfall satellite data were collected from National Meteorological Agency (NMA), which includes mean annual precipitation and temperature for all 15 metrological stations belongs to the study area for 25 years records (1990 to 2015) used for satellite interpolated rainfall image verification. Demographic characteristics, geological topographic and other data were gathered from Central Statistical Agency and Geological Survey of Ethiopia, respectively. Resampled soil property data were downloaded from world soil information center (www.isric.org) Harmonized soil database geoportal.

3.2.2 Tools

In order to achieve the objectives of this study, the following hardware and software were utilized:

a) Hardware:

- Laptop with a monitor display of 1024x768 pixels, Memory, 3.0 GB RAM and 2.1 GHz processor speed.

- External Hard disk: 1 TB storage size.
- Handheld GPS receiver: Garmin, with 10 m positional accuracy, used for sample point collection used for LU/LC verification.
- Digital Camera: Resolution, 14.1 Mega pixel, which used for capturing sample point land-cover.

b) Software:

The software packages used for this study were:

ERDAS Imagine 2014: This was used for satellite image pre-processing and post-processing including layer stacking and mosaic for LU/LC classification.

ArcGIS 10.3: ArcGIS 10.3 was used for storing and managing geographic data in geodatabase package, compile and edit GIS datasets and display and analyze spatial data in both vector and raster format.

Geomatica 2015: Geomatica 2015 was used for geological lineament extraction of satellite image for lineament proximity layer preparation.

IDRISI Silva 17.00: Terrset formerly IDRISI Silva was used for decision support and uncertainty management of weighting criteria, fuzzy standardization, and an extensive set of criteria aggregation procedures based on weighted linear combination.

Microsoft Office Package (2013): Provides the necessary environment for MS Excel, MS Word, MS Power point and MS access.

3.3 Method

The following three-tier methodological approach was employed in carrying out this research.

1. Thematic layer preparation: Appropriate layers were prepared using Landsat 8 OLI Satellite data, Digital elevation model and other thematic and collateral data.
2. Data analysis and integration: Depending on the layers prepared in stage 1, digitization, data editing, field verification, data validation, data integration, Attribute Table Design and entry were done.

3. Developing Decision Rule: The following consecutive procedures were undertaken to finalize the model successfully: these were standardizing criteria, reclassifying input layers, fuzzification, comparison, aggregation, considering constraints, running the model and identifying the potential RWH sites. Overview of the methodology is illustrated in the following methodological flow chart (Figure 8).

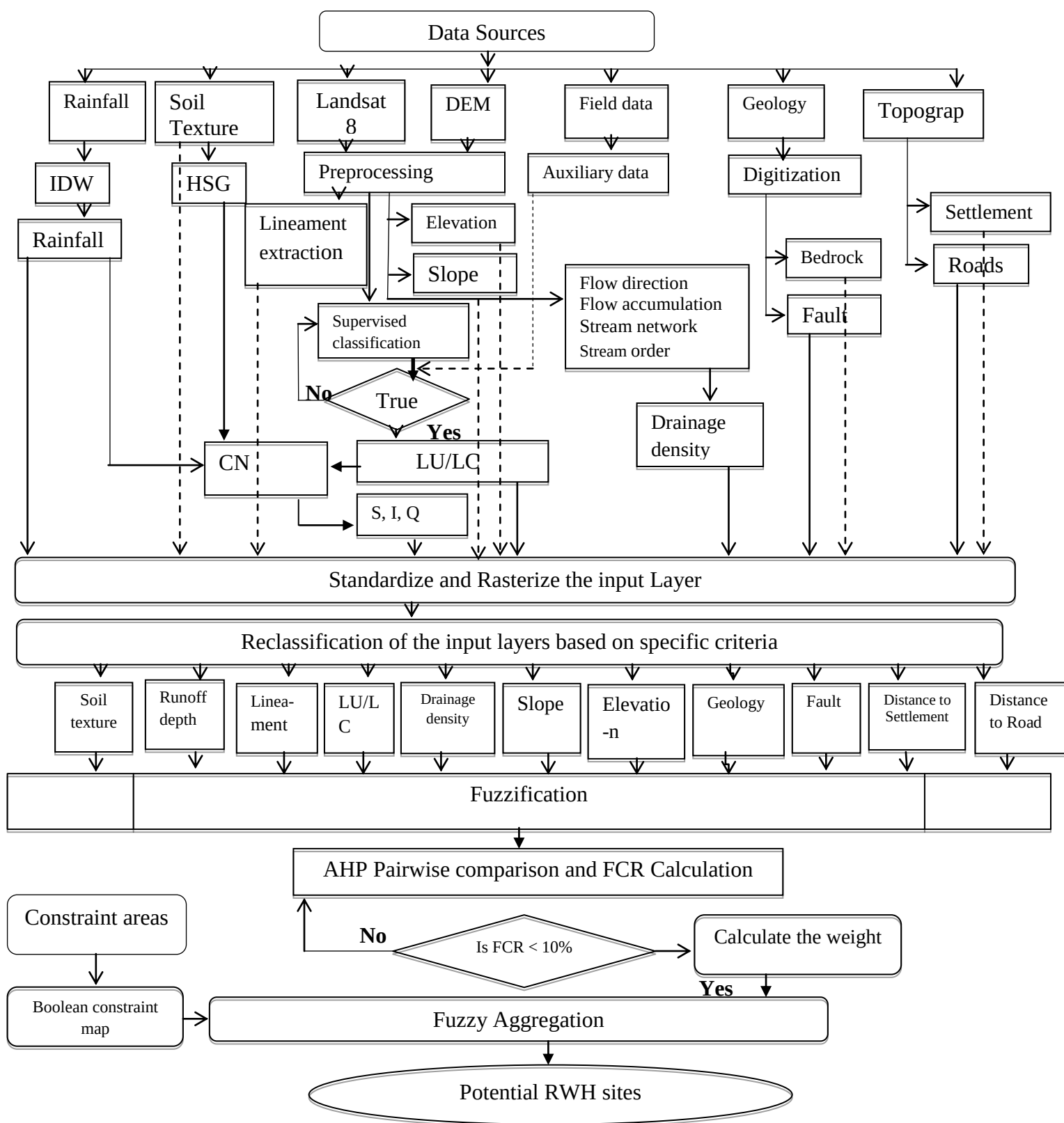


Figure 8 : Methodological flow chart.

3.4 Data Analysis

In this section the procedure for identification of relevant evaluation criteria data sets through data collection, data preparation/organization, data preprocessing and editing, analysis, field verification, data validation, data Integration, attribute table design and entry, constraint identification and preparation, standardizing criteria and model development was covered.

3.4.1 Criteria Layer Preparation and Preprocessing

For the successful implementation of potential RWH site selection modeling, suitable criteria and constraint factors had to be defined. The criteria chosen for this research were land-use/land-cover, slope, lithology, soil texture, runoff depth, drainage density, elevation, distance from roads, distance from settlements, lineament proximity and distance from faults. In addition to the criteria, constraint or restricted area layers used in this research were faults, settlements and major roads.

Correlation coefficient

The correlation coefficient matrix was computed between each factor to avoid the redundancy of factors in the model, After the layer map of the factors were prepared, the correlation analysis was carried by extracting 5000 sample value data of each of the factors. This indicates that how much one parameter does another represent. The value of correlation coefficients for all factors were near to zero, this indicated that all factors are not correlated and appropriate for the modeling (See Annex IV for correlational coefficient). The correlation coefficient (R^2 -value) measures the percentage of variation in the values of the dependent variable that can be explained by the variation in the independent variable.

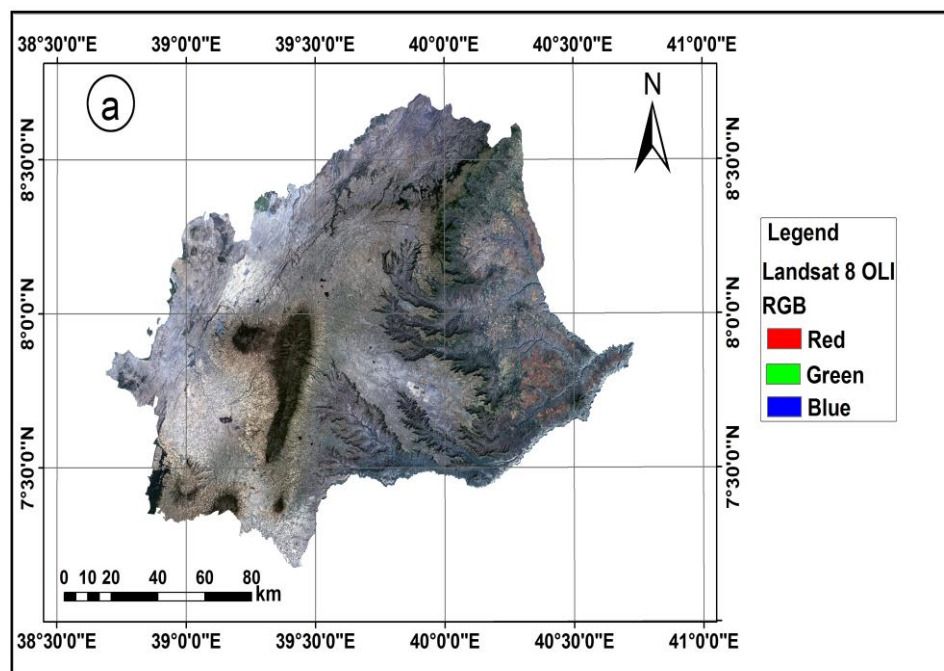
Image Preprocessing

Image pre-processing was done on the initial processing of the raw data, which was applied in this study like geometric and radiometric corrections, image enhancement and topographic corrections. In the first step the acquired data were stacked and layer sub-setting was done into composite images of the study area. In order to make the data compatible with each other, the projection transformation was carried out and was assigned the Adindan _ UTM _ Zone_37N

coordinate system projection. For the final overlay analysis, all layers were resampled to the same 1 km spatial resolution. Overall analysis done for layer preparation is discussed below:

3.4.2 Land-use/Land-cover

Land-use/land-cover was extracted from four Landsat 8 OLI Satellite Imagery, using ERDAS Imagine 2014 software to preprocess and classify the image. A different LU/LC classes were applied through supervised classification, with a combination of three consecutive bands as false color composite (FCC) of Band 3, Band 4 and Band 5. Images and maps such as reference and topographic maps, Google earth and world land-cover images (The European Space Agency Climate Change Initiative - Land Cover project 2014-2017) were used to define detail training sites. Then the image processing algorithm was develop a statistical characterization of the reflectance for each information class as a signature analysis, and involve developing a characterization as simple as the mean or the range of reflectance on each bands, or as complex as detailed analyses of the mean, variances and covariance over all bands. Once a statistical characterization was achieved for each information class, the image was classified by examining the reflectance for each pixel and making a decision about which of the signatures it resembles most (Eastman, 2009). Major classified land-use is presented in Figure 9.



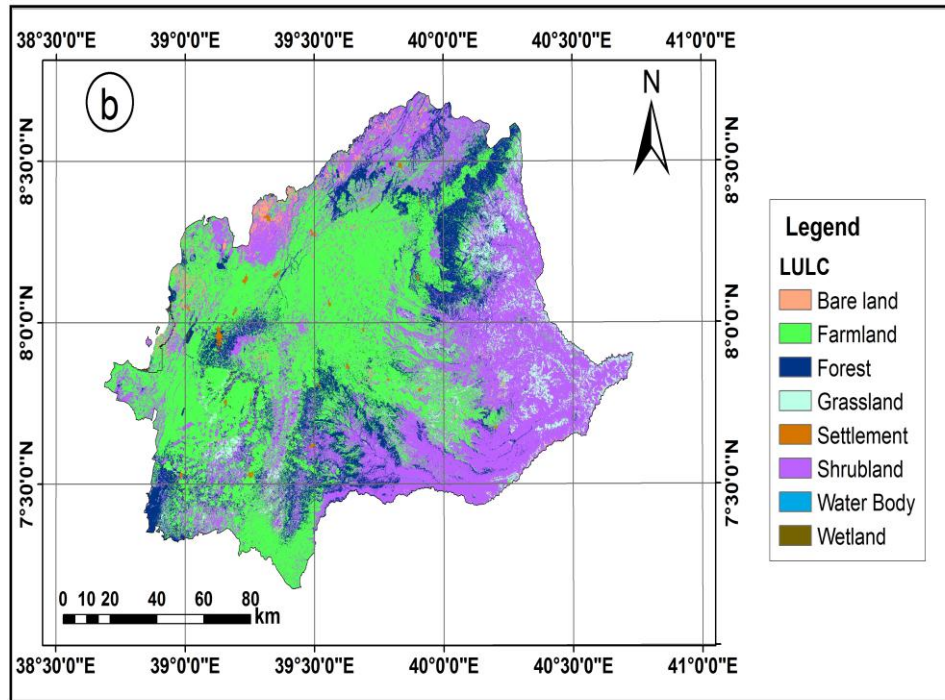


Figure 9: Land-use/land-cover a) satellite image b) classified land-use/land-cover map.

3.4.3 Rainfall

Spatial interpolation technique was carried out by estimating and evaluating a regionalized value at unsampled points based on the values of sampled regionalized values of 15 NMA rain gauge station records. The general formula for spatial interpolation is as follows:

$$Z_g = \sum_{i=1}^{ns} \lambda_i z_{s_i} \quad (1)$$

Where Z_g is the new estimated value at the required points, Z_{s_i} is the recorded known value at point i , ns is the total number of observed points and $\lambda = (\lambda_i)$ is the weight contributing to the interpolation. From other interpolation techniques, an IDW deterministic, nonlinear interpolation algorithm is preferable technique for rainfall data interpolation by most scholars, which was selected for interpolating the precipitation data for the entire study area. This algorithm estimates cell values by averaging the values of nearby sample data points. The closer a point is to the center of the cell that is being estimated, the more weight it is given. It was calculated as follows:

$$\hat{V}_i = \frac{\sum_{i=1}^n \frac{1}{d_i^p} V_i}{\sum_{i=1}^n \frac{1}{d_i^p}} \quad (2)$$

Where $\hat{V}_i$ is values of the unknown points to be estimated V_i is known sampled points values d_{pi} and d_{pn} is the distances from the n value points to the power of p of the points that estimated (Figure 10). The interpolated rainfall map was verified with satellite drive climate data.

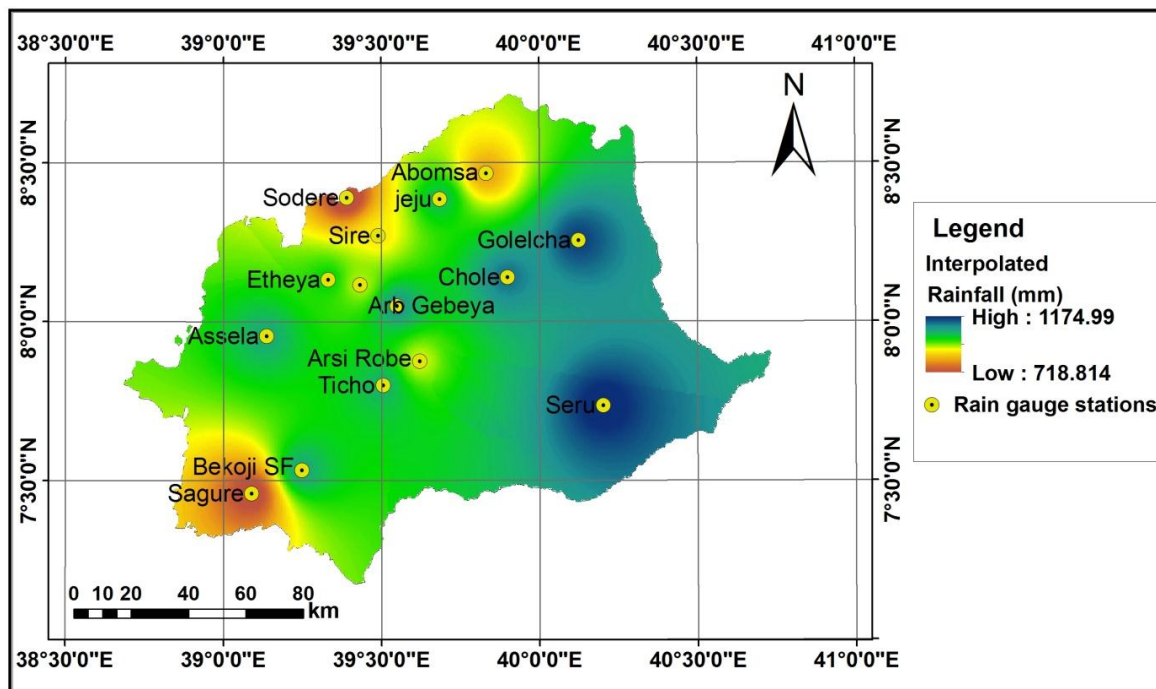


Figure 10: Interpolated Mean Annual Rainfall (mm) of 15 rain gauge stations records.

3.4.4 Soil Texture

Soil textural class is described by the sizes of the inorganic particles and the percentage of each size particle (clay, silt and sand) presents in a given land unit. Soil texture of the study area was reclassified into hydrologic soil groups (HSG's) (Table 5), which indicate the minimum rate of infiltration obtained for bare soil after prolonged wetting. The HSG's, which are A, B, C and D are symbols used in determining runoff curve numbers. The HSG of the study area map is presented as shown in Figure 11 below.

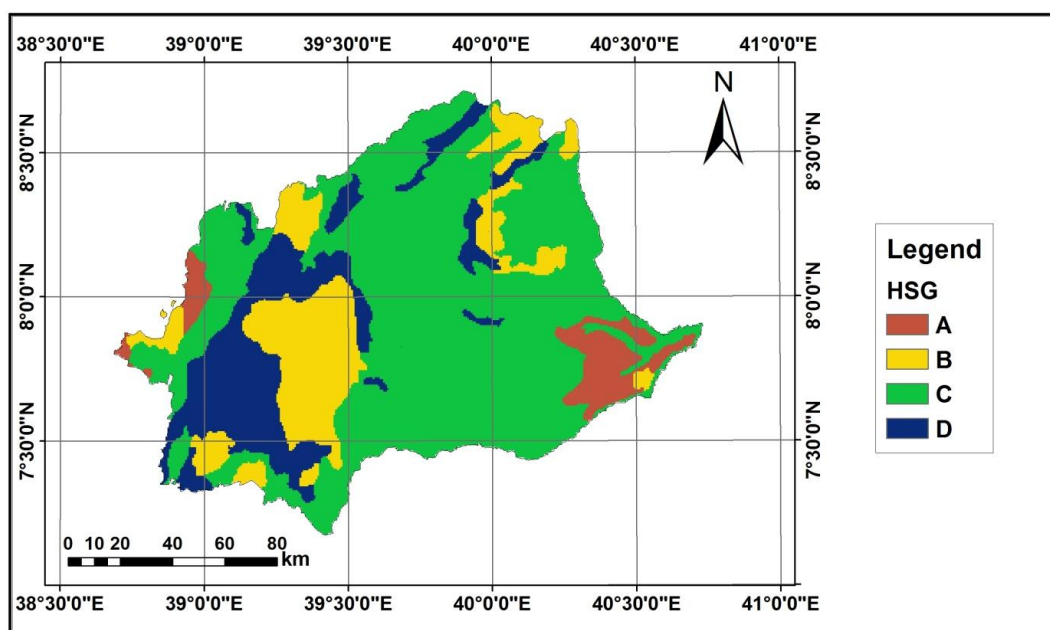


Figure 11: Hydrological soil group map of the study area.

Table 5: Hydrologic soil groups, soil texture and coverage.

HSG	Soil texture	Area (km ²)
A	Sandy loam	1,106.51
B	Sandy Clay loam	3,523.83
C	Clay loam	12,607.87
D	Clay	3,456.25

3.4.5 Runoff Depth

Soil Conservation Service Curve Number (SCS-CN) method was used to calculate the potential runoff in the study area. This method requires the determination of the maximum retention (S), which is dependent on the of the curve number (CN). Curve number values are dependent on the land-use classification and the hydrological soil group (HSG) of the land parcel. The land-use/land-cover corresponds to the water retention capacity of the soil, which is a determinant factor for the rainfall-runoff relationship. Based on world land-use/land-cover classes, it was found that the area consists of sixteen land-cover classes. According to the SCS-CN model LU/LC and HSG determine infiltration and runoff rate (See Annex I for runoff curve numbers with different land-classes). Then, CN value for each land-cover has been obtained from the CN Table (Table 6). In addition to that, runoff was generated by rainfall and its occurrence and

quantity are dependent on the characteristics of the rainfall event especially on intensity, duration and distribution. Factors that influence runoff characteristics and runoff depth are discussed below as follows:

3.4.5.1 Curve Number

Hydrologic condition of an area refers to the effect of the land-cover, and represents the surface conditions in the basin in relation to infiltration and runoff extent (Munyao, 2010). The classified land-cover was used together with a map of HSG in ArcGIS to match the hydrologic soil group with the land-cover (see Appendix 1 for Runoff curve numbers for different land-classes). The curve number value of the study area was assigned based on the SCS classification system (Figure 12). The Curve numbers was generated using the USGS land-cover and Hydrologic Soil Group classification system (Maidment, 1996). The curve number value for each hydrologic soil group and corresponding LU/LC classes is presented in Table 6. A high value of the curve number (such as 98) refers to an area that has a high runoff potential and low infiltration. A low value to the curve number (such as 40) indicates an area that has relatively low runoff potential and high infiltration (Table 7).

Table 6: Unified soil classification system curve number of the study area.

LU/LC	Soil Groups			
	A	B	C	D
Dense forest	26	40	58	61
Moderate forest	28	44	60	64
Sparse forest	43	65	76	82
Woodland	36	60	73	79
Closed grassland	39	61	74	80
Closed Shrubland	45	65	75	80
Open grassland	49	69	79	84
Open shrubland	49	69	79	84
Perennial crop land	72	81	88	91
Annual crop land	72	81	88	91
Wet land	100	100	100	100
Water body	100	100	100	100
Settlement /building	61	75	83	87
Bare soil/fallow	77	86	91	94
Rock outcrop (averaged)	98	98	98	98
Lava flow	78	87	95	98

Source: (USDA-SCS, 1985).

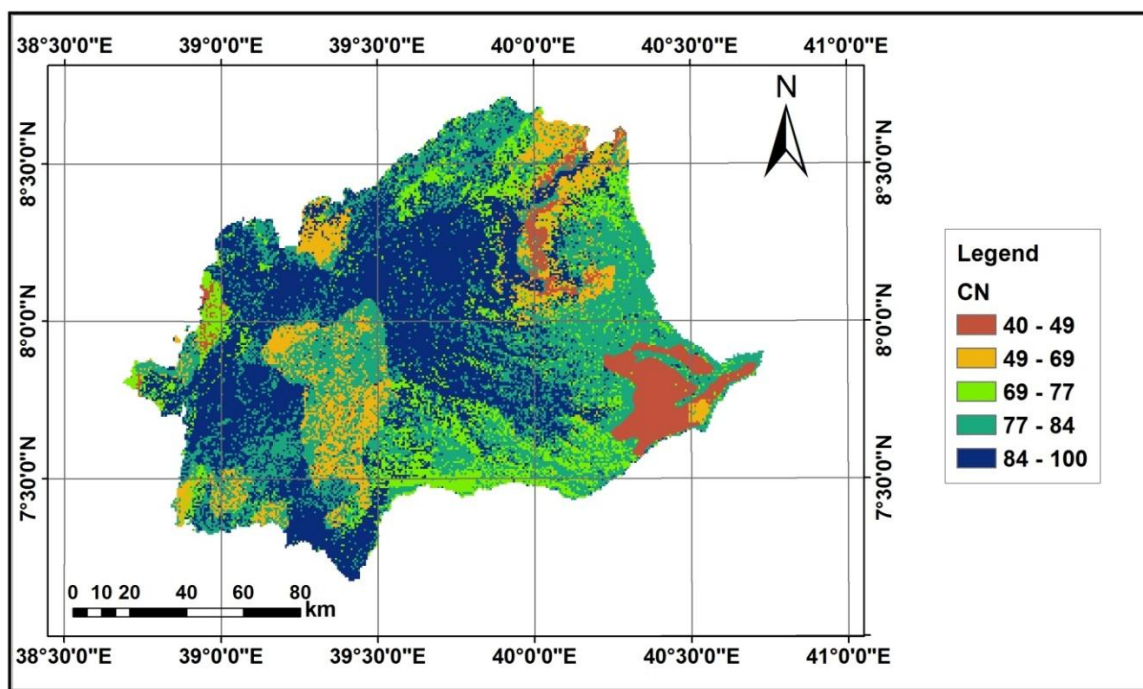


Figure 12: Soil Conservation Service Number map of the study area.

Table 7: Curve number, runoff potential and area coverage of the study area.

Curve number range	Runoff potential	Area (km ²)
$40 > CN \leq 71$	Low	3,373.65
$71 > CN \leq 88$	Moderate	14,847.56
$88 > CN \leq 100$	High	2,473.20
Total Area		20,694.41

Source: (Nagarajan *et al.*, 2015).

3.4.6 Estimation of Runoff Depth

The SCN-CN method uses curve numbers that were determined based on a number of factors including land-cover type, HSG and hydrologic condition. Runoff depth estimation was used to estimate the available annual water supply according to mean annual rainfall data. Mean annual rainfall of the study area was used as a rainfall factor for this model. The SCN-CN is expressed mathematically according to Equation (6) to calculate the runoff depth (Maidment, 1996) within the GIS environment (Figure 13).

$$P = Ia + F + Q, \quad (3)$$

$$\frac{Q}{P-Ia} = \frac{F}{S} \quad (4)$$

$$Ia = \lambda S \quad (5)$$

Where P is the total precipitation (mm); Ia the initial abstraction (mm); F the cumulative infiltration (mm); Q the direct runoff (mm); S the potential maximum retention (mm) and λ the initial abstraction coefficient. The SCS-CN equation, as expressed below is derived from the combination of the first two equations:

$$Q = \frac{(P-Ia)^2}{P-Ia+S} \quad (6)$$

Initial abstraction (Ia) includes all water lost before runoff begins, and includes water that is retained on the surface in depressions and water that was held by vegetation. It also includes evaporation and infiltration. Studies on many watersheds have shown that Ia can be approximated by:

$$Ia = 0.2S \quad (7)$$

S is related to the soil and land-cover type of the study area through the curve number, which ranges between 0 to 100. S was derived using the following alternative equations.

$$S = \frac{25,400}{CN} - 254 \quad (8)$$

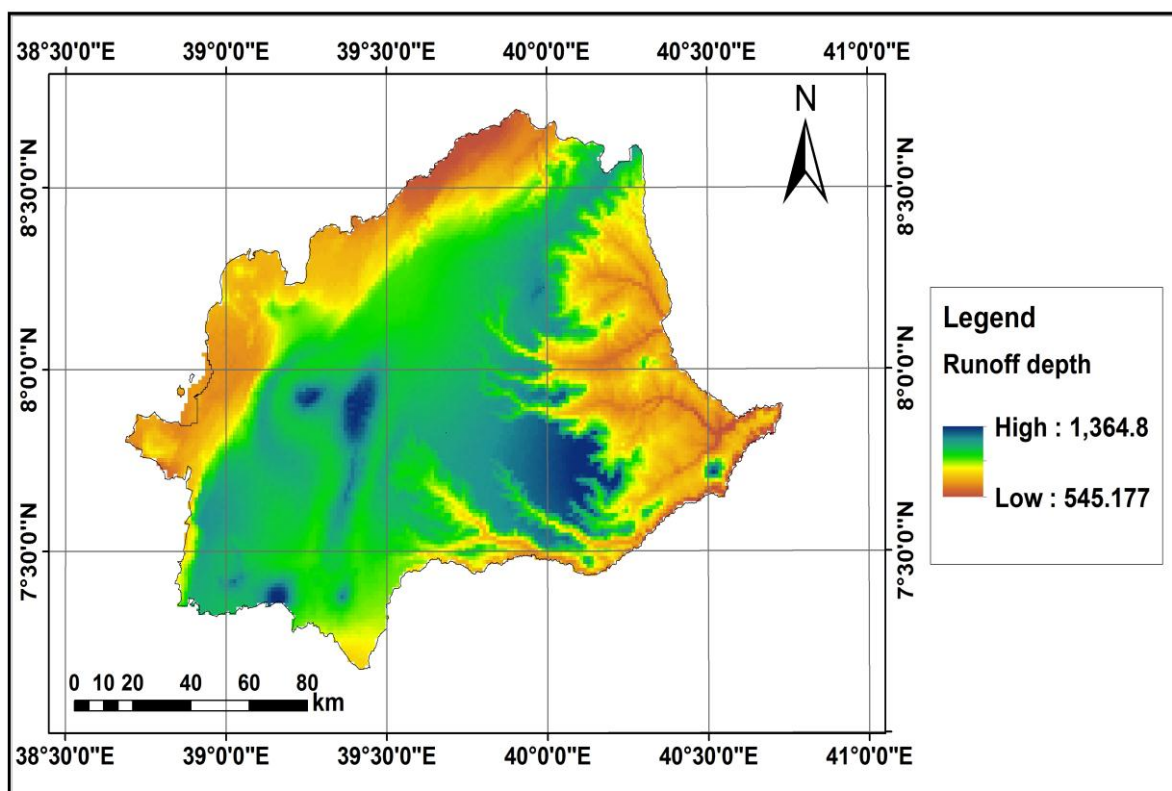


Figure 13: Runoff depth map of the study area.

3.4.7 Digital Elevation Model (DEM)

The hydrological parameters such as flow accumulation, flow direction, stream network and stream order were derived from the DEM with 30 m resolution, whereas elevation, aspect and slope were derived from 1 km resolution DEM data. An Arhydro tool in ArcGIS 10.3 was used to extract the hydrological parameters. All sinks and cuts were filled in order to keep continuity of flow to the basins of study area before using the DEM to estimate any parameters. The DEM after filling sinks is illustrated in Figure 14.

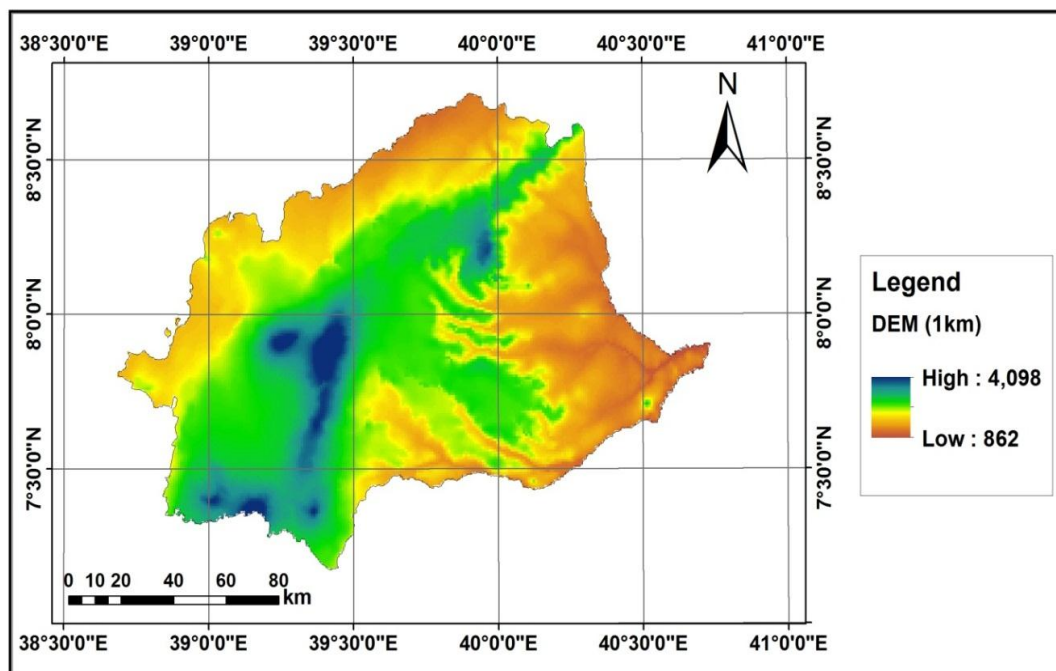


Figure 14: Digital elevation map of the study area.

3.4.8 Slope

The slope was derived from the DEM after preprocessed. According to the FAO slope classification which depend on land surface percentage rise (Sheng, 1993) (Table 8), the study area was classified into seven slope zones, which extends from nearly level (less than 1%) to extremely steep (greater than 35%) (Figure 15b).

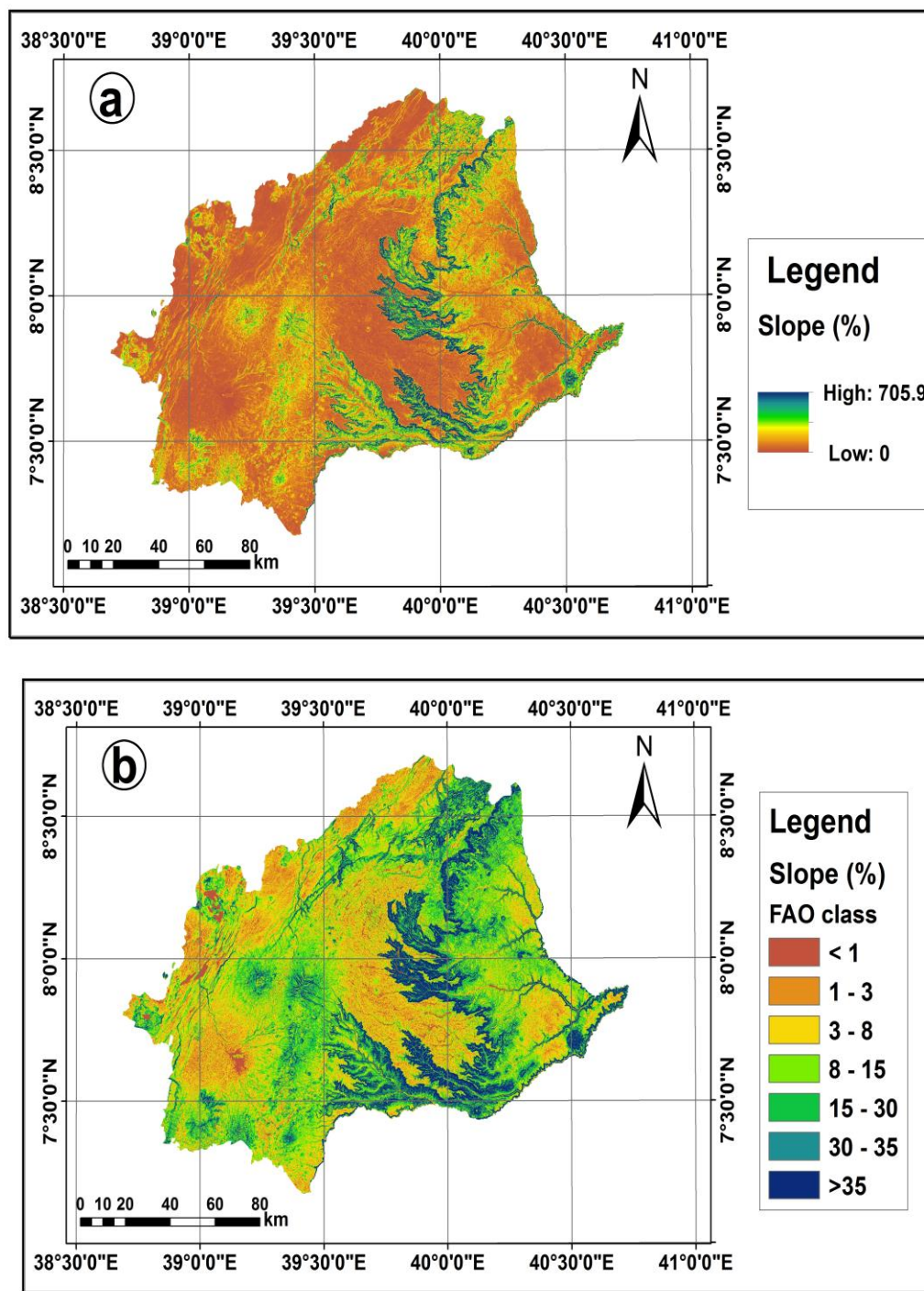


Figure 15: a) Slope map b) Slope class.

Table 8: Slope classification of the study area (FAO class).

No.	Slope (%)	Slope Category
1	0 – 1	Nearly Level
2	1 – 3	Very gently sloping
3	3 – 8	Gently sloping
4	8 – 15	Moderately sloping
5	15 – 30	Steep sloping
6	30 – 35	Very steep sloping
7	> 35	Extremely steep

3.4.9 Drainage Density

Drainage density was defined by Horton (1945) as the ratio of the total length of streams in a watershed over its contributing area as stated in equation 9. In this study of the analysis, DEM hydro-processing tool was used for extraction of drainage parameters from DEM.

$$Dd = \frac{\sum L_k}{A_k} \quad (9)$$

Where Dd = Drainage density, $\sum L_k$ = Total length of all stream segments in a given basin and A_k = Total area of the basin. In the present study, the following hydrological parameters was extracted from hydrological tools of ArcGIS environment to prepare layers for drainage density. The methods followed to calculate the drainage density and stream order calculation was done as shown below.

3.4.9.1 Flow Direction

The flow direction of the study area was calculated using flow direction tool, which creates a raster of flow direction from each cell to its steepest down slope neighbor, by computing the flow direction for a given grid. The value in any given cell of the flow direction grid indicates the direction of the steepest descent from that cell to one of its neighboring cells using the eight directions. This operation was used for required input to create stream order raster for the next steps of drainage creation and as input for flow accumulation calculation.

3.4.9.2 Flow Accumulation

The flow accumulation raster layer was derived from flow direction raster grid as input, in order to determine the accumulated number of raster grids that are draining to each raster grid in the surface. The result of this function was a raster of accumulated flow to each grid, as determined by accumulating the weight for all grids that flow into each down slope grid. This was used to generate stream, which is required as an input to create stream order of the basins.

3.4.9.3 Stream Raster

The detail streams of the area was calculated and derived from flow accumulation that gives the number of raster grid cells that drain to a particular grid cell, which was used to define a stream. It is assumed that a stream is formed when a certain threshold area drains to a point. This threshold is defined by using the amount of raster grid cells in the flow accumulation grid. One thousand threshold values were used to form a stream raster for this research. Grid cells that have more than 1000 cells flowing into them were used to define the stream network. In ArcGIS software environment a tool called Con was used to create a stream network raster where flow accumulation values of 1000 or greater go to one, and the remained are put to the background (No Data).

3.4.10 Strahler Stream Order

Stream order that is used for the generation of drainage density stream order layer was derived from the streams of the area. A headwater stream with no tributaries is considered as a first order stream. A segment downstream of the confluence of two first order streams is a second order stream (Strahler, 1952). Thus, n^{th} order stream is always located downstream of the confluence of two $n-1^{\text{th}}$ order streams. Stream order only increases when streams of the same order intersect (Figure 16).

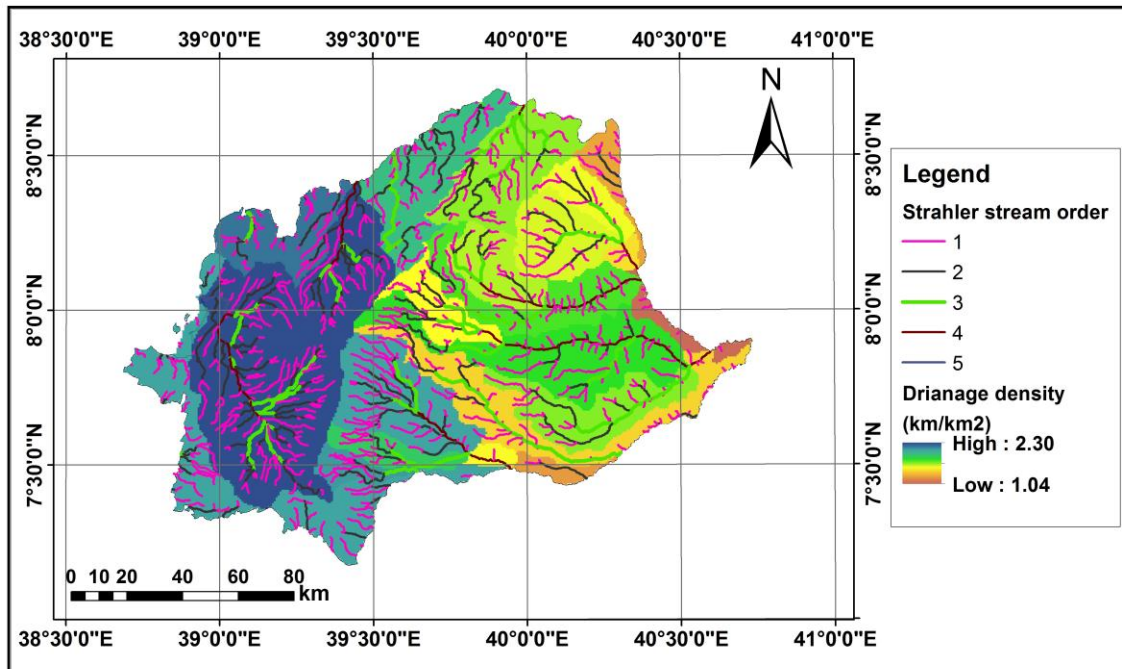


Figure 16: Drainage density and Strahler stream order map of the study area.

3.5 Dataset Standardization

Dataset standardization was done using the criteria and constraint datasets together with their attributes for each of the criteria using the factor criteria as inputs. Some factor and constraints datasets were derived from other dataset layers, such as slope, streams and drainage density were derived from the DEM.

Euclidean distance tool was implemented in a GIS environment, which identifies for each cell, the straight-line distance to the closest source cell, set of source cells, or source location. Euclidean distance was set for proximity for the road, settlements, lineaments and faults. Lineament proximity layer was prepared from Landsat 8 band 7 satellite image in Geomatica software environment.

Both criterion of thematic layers and constraint layers were converted into raster data format using one of the required attributed column to form each layer. All converted layers were reclassified according to reviewed literatures and some of them were customized in order to meet site-specific requirement. Reclassification was used to simplify the interpretation of raster data

by changing a single input value into a new output value. It also used to group ranges of cell values into a single value. By using reclassified layers, which results in a generalization and simplification of the original dataset, input layers was categorized based on the same ranking scheme that can be used to compare and rank the least and most suitable sites.

3.5.1 Elevation

Site topography standardized classification was done based on the suitability rate of RWH structure site location, which will affect the amount of pumping needed to distribute the harvested water to nearby area (Table 9). This was done to get the new standardized and reclassified elevation factor map (Figure 17).

Table 9: Elevation suitability class.

Factor	Elevation (m)	Rate	Classification
Elevation (E)	$E < 1,300$ OR $E > 2,600$	1	Not Suitable
	$1,300 < E \leq 1,600$	2	Less Suitable
	$1,600 < E \leq 2,000$	3	Suitable
	$2,000 < E \leq 2,400$	4	Very Suitable
	$2,400 < E \leq 2,600$	5	Extremely Suitable

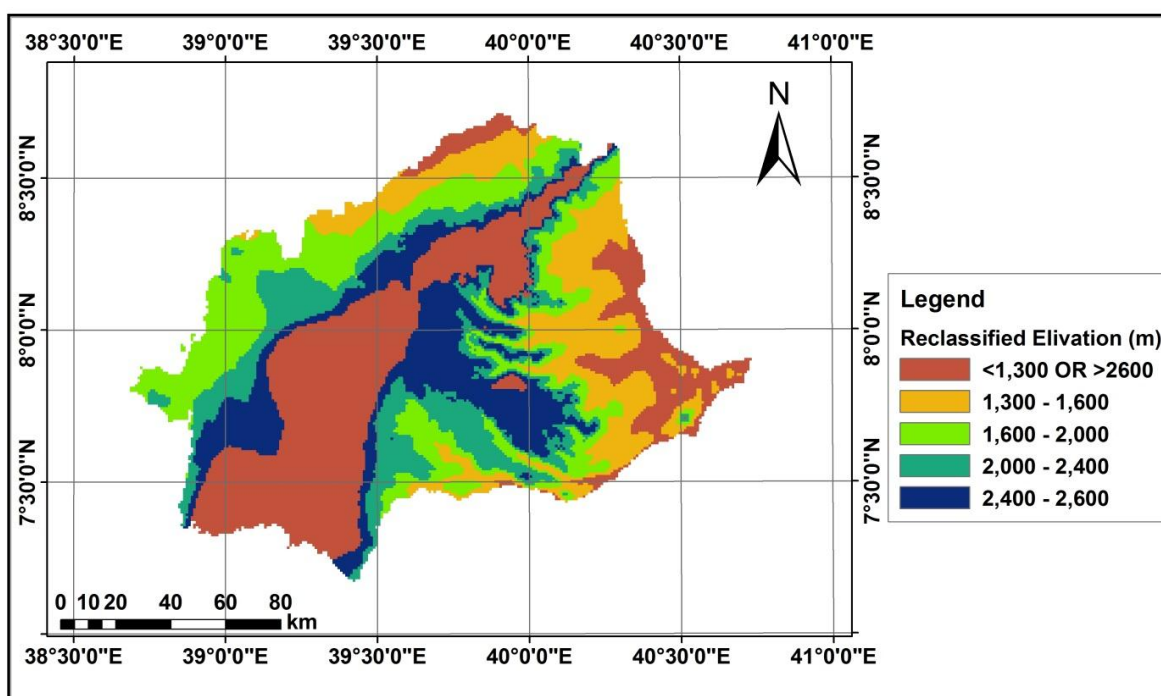


Figure 17: Reclassified elevation factor map of the study area.

3.5.2 Slope

Slope gradient standardized classification was done based on the suitability rate of RWH structure type and site location of each land unit for most RWH structures, with regard to the erosion control measurement (Table 10) (Hatibu and Mahoo, 2000). The pre-processed DEM layer was used to get the new standardized and reclassified slope factor map (Figure 18).

Table 10: Slope suitability class.

Factor	Rise (%)	Rate	Classification
Slope (S)	$S > 30\%$	1	Not Suitable
	$10\% < S \leq 30\%$	2	Less Suitable
	$5\% < S \leq 10\%$	3	Suitable
	$2\% < S \leq 5\%$	4	Very Suitable
	$S < 2\%$	5	Extremely Suitable

Source: (Maina and Raude, 2016)

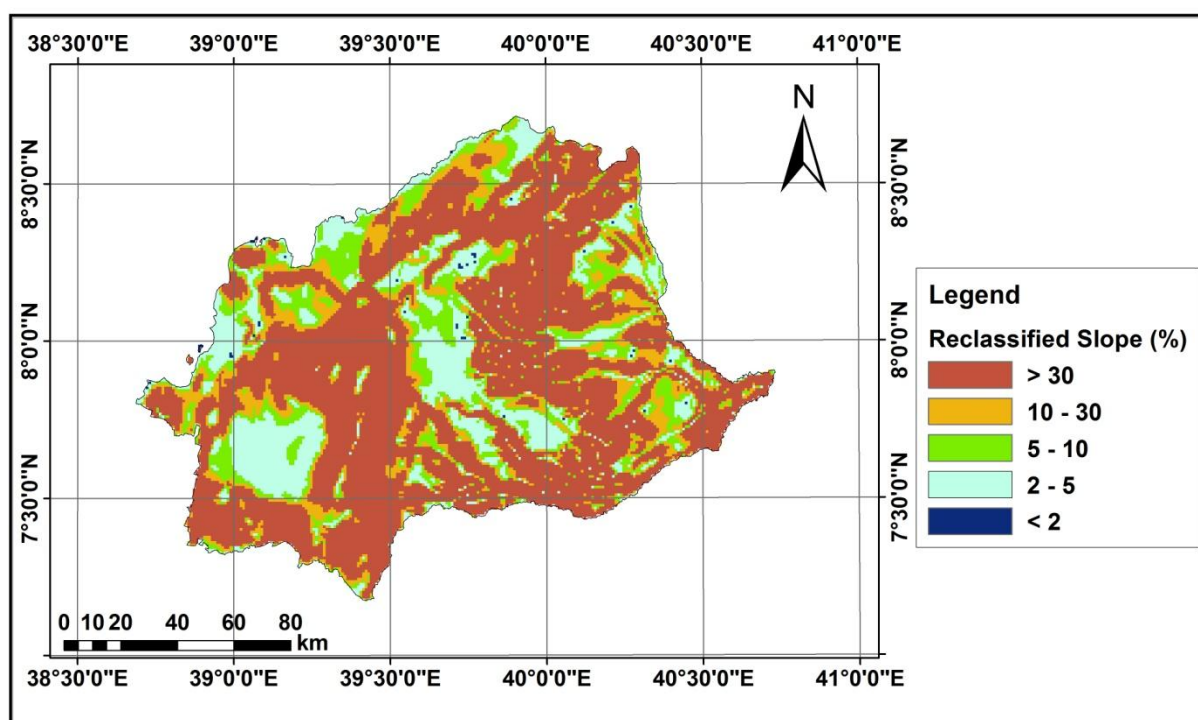


Figure 18: Reclassified slope factor map of the study area.

3.5.3 Runoff

Calculated runoff depth map was reclassified into standardized five suitability Zones, from low runoff depth to high runoff depth potential (Table 11), depending on mean annual rainfall-runoff depth estimated. An area with high runoff depth was rated high and an area rated low was where runoff depth was minimum, considering time taken to fill water in RWH structure annually (Figure 19).

Table 11: Runoff suitability class.

Factor	Runoff depth (mm)	Rate	Classification
Runoff (R)	$R < 250$	1	Not Suitable
	$250 < R \leq 600$	2	Less Suitable
	$600 < R \leq 750$	3	Suitable
	$750 < R \leq 1000$	4	Very Suitable
	$R > 1000$	5	Extremely Suitable

Source: (Munyao, 2010).

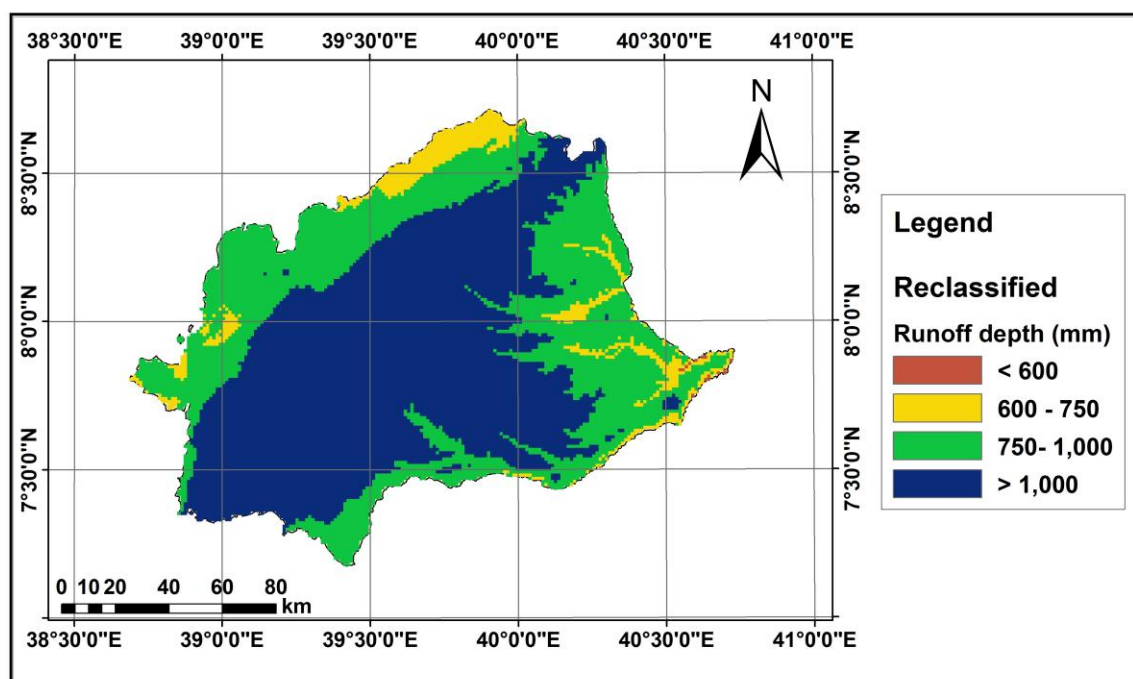


Figure 19: Reclassified runoff depth factor map of the study area.

3.5.4 Soil Texture

Soil texture of study area was classified based on the importance of soil characteristic in determination of land surface for RWH, which determines water infiltration rate and water storage in the soil (Donahue *et al.*, 1983) (Figure 20). Fine and medium textured soils are generally the more desirable for RWH because of their superior retention of nutrient and water. Soils with high percentage of clay particles was rated high, which have higher water-holding capacity and area with soils having minimum percentage of clay was rated low with regarding to higher infiltration rate (Ball, 2001) (Table 12).

Table 12: Soil texture suitability class.

Factor	Clay content (%)	Rate	Classification
Soil texture (C)	$C < 10$	1	Not Suitable
	$10 > C \geq 25$	2	Less Suitable
	$25 > C \geq 30$	3	Suitable
	$30 > C \geq 35$	4	Very Suitable
	$C > 35$	5	Extremely Suitable

Source: (Abdel Rahman, 2016).

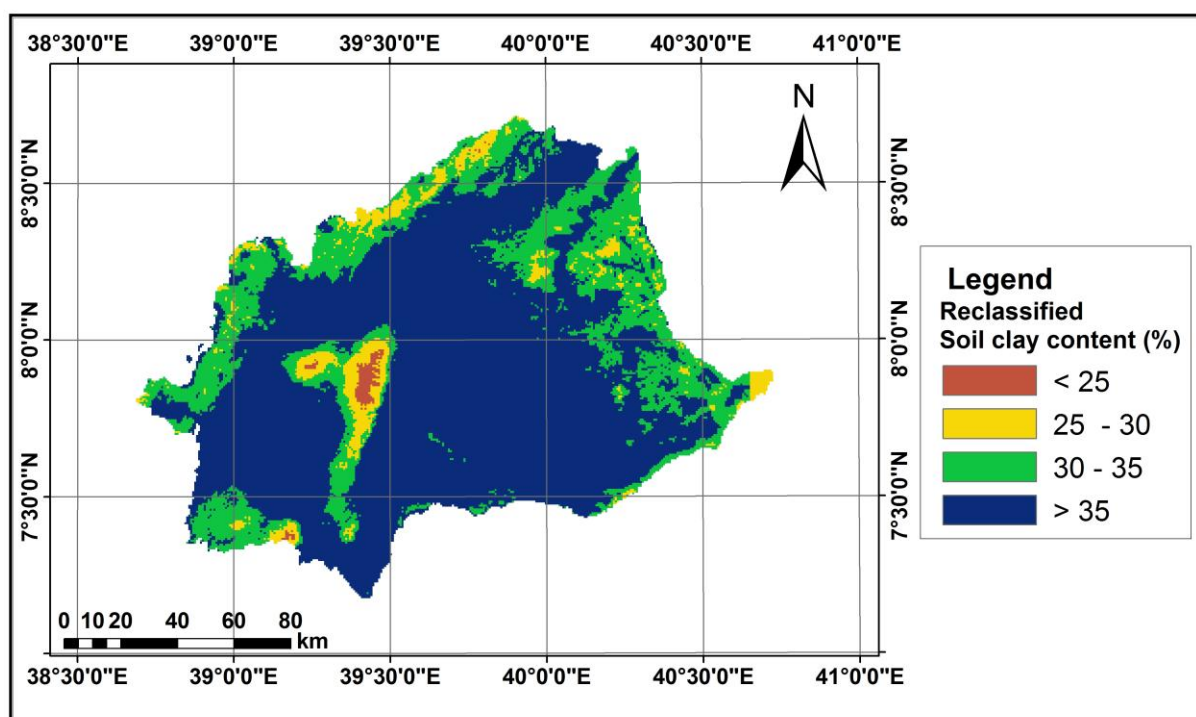


Figure 20: Reclassified soil texture map of the study area.

3.5.5 Land-use/Land-cover

Land-use/land-cover layer map analyzed and classified in section 3.4.2 was reclassified based on the effects of land-cover classes on both the surface runoff depth and RWH structural technologies. Barelands and cultivated lands was rated in high suitability class, for their suitability for most types of RWH technologies whereas settlements and forest was rated low, for their unsuitable and uneconomical nature (Table 13). This new categorized, reclassified and standardized LU/LC layer (Figure 21) used for further analysis.

Table 13: Land-use/land-cover suitability class.

Factor	Type	Rate	Classification
LU/LC	Settlement	1	Not Suitable
	Forest	2	Less Suitable
	Shrub land	3	Suitable
	Agricultural land	4	Very Suitable
	Bareland	5	Extremely Suitable

Source: (Ravikumar, 2016).

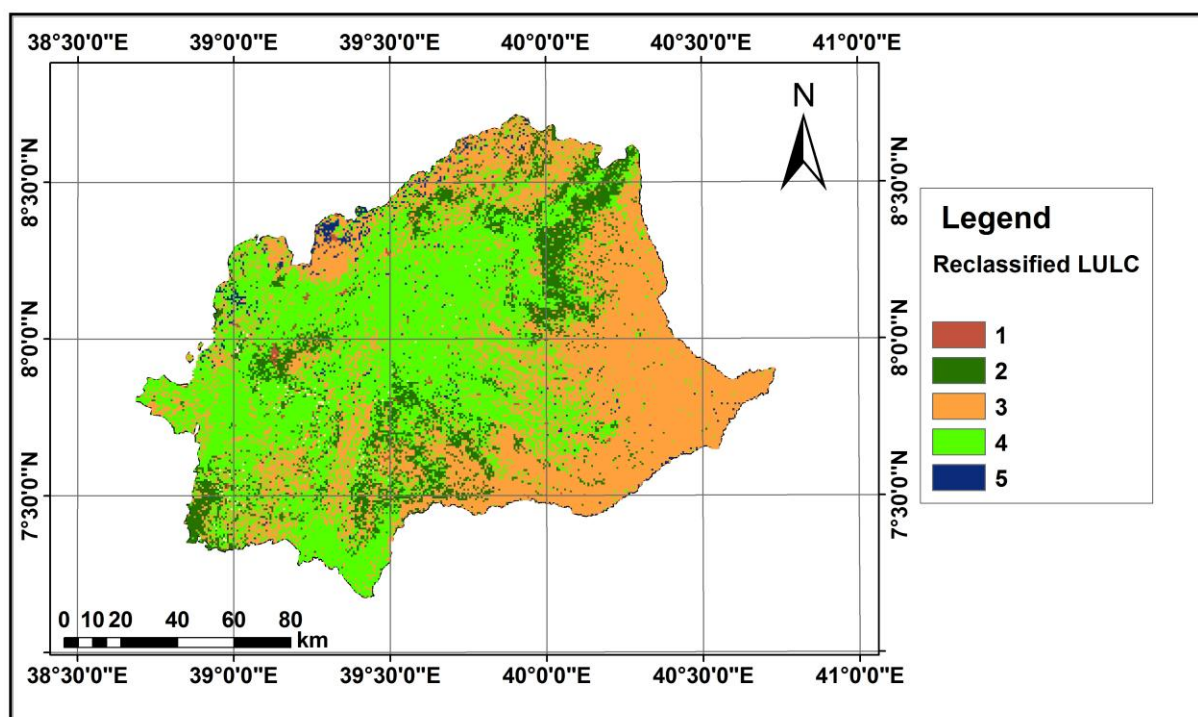


Figure 21: Reclassified Land-use/land-cover factor map of the study area.

3.5.6 Drainage Density

Standardized reclassification of drainage density layer was done based on the length of streams presents in each basin area (Table 14) as discussed in section 3.4.9. Potential rainwater harvesting sites selection is more depend on the density of drainage present in a given areas, especially in areas where irrigation led agricultural activities is common. An area with high drainage density was rated higher in suitability for RWH structures compared to areas of low drainage density (Prinz *et al.*, 1998) (Figure 22).

Table 14: Drainage density suitability class.

Factor	Drainage Density(km/mk2)	Rate	Classification
Drainage density (Dd)	$Dd < 1.5$	1	Not Suitable
	$1.5 > Dd \geq 1.7$	2	Less Suitable
	$1.7 > Dd \geq 1.8$	3	Suitable
	$1.8 > Dd$	4	Very Suitable
	$Dd > 2$	5	Extremely Suitable

Source: (Abdel Rahman, 2016).

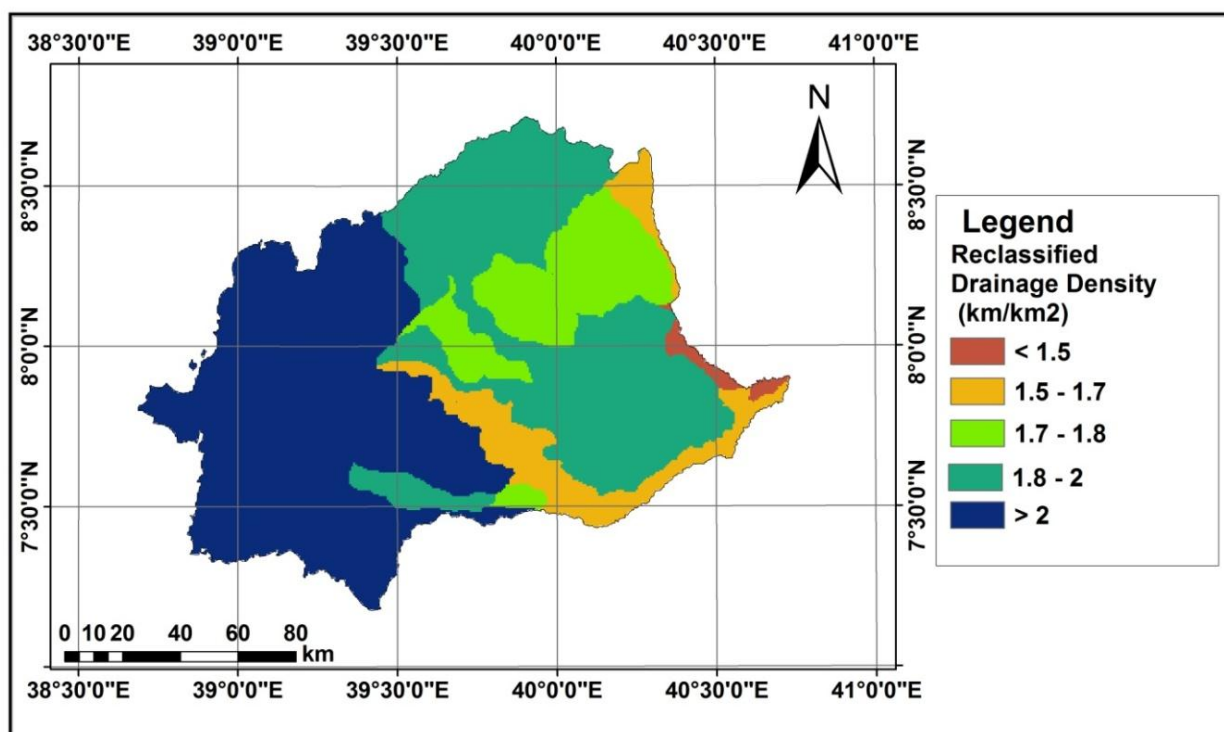


Figure 22: Reclassified drainage density factor map of the study area.

3.5.7 Lithology

Lithology of study area was reclassified based on the nature and permeability of lithological structure (Figure 23), which determine the infiltration of water to the ground (Table 15). Weathering, age and other factors make the lithology to fracture; this increases the permeability of bedrock to transmit water (see Appendix for detail lithological composition of study area). The study area does not have extreme permeable bedrock area (Rate 1).

Table 15: Lithology suitability class.

Factor	Type	Rate	Classification
Lithology	Upper sandstone (Ka)	2	Less Suitable
	Upper limestone (Mulsst), sedimentary (Musst), Alaji basalt (N1a), Ignimbrite, tuff (Tv3(2))	3	Suitable
	Basalt flow (Tv4), Late (Tv6), Pliocene trachyte (Tv7)	4	Very Suitable
	Quaternary basalt (Qv1)	5	Extremely Suitable

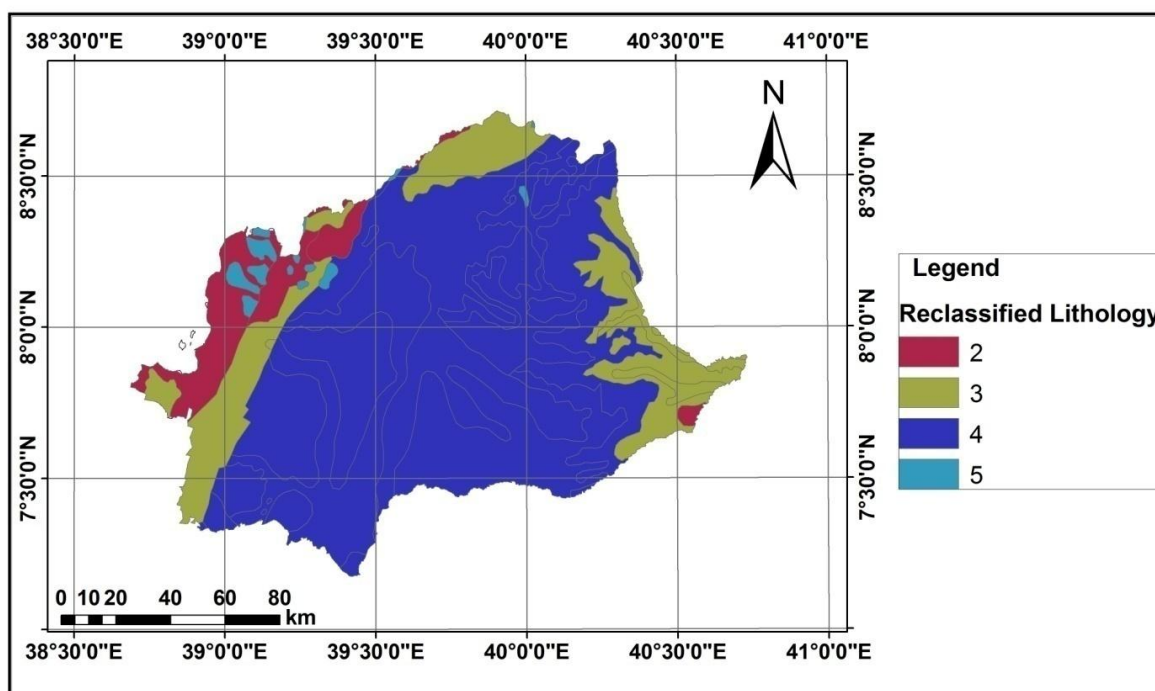


Figure 23: Reclassified lithology factor map of the study area.

3.5.8 Fault Proximity

Reclassification of fault layer was done based on the proximity of each land units to the nearby fault line (Table 16). Rainwater harvesting structure must not build within 1 km distance to major faults as result of geological nature of the study area. As the proximity of RWH structure to fault lines decreases, the area becomes more unreliable and unsuitable, which was rated low with regard to seismic activity of study area. On the other hand as land unit proximity is far apart from fault line, the land unit was reclassified and rated higher (Figure 24).

Table 16: Fault Proximity suitability class.

Factor	Fault distance (km)	Rate	Classification
Fault Proximity (F)	$F < 1$	1	Not Suitable
	$1 > F \geq 3$	2	Less Suitable
	$3 > F \geq 5$	3	Suitable
	$5 > F \geq 10$	4	Very Suitable
	$F > 10$	5	Extremely Suitable

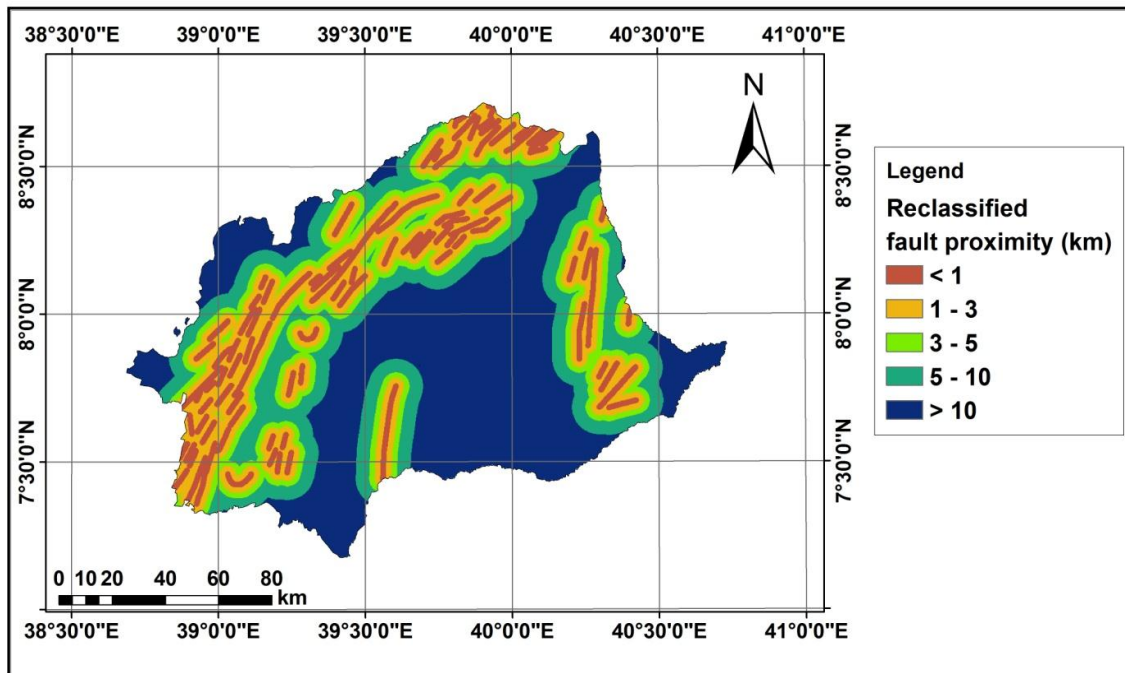


Figure 24: Fault proximity factor map of the study area.

3.5.9 Lineament Proximity

The amount of lineaments that were extracted from Landsat 8 OLI Band 7 image were analyzed with the occupied area to get the lineament proximity. Each land unit of the study area was

computed according to the Euclidean distance to the nearby lineament. Lineament proximity layer were reclassified into standardized category based on the amount of lineament present in a given area (Figure 25). A land unit present in higher lineament density (proximity) rated lower, and a land unit located in no lineaments or less lineament density area rated higher (Table 17).

Table 17: Lineament proximity suitability class.

Factor	Lineament density (km/km ²)	Rate	Classification
Lineament density (L)	$L > 3$	1	Not Suitable
	$2.5 > L \geq 3$	2	Less Suitable
	$1.5 > L \geq 2.5$	3	Suitable
	$0.75 > L \geq 1.5$	4	Very Suitable
	$L < 0.75$	5	Extremely Suitable

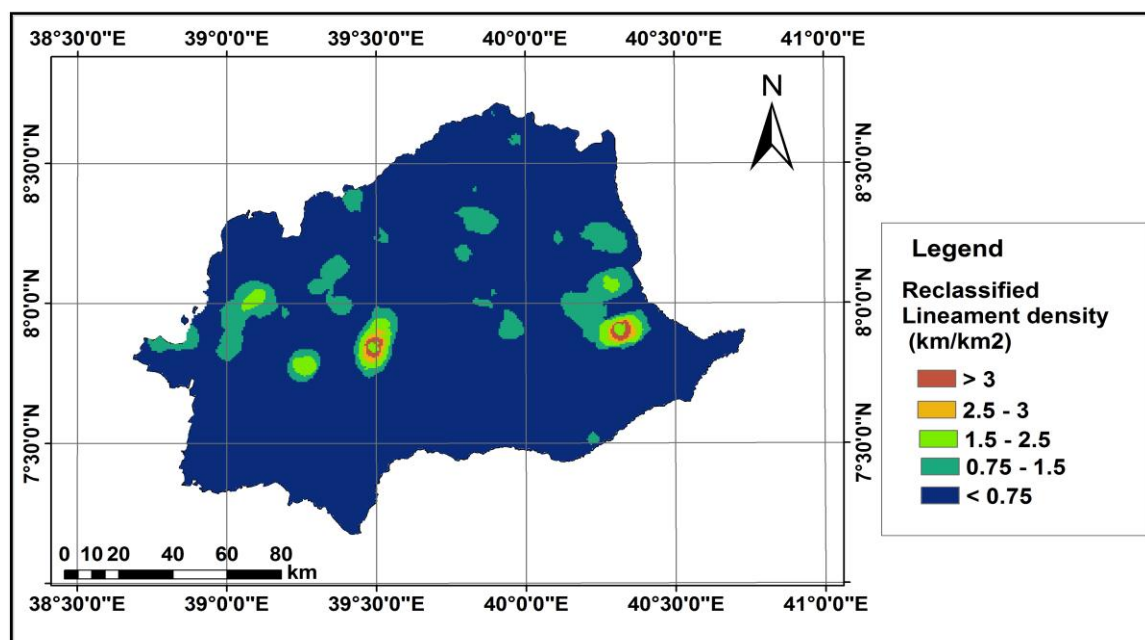


Figure 25: Lineament density factor map of the study area.

3.5.10 Distance to Settlement

Settlement layer was used to derive settlement proximity layer. The distance to settlement proximity layer was reclassified into five suitability classes (Table 18). In Arsi Zone where health facility is inadequate, farmers are prone to water borne diseases especially for malaria, which is stable surface water is suitable for mosquito reproduction (Kasahun, 2011). Therefore selecting a site away from settlement is more preferable. The standardized reclassification of this

layer was done based on the distance of each land parcel to the nearby settlements. As the land unit closes to the settlement the rate of the land unit become lower, as well as the land unit was rated higher if it is far from settlement (Figure 26).

Table 18: Distance to settlement suitability class.

Factor	Proximity(m)	Rate	Classification
Distance to Settlement (Ds)	$Ds < 1,000$	1	Not Suitable
	$1,000 < Ds < 5,000$	2	Less Suitable
	$5,000 < Ds < 10,000$	3	Suitable
	$10,000 < Ds < 15,000$	4	Very Suitable
	$Ds > 15,000$	5	Extremely Suitable

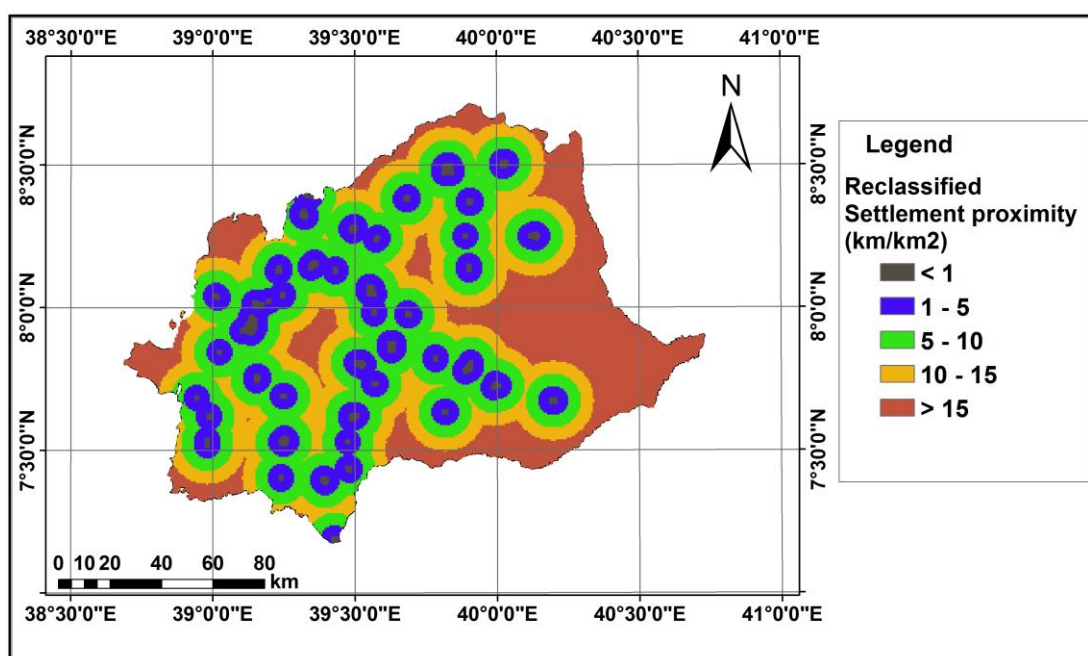


Figure 26: Distance to settlement proximity factor map of the study area.

3.5.11 Distance to Main Road

Road layer was used to derive road proximity layer of the study area. The distance to road proximity layer was reclassified in five suitability classes (Table 19). In Arsi Zone where most people settled and constructed a village near to the road, in some cases the RWH reservoirs may generate a flood to nearby areas. Therefore selecting a RWH sites away from road is more preferable. The standardized Reclassification of this layer was done based on the distance of

each land parcel to the nearby roads. As the land unit closes to the roads the rate of the land unit become lower, as well as the land unit was rated higher if it was far from road (Figure 27).

Table 19: Distance to main road suitability class.

Factor	Proximity (m)	Rate	Classification
Distance to Main Road (Dmr)	Dmr < 500	1	Not Suitable
	5,00 < Dmr < 1,000	2	Less Suitable
	1,000 < Dmr < 1,500	3	Suitable
	1,500 < Dmr < 2,000	4	Very Suitable
	Dmr > 2,000	5	Extremely Suitable

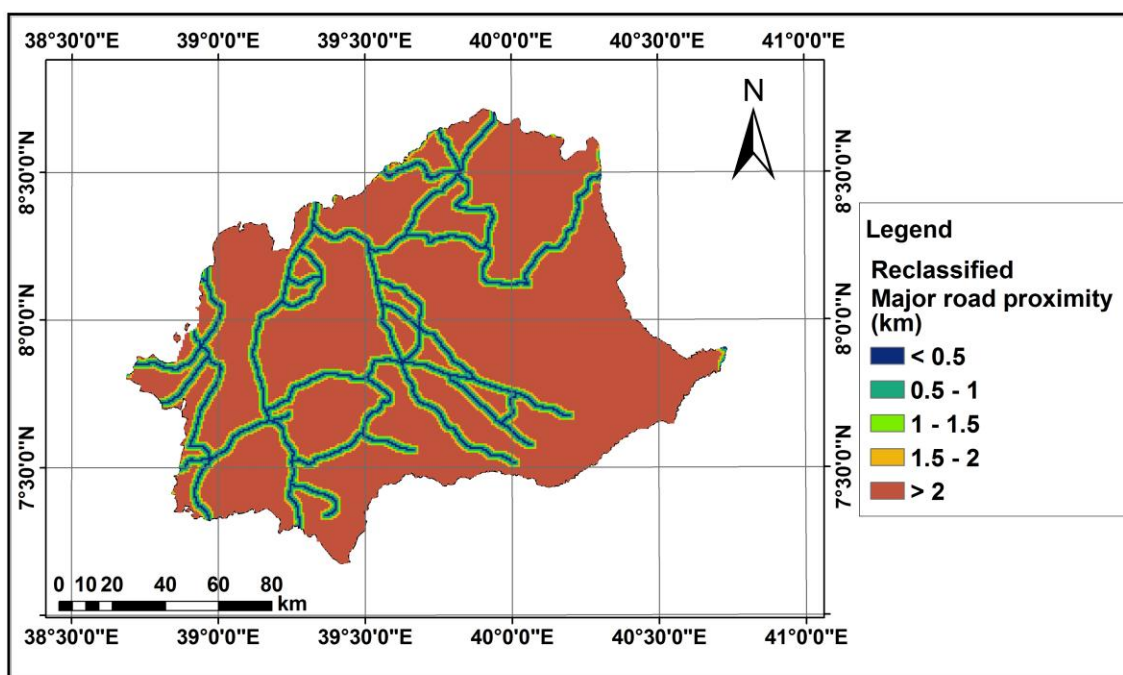


Figure 27: Distance to main road proximity factor map of the study area.

3.6 Modeling Fuzzy AHP

The above-standardized factor layers were fuzzified to get the fuzzified membership result of all criteria layers according Table 20, based on the reclassification made in the above section.

Table 20: Fuzzy standardized attribute values based on suitability for the RWH.

	Not Suitable	Less Suitable	Suitable	Very Suitable	Extremely Suitable
Fuzzy Score	0	0.2	0.5	0.8	1
Soil texture (clay content (%))	< 10	10 – 25	25 – 30	30 – 35	> 35
Slope (%)	$S > 30$	$10\% < S \leq 30$	$5\% < S \leq 10$	$2\% < S \leq 5$	$S < 2$
Elevation (m)	< 1,300 OR >2,600	1,300 – 1,600	1,600 – 2,000	2,000 – 2,400	2,400 – 2,600
Geology	-	High permeable Sandstone	Permeable and high grain size limestone and sedimentary	Felsic ignimbrite and tuffs	Basalt
Lineament	> 3	2.5 – 3	1.5 – 2.5	0.75 – 1.5	< 0.75
Fault (km)	< 1	1 – 3	3 – 5	5 – 10	> 10
LU/LC	Settlement	Forest	Shrubland	Agricultural land	Bareland
Runoff (mm)	< 250	250 – 600	600 – 750	750 – 1000	>1000
Drainage density (km/km ²)	< 1.5	1.5 – 1.7	1.7 – 1.8	1.8 – 2	> 2
Towns Proximity (m)	< 1000	1000 – 5000	5000 – 10000	10000 – 15000	>15000
Major Road Proximity	< 0.5	0.5– 1	1– 1.5	1.5 – 2	> 2

3.6.1 Establishing Decision Hierarchy

The decision hierarchy model of RWH site structured as shown in Figure 28, the hierarchy consists of the main objective at the top (RWH), followed by three levels of hierarchy. The 11 criteria (also known as factors) used in this research were divided into three main groups; environmental, hydrological and socio-economic factors, to form the second hierarchy. These were also further split into eight factors of which, four were environmental (Topography, Geology, Soil texture and LU/LC), two were hydrological (Runoff depth and Drainage density) and two were socio-economical (Distance from roads and Distance from settlements) to form the third hierarchy. The final hierarchy formed by dividing the topography and geology factors. Topography divided into slope and elevation sub-factors and Geology was divided into three sub-factors of lithology, faults and lineaments proximity. The examined criteria were selected based on the relevant literature specific major study area problem.

Layer in the higher hierarchical level was considered as a major influential layer for those in the lower level because major influential layer have an effect directly or indirectly to the lower one (Baban and Wan-Yusof, 2003). In addition, in a complete hierarchy, every layer in the lower hierarchical level affects every element in the upper hierarchical level. Therefore, the elements in the lower hierarchical level were then compared to each other based on their effect on the major influential layer above.

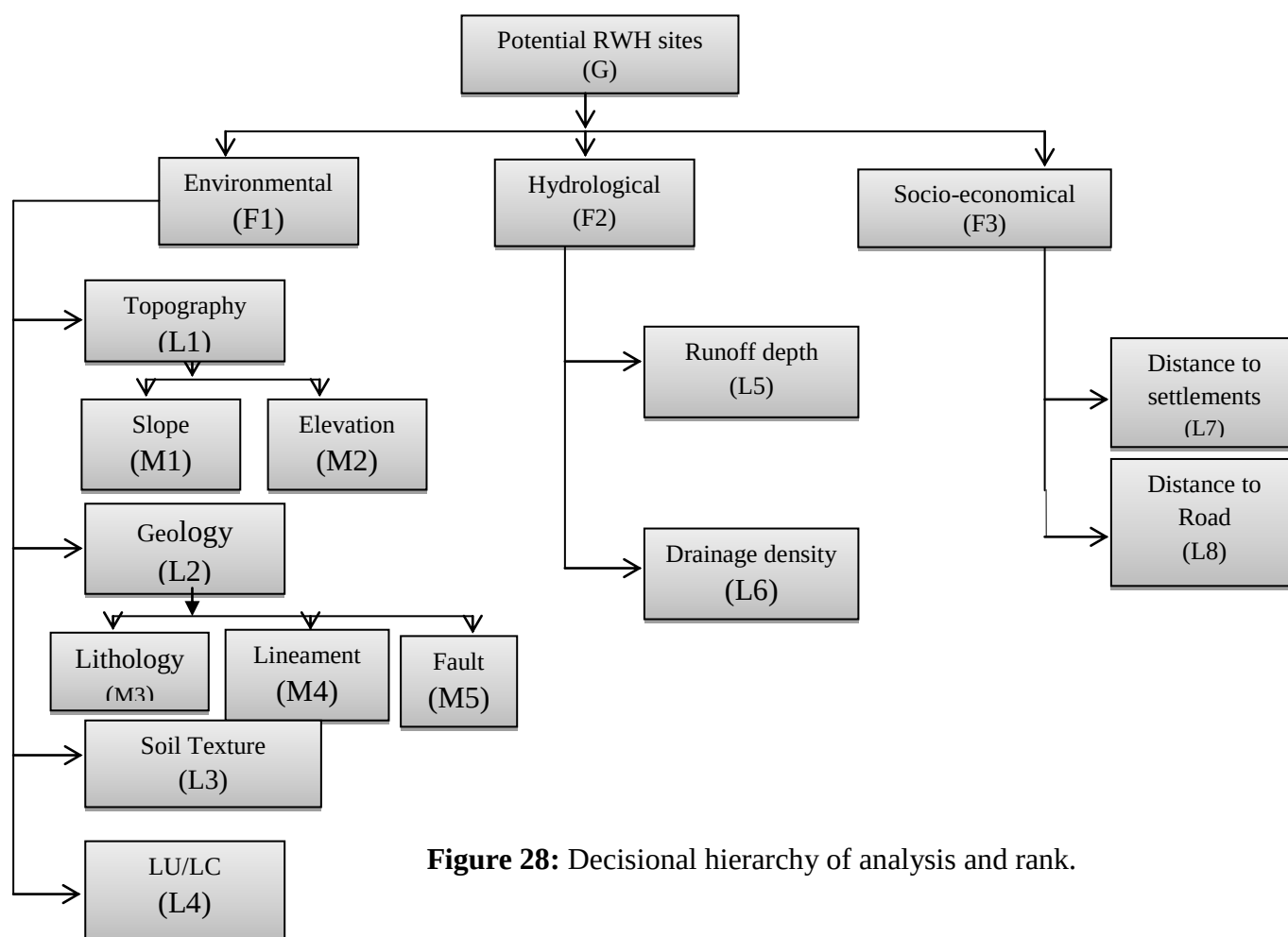


Figure 28: Decisional hierarchy of analysis and rank.

3.6.2 Triangular Fuzzy AHP Pairwise Comparison

Standardize layer Reclassification and rating were done to each criterion layers for determination of their relative importance. Each criteria layers was had their own impact on the outcome, through a quantitative rating. Therefore, it was possible to make most influential criteria have better impact on the result. Pairwise comparison method was selected for the assignment of weight for criteria layers. This method was selected because it directs the decision making

process to give a consideration thorough all criteria of a decision problem. Using this method each criterion layer was compared against every other criterion through personal experience, and understanding of the decision making problem. Pairwise comparison matrices were created for each of the lower hierarchical levels one matrix for each element in the level immediately above. This was done by considering which layer effect is dominant than the other. This decision matrix is expressed as integer value of ranging from 1 to 9 (Table 20). The fuzzy TFN approach was used to assign interval judgments that allows and minimize the decision making process ambiguity and complexity, which is expressed as l , m and u . Triangular fuzzy number membership functions is represented as follows:

$$\mu_A(x) = 0, \forall x \in (-\infty, l) \cup (u, \infty)$$

$$\mu_A(x) = 1, x = m \tag{10}$$

$$\mu_A(x) = (x-l)/(m-l), \forall x \in [l, m]$$

$$\mu_A(x) = (u-x)/(u-m), \forall x \in [m, u]$$

Table 21: Triangular Fuzzy Numbers (TFNs), linguistic variables used in this study.

Saaty's scale of relative importance	Definition	Membership function	Domain	TFNs scale (l,m,u)	Reciprocal-of Triangular-Fuzzy Numbers
	Just equal			(1.0,1.0,1.0)	(1.0,1.0,1.0)
1	Equal importance	$\mu_A(x)=(3-x)/(3-1)$	$1 \leq x \leq 3$	(1.0,1.0,3.0)	(1.0/3.0,1.0,1.0)
3	Moderately importance	$\mu_A(x)=(x-1)/(3-1)$	$1 \leq x \leq 3$	(1.0,3.0,5.0)	(1.0/5.0,1.0/3.0,1.0)
		$\mu_A(x)=(5-x)/(5-3)$	$3 \leq x \leq 5$		
5	Essential or strong importance	$\mu_A(x)=(x-3)/(5-3)$	$3 \leq x \leq 5$	(3.0,5.0,7.0)	(1.0/7.0,1.0/5.0,1.0/3.0)
		$\mu_A(x)=(7-x)/(7-5)$	$5 \leq x \leq 7$		
7	Demonstrated importance	$\mu_A(x)=(x-5)/(7-5)$	$5 \leq x \leq 7$	(5.0,7.0,9.0)	(1.0/9.0,1.0/7.0,1.0/5.0)
		$\mu_A(x)=(9-x)/(9-7)$	$7 \leq x \leq 9$		
9	Extreme importance	$\mu_A(x)=(x-7)/(9-7)$	$7 \leq x \leq 9$	(7.0,9.0,9.0)	(1.0/9.0,1.0/9.0,1.0/7.0)
2,4,6,8	Intermediate	-	-	-	-

Using TFN, the fuzzy decision matrices $\tilde{A}(\tilde{a}_{ij})$, used to construct pairwise comparisons for criteria layers at each level of the decision hierarchy, were in the form of:

$$\tilde{A} = (\tilde{a}_{ij})_{n \times n} \begin{bmatrix} (1.0, 1.0, 1.0) (l_{12}, m_{12}, u_{12},) \dots \dots \dots (l_{1n}, m_{1n}, u_{1n},) \\ (l_{12}, m_{12}, u_{12},) (1.0, 1.0, 1.0) \dots \dots \dots (l_{2n}, m_{2n}, u_{2n},) \\ (l_{n1}, m_{n1}, u_{n1},) (l_{n2}, m_{n2}, u_{n2},) \dots \dots \dots (1.0, 1.0, 1.0) \end{bmatrix} \quad (11)$$

Where $\tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij}) = \tilde{a}_{ij}^{-1} = (1/u_{ji}, 1/m_{ji}, 1/l_{ji})$ for $i, j = 1, \dots, n$ and $i \neq j$.

The number of comparisons at each decision hierarchy level was determined by the formulae $n(n-1)/2$, where n is the total number of criteria layers.

3.6.3 Determining Weights of Criteria

This research was used the Fuzzy Extent Analysis (FEA) method to get the weight of each criteria layer (Chang, 1996), which was applied after pairwise fuzzy comparisons decision matrix was done. The consecutive methodological steps followed for criteria weight determination were:

Step 1: Fuzzy synthetic extent value or normalized values of row sums were calculated for each of the of fuzzy TFN decision matrices, by using a fuzzy arithmetic operations as formulated in Equation 12.

$$\hat{S} = \sum_{j=1}^n \tilde{a}_{ij} \otimes \left[\sum_{k=1}^n \sum_{j=1}^n \tilde{a}_{kj} \right]^{-1} \quad (12)$$

Where $\otimes$ represents the extended multiplication of two fuzzy numbers. To find $\sum_{j=1}^n \tilde{a}_{ij}$ the fuzzy addition operation was applied to the fuzzy numbers in the fuzzy decision matrices, such that,

$$\sum_{j=1}^n \tilde{a}_{ij} = (\sum_{j=1}^n l_j, \sum_{j=1}^n m_j, \sum_{j=1}^n u_j) \quad (13)$$

To find $\left[\sum_{k=1}^n \sum_{j=1}^n \tilde{a}_{kj} \right]^{-1}$, the fuzzy addition operation was used to the column values in the matrix obtained from Equation 13, followed by computation of the inverse of the resulting vector such that

$$\left[\sum_{k=1}^n \sum_{j=1}^n \tilde{a}_{kj} \right]^{-1} = \left(\frac{1}{\sum_{k=1}^n u_k}, \frac{1}{\sum_{k=1}^n m_k}, \frac{1}{\sum_{k=1}^n l_k} \right) \quad (14)$$

Step 2: In this step two criteria at a time were taken and using their normalized TFN's obtained from Equation 12, to determine the degree of possibility of one criterion fuzzy number's being greater than or equal to the other criteria fuzzy number's ($\hat{S}_i \geq \hat{S}_j$). This can be represented as Equation 15.

$$V(\hat{S}_i \geq \hat{S}_j) = \sup_{y \geq x} [\min(\hat{S}_j(x), \hat{S}_i(y))] \quad (15)$$

This can be equivalently expressed as,

$$V(\hat{S}_i \geq \hat{S}_j) = \begin{cases} 1 & \text{if } m_i \geq m_j \\ \frac{l_j - u_j}{(m_i - u_i) - (m_j - l_j)} & \text{if } l_j \geq u_j \\ 0 & \text{Otherwise} \end{cases} \quad (16)$$

Where $\hat{S}_i = (l_i, m_i, u_i)$ and $\hat{S}_j = (l_j, m_j, u_j)$

In order to compare, $\hat{S}_i$ and $\hat{S}_j$, both the value of $V(\hat{S}_i \geq \hat{S}_j)$ and $V(\hat{S}_j \geq \hat{S}_i)$ were computed

Step 3: The basic principles in Step 2 were then extended to calculate the degree of possibility of, $\hat{S}_i$, of one criterion, being greater than all the other $(n-1)$ convex fuzzy numbers, $\hat{S}_j$, of other criteria. This can be defined as follows,

$$V(\hat{S}_i \geq \hat{S}_j | j=1, \dots, n; j \neq i) \quad (17)$$

By taking the minimum values in the degree of possibility sets created from Equation 17, it was possible to determine a weight vector, w , as follows,

$$w = (d^*(A_1), d^*(A_2), \dots, d^*(A_n))^T, \text{ where } d^*(A_i) = \min V(\hat{S}_i \geq \hat{S}_j | j=1, \dots, n; j \neq i) \quad (18)$$

Step 4: The normalized weight vectors for each fuzzy comparison matrix, $\tilde{A}$, at each level of the hierarchy were then determined by normalizing the weight vector, w . By dividing each value in the weight vector (w), by their total sum as follows,

$$w_i = \frac{V(\hat{S}_i \geq \hat{S}_j | j=1, \dots, n; j \neq i)}{\sum_{k=1}^n V(\hat{S}_i \geq \hat{S}_j | j=1, \dots, n; j \neq k)}, i = 1, \dots, n \quad (19)$$

The result of calculated weight (W) for each criteria layers in the decisional hierarchy is shown in the last column for Tables 22 to 27.

3.6.4 Fuzzy Consistency Ration

Fuzzy consistency ratio method was used to determine whether the weight criteria layers is consistent or not. The computation of this algorithm is based on the preference ratio concept. The followed steps of the algorithm were:

Step 1: A fuzzy matrix $\tilde{H}$ was defined such that:

$$\tilde{h}_{ij} = w_j * \tilde{a}_{ij} \quad (20)$$

where w_j is the weight for the j^{th} criteria or attribute, for $j = 1 \dots, n$, and $\tilde{a}_{ij}$ are the TFN's in the fuzzy judgement matrix.

Step 2: $\tilde{h}_{ia}$ values in each i^{th} row of the matrix $\tilde{H}$ were summed as follows, n

$$\tilde{S} = \sum_{j=1}^n \tilde{h}_{ij} \quad (21)$$

Step 3: $\tilde{\lambda}$ (for $i = 1$ to n) value is calculated

$$\tilde{\lambda} = \frac{\tilde{S}_i}{w_i} \quad (22)$$

Step 4: The Consistency Index (CI) was then calculated as follows:

$$CI = \frac{\frac{1}{n} \sum (\tilde{\lambda}_i - n)}{n-1} \quad (23)$$

Where n is the dimension of the fuzzy judgment matrix

Step 5: The FCR was then calculated using the following formula:

$$FCR = \frac{CI}{RI} \quad (24)$$

Where RI is the random consistency index, which is obtained from Table 21.

Table 22: Random Indices for Consistency Check.

N	2	3	4	5	6	7	8	9	10
RI	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.51

N = dimension of judgment matrix.

Table 23: The TFN pairwise comparison matrix of G ← F1–F3.

G	F1	F2	F3	W
F1	(1,1,1)	(1.0,3.0,5.0)	(3.0,5.0,7.0)	0.573454
F2	(0.20,0.333,1)	(1,1,1)	(1.0,3.0,5.0)	0.375408
F3	(0.143,0.2,0.333)	(0.20,0.333,1)	(1,1,1)	0.051138

FCR = 0.011927035, G = Rainwater harvesting site suitability, F1 = Environmental factors, F2 = Hydrological factors, F3 = Socio-Economic factors and W is the weight of F1, F2 and F3 to G.

$V(SF1 \geq SF2, SF3) = 1$; $V(SF2 \geq SF1, SF3) = 0.654643557$; $V(SF3 \geq SF1, SF2) = 0.089175$

Table 24: The TFN pairwise comparison matrix of F1 ← L1–L4.

F1	L1	L2	L3	L4	W
L1	(1,1,1)	(1.0,3.0,5.0)	(3.0,5.0,7.0)	(5.0,7.0,9.0)	0.475603
L2	(0.2,0.333,1)	(1,1,1)	(1.0,3.0,5.0)	(3.0,5.0,7.0)	0.337951
L3	(0.143,0.2,0.333)	(0.2,0.333,1)	(1,1,1)	(1.0,3.0,5.0)	0.150307
L4	(0.111,0.143,0.2)	(0.143,0.2,0.333)	(0.2,0.333,1)	(1,1,1)	0.036139

FCR = 0.016, F1 = Environmental factors, L1 = Topography, L2 = Geology, L3 = Soil, L4 =

LU/LC, W is the weight of L1, L2, L3, L4 to F1. $V(SL1 > SL2, SL3, SL4) = 1$; $V(SL2 > SL1,$

$SL3, SL4) = 0.710573$; $V(SL3 > SL1, SL2, SL4) = 0.316035$; $V(SL4 > SL1, SL2, SL3) =$

0.075987

Table 25: The TFN pairwise comparison matrix of F2 ← L5–L6.

F2	L5	L6	W
L5	(1,1,1)	(1.0,3.0,5.0)	0.700023
L6	(0.2,0.333,1.0)	(1,1,1)	0.299977

FCR = 0.000, F2 = Hydrological factors, L5 = Runoff, L6 = Drainage density, W is the weight of

L5, L6 to F2 $V(SL5 \geq SL6) = 1$; $V(SL6 \geq SL5) = 0.428525512$

Table 26: The TFN pairwise comparison matrix of F3 ← L7–L8.

F3	L7	L8	W
L7	(1,1,1)	(1.0,3.0,5.0)	0.700023
L8	(0.2,0.333,1.0)	(1,1,1)	0.299977

FCR = 0.000, F3 = Socio-economic factors, L7 = Distance from settlement, L8 = Distance from

Road, W is the weight of L7, L8, to F3. $V(SL7 \geq SL8) = 1$; $V(SL8 \geq SL7) = 0.428525512$

Table 27: The TFN pairwise comparison matrix of L1 ← M1–M2.

L1	M1	M2	W
M1	(1,1,1)	(1.0,3.0,5.0)	0.700023
M2	(0.2,0.333,1.0)	(1,1,1)	0.299977

FCR = 0.000, L1 = Topographic factor, M1 = Slope, M2 = Elevation, W is the weight of M1,

M2, to L1. $V(SM1 > SM2) = 1$; $V(SM2 > SM1) = 0.428525512$

Table 28: The TFN pairwise comparison matrix of L2 ← M3–M5.

L2	M3	M4	M5	W
M3	(1,1,1)	(1.0,3.0,5.0)	(3.0,5.0,7.0)	0.573454
M4	(0.20,0.333,1)	(1,1,1)	(1.0,3.0,5.0)	0.375408
M5	(0.143,0.2,0.333)	(0.20,0.333,1)	(1,1,1)	0.051138

FCR = 0.016, L2= Geologic factor, M3 = Lithology, M4 = Lineament, M5= Fault W is the weight of M3, M4, M5, to L2. $V(SM3 > SM4, SM5) = 1$; $V(SM4 > SM3, SM5) = 0.654643557$; $V(SM5 > SM3, SM4) = 0.089175$;

The FCR of all decision matrices were below 10%, which indicates that the assigned weight of all criteria layers were acceptable.

3.6.5 Calculating the Final Weights of Each Criteria Layers

The weight (W_i) of every criteria layers to the main objective of the decisional hierarchy (G) was calculated by normalizing the weight (w) of each factor shown in TFN pairwise comparison matrices. This was done by multiplying the weight of a factor in the lower level by that of the element/s in the upper level if only if they are in the same decisional hierarchical family. For example, to get the final weight of the slope criteria layer (represented by M1 in the hierarchy), the following formulae was used,

*Final weight of M1 = weight of M1to L1 * weight of L1 to F1* weight of F1 to the objective of G*

This was done for all the criteria layers, resulting sum of all the final weights is 1.

3.6.6 Fuzzy Weighted Linear Aggregation

Weighted Linear Combination (WLC) method was used for fuzzy aggregation, for multi-criteria evaluation analysis. This weighted linear combination was employed to calculate the sum of the weighted criteria. Weighting was given by multiplying the weight of the criteria layers by its standardized membership value as shown in Equations 25.

$$S_s = \sum W_i * X_i \quad (25)$$

Where, S_s is suitable site, W_i is weight of criteria layer i and X_i is the membership value of criteria layer i .

3.7 Constraints

In this study faults, settlements and major roads were considered as a constraint. Faults were buffered as they represents spatial influence that would lead to leakage for the surface water, similarly Settlement and major roads were also buffered as they have not socio-economic benefits and to avoid risk of malaria and water-borne diseases. After the constraints was considered in the suitability analysis, the final potential RWH sites suitability is represented in equation 26.

$$S_s = (\sum w_i * x_i) * \prod c_j \quad (26)$$

Where, C_j is the criteria score of the constraint j .

3.8 Sites Proposing for Rainwater Harvesting Structure

In this research from multiple RWH structure types Check dam, Farm pond and Percolation tank were chosen. Based on the result of final potential RWH layer as well as the drainage network layer, LU/LC, lithology and slope layer, potential sites were identified. Possible potential RWH site locations and structure types were chosen based on reviewed literature criteria (Table 29).

Table 29: Rainwater harvesting structure criteria's.

Type	Geology	LU/LC	Slope	Drainage
Check Dam	Granite/Genissic Fine textured soil	Cropping land and The rainfall in the catchment should be less than 1000 mm/yr	Gentle Slope, < 15%	fifth and sixth order Stream
Farm pond	Fine textured soil	Agriculture	Land slope: < 3%	Second and third order
Percolation Tank	Terrain with highly fractured and weathered rock, light sandy type	Land with Scrub/shrub and area should be uncultivated as far as possible	Moderate Slope 3 to 5% and A tank can be located either across small streams.	second, third or fourth order stream

Source: (Prasad *et al.*, 2014; Zende and Atal, 2015).

CHAPTER FOUR

4 RESULTS

4.1 Criteria layers weight

The result of the calculated criteria layers weight shows that, runoff depth is the dominant factor followed by slope, drainage density, lithology, soil texture, elevation, lineament density, distance to settlement, LU/LC, distance to major road and distance to fault as shown in Table 30.

Table 30: Final weight criteria for all thematic factors layers.

Objective G	Hierarchy F	Hierarchy L	Hierarchy M	W _f
G	F1	L1	M1	0.190921783
			M2	0.08181466
		L2	M3	0.111135014
			M4	0.072753827
			M5	0.009910511
		L3		0.08619415
		L4		0.020724054
	F2	L5		0.262794234
		L6		0.112613766
		L7		0.035797776
	F3	L8		0.015340224
Total				1.00

4.2 Rainfall and Runoff Characteristics

The result of average rainfall per month for the 25-year period (1990–2015) shows that the rainy season begins in July and ends in September. Dry season occurs from October to February (Figure 29). Rainfall was lowest in December, with monthly average of 13.13 mm, while highest rainfall falls in August, with monthly average of 175 mm. The main rainfall season was during July – September and the short rainfall season is during October – February contributing 56% and 16.12% respectively, of the total mean annual runoff.

The correlation between rainfall and runoff depth layers was 0.9893, which was near to one. This indicates that the two criteria have high positive correlation in most part of the study area (Figure

30). Both highly correlated factors will not be included as a criteria layer in analysis, to avoid redundancy and factor dominance in the result.

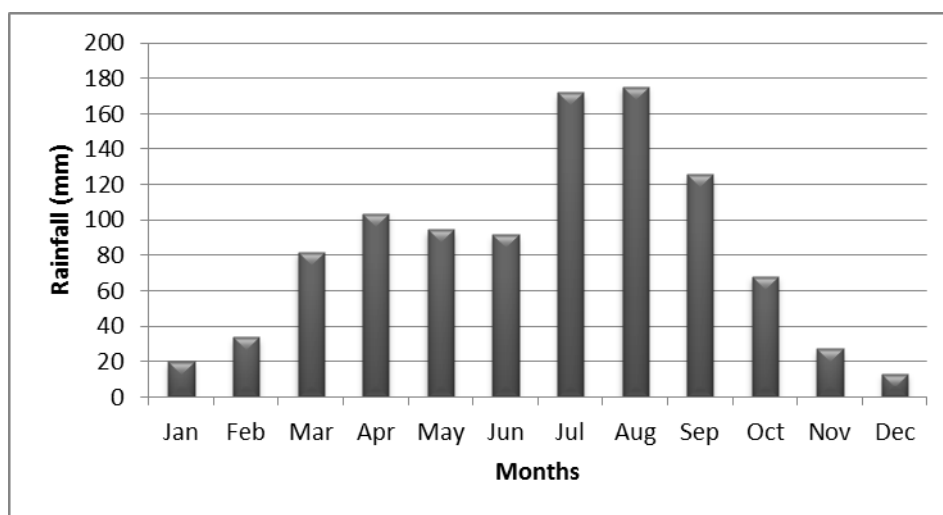


Figure 29: Average of monthly rainfall in the study area (1990–2015).

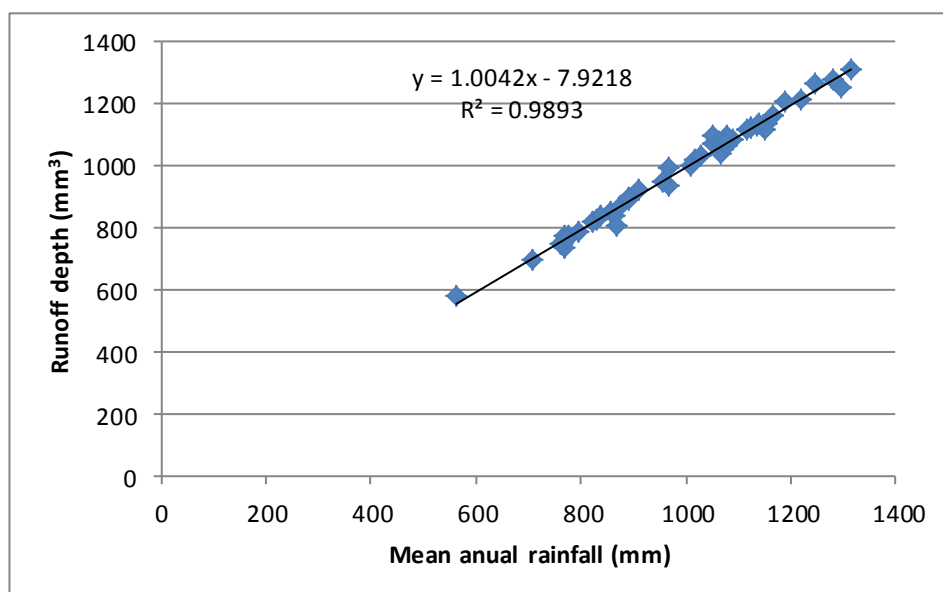


Figure 30: Correlation between mean annual rainfall and annual runoff depth.

4.3 Fuzzy Membership Result

The result of standardized and fuzzified suitability map of each criteria layer of soil texture, slope, elevation, geology, lineament proximity, fault, LU/LC, runoff depth, drainage density, settlement proximity and major road proximity was presented according to the standardized attribute values based on potential RWH suitability sites selection (Table 20).

Soil Texture

The fuzzified soil texture result (Figure 31) revealed that, most part of the study area are under extremely suitable class for RWH, except in central mountainous area, northern, north eastern and some western part of the study area.

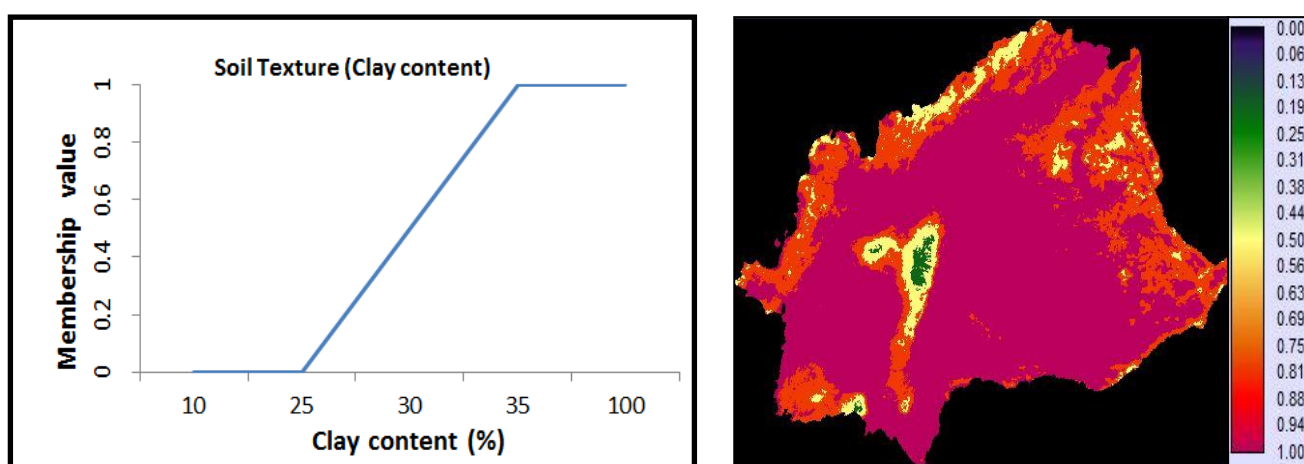


Figure 31 Fuzzified soil texture suitability of the study area.

Slope

Fuzzified slope layer result reveals that, the study area is covered with erratic topography that make most part of the study area under sloping level. Some parts of the study area are under not suitable class and less suitable class for RWH, i.e. eastern, southern and some central part of the study areas are covered with higher altitude mountains such as Chilalo Mountain that generate high steeply land surface. Some central southwestern parts of the study area are suitable for RWH as shown in Figure 32.

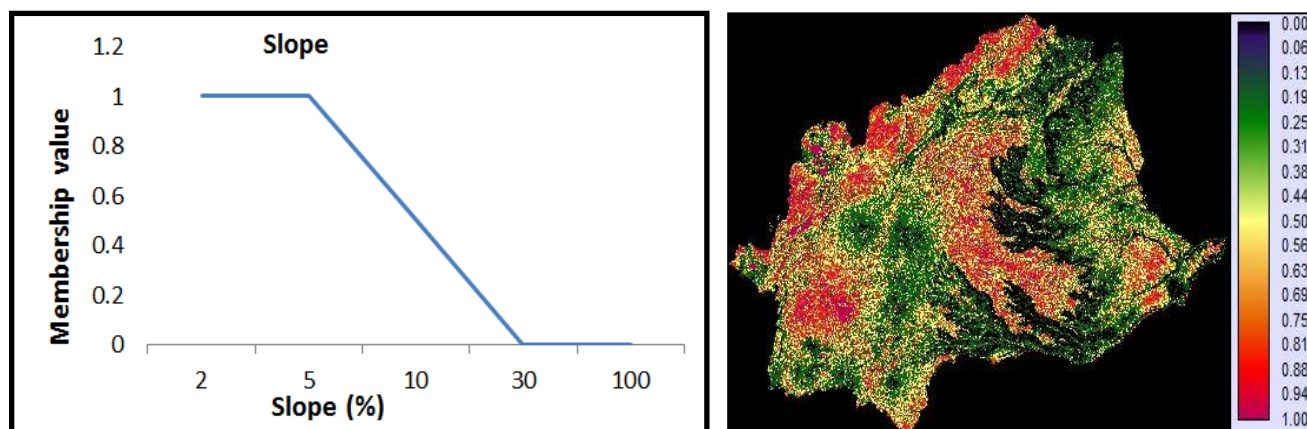


Figure 32: Fuzzified slope suitability of the study area.

Land-use/land-cover

Result of fuzzified LU/LC map reveal that, most central part of the study area are covered with agricultural/cropland and bareland, which is suitable for RWH. An area under settlement is fuzzified as not suitable class (0 membership values) as shown in Figure 33.

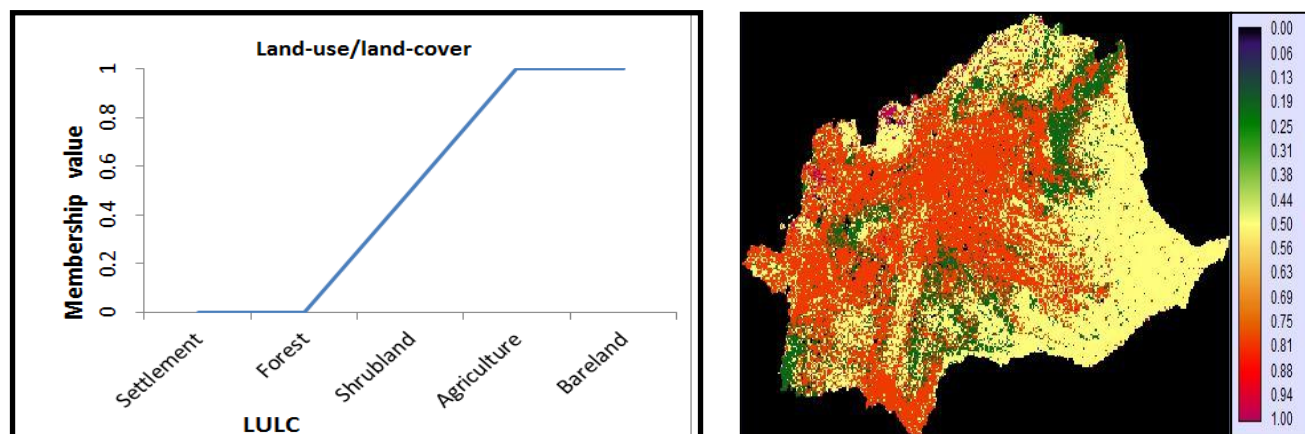


Figure 33: Fuzzified land-use/land-cover suitability of the study area.

Runoff depth

The result of fuzzified runoff depth layer map shows that, most part of the study areas are fuzzified under the range of very suitable to extremely suitable (0.8 – 1) classes. These reveal that most part of the study area is suitable for RWH interms of runoff depth. However, some eastern, northern and wester part of the study area are less suitable for RWH as shown in Figure 34 .

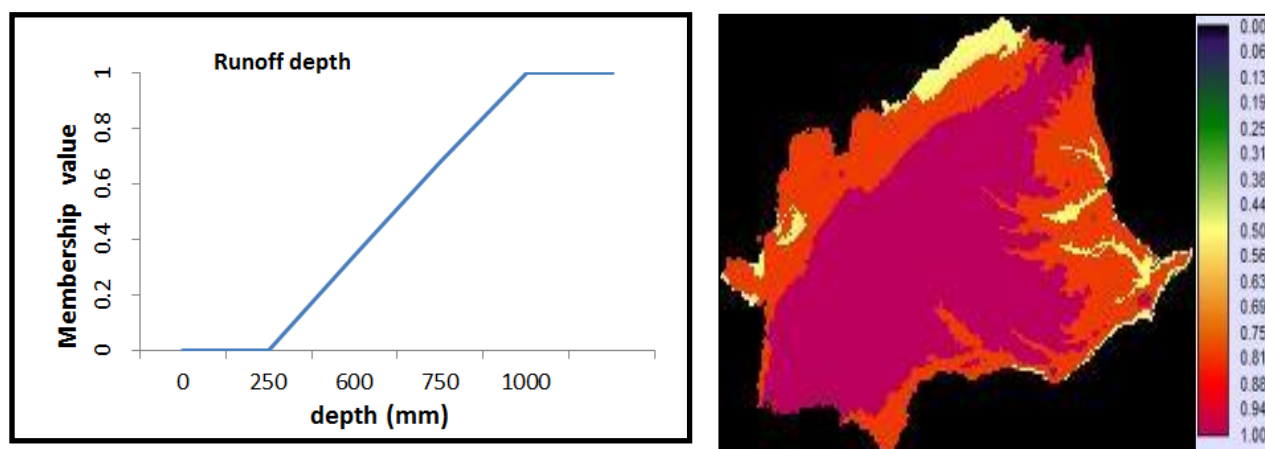


Figure 34: Fuzzified runoff depth suitability of the study area.

Lineament proximity

The fuzzification result of lineament proximity/density shows that, several part of the study area is exposed for lithological discontinuities. Eventhogh, most part of the study area is suitable for RWH, some western, central and eastern part of the study area is not suitable (Figure 35).

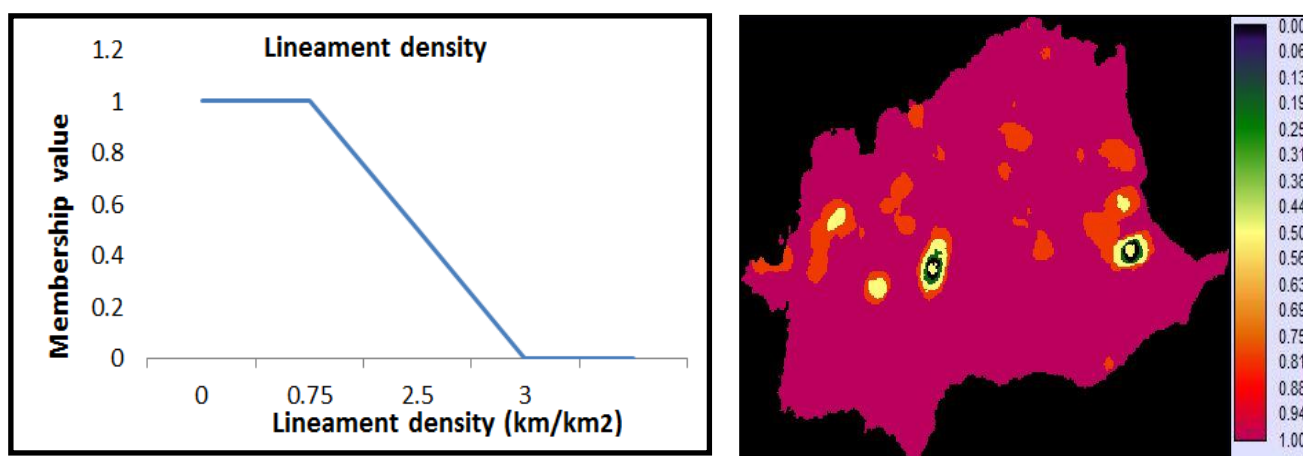


Figure 35: Fuzzified Lineament proximity suitability of the study area.

Fault proximity

The fuzzified fault layer result shows that, most part of the study area is exposed to nearby faults, which is not suitable especially the area lies inside main Ethiopian rift vally and eastern part of the study area where large altitudinal difference exists. Central part of the study area located far

from neighbouring fault lines, which is rated greater than 0.8 membership value is still extremely suitable for RWH (Figure 36).

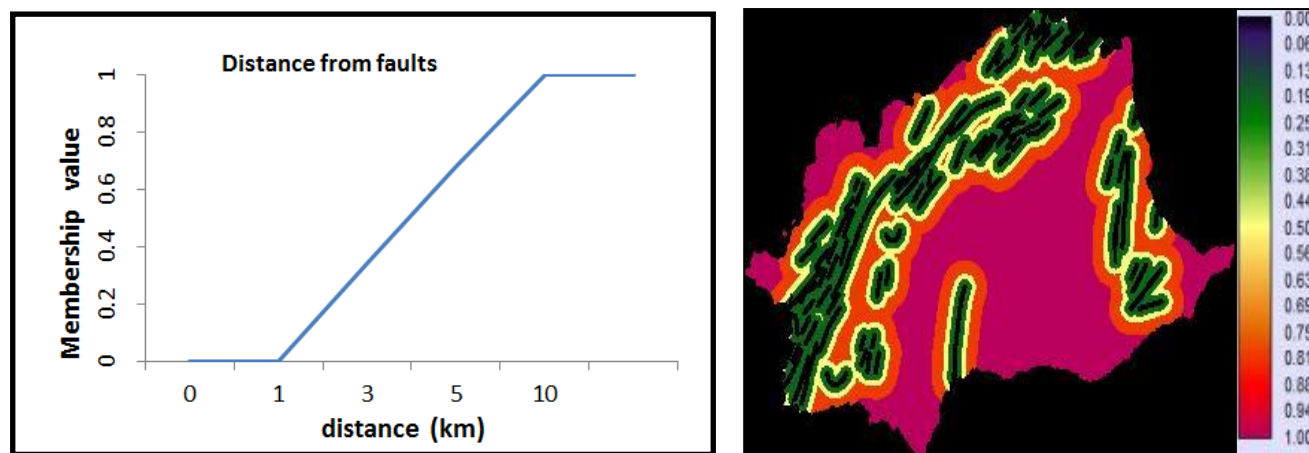


Figure 36: Fuzzified fault proximity suitability of the study area.

Drainage density

The result of drainage density fuzzification reveals that, southern and western part of the study area is extremely suitable, as well as most northern and eastern part of the study area is very suitable. However, particular areas in southeastern and northern part of the study area resemble to less suitable (Figure 37).

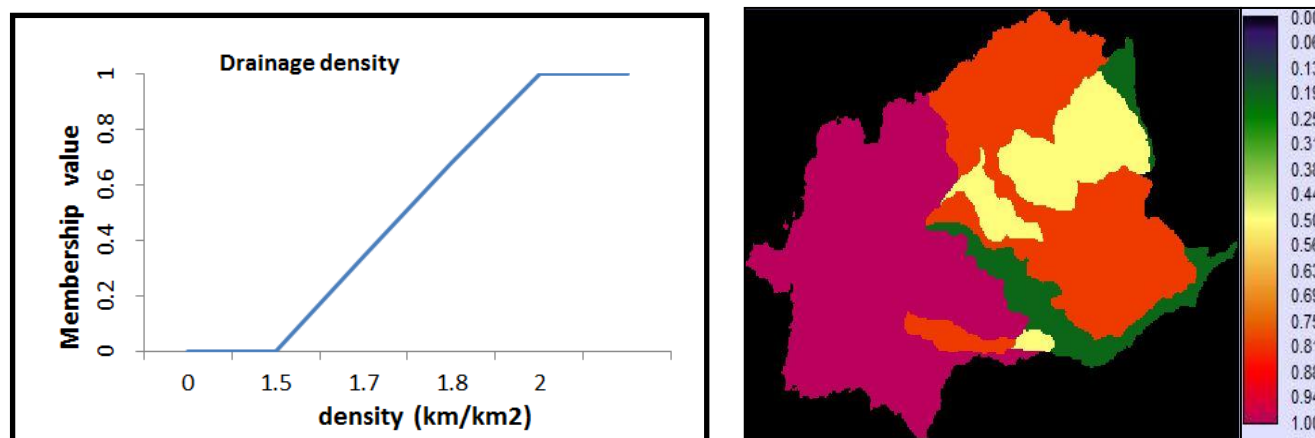


Figure 37: Fuzzified drainage density suitability of the study area.

Elivation

Eventhough, the fuzzification elivation result shows most central and southern part of the study area is rated greater than 0.8 fuzzification value, which is suitable for RWH. But large eastern, western and north western part of the study area is fuzzified below suitable class of 0.5 fuzzification value (Figure 38).

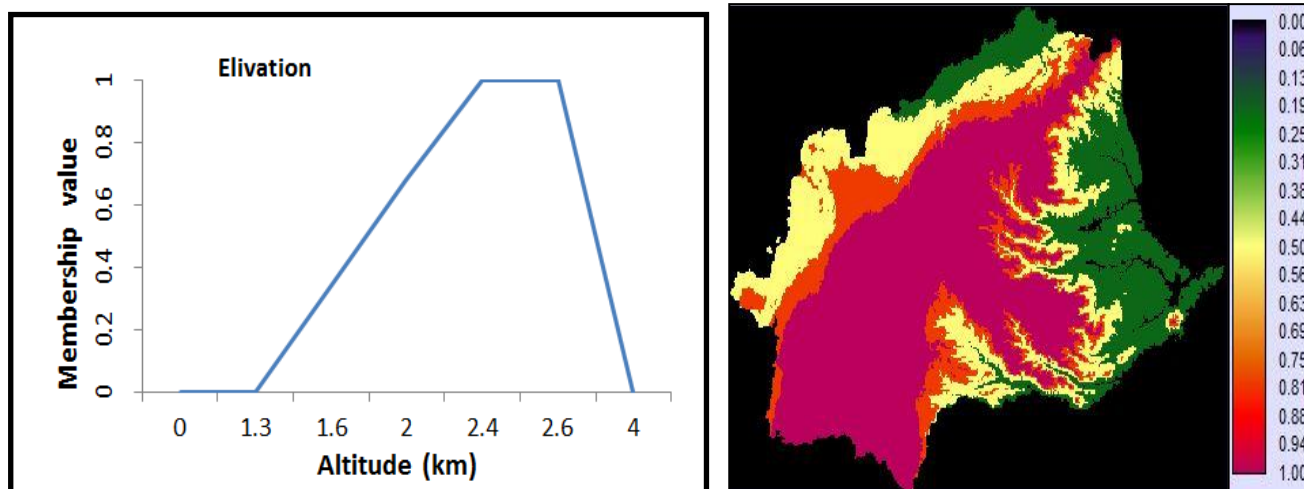


Figure 38: Fuzzified elevation suitability map of the study area.

Major road proximity

Large portion of the study area is suitable, scoring fuzzification value of greater than 0.8. Some part of a study area is less suitable, where a land unit is close to 1 km from major road (Figure 39).

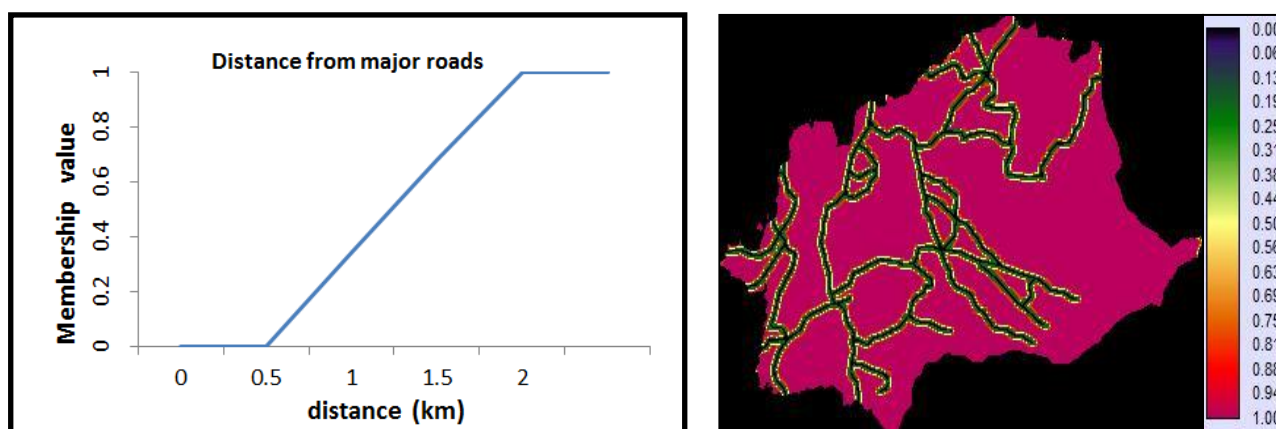


Figure 39: Fuzzified major road proximity suitability map of the study area.

Settlement Proximity

The fuzzified settlement proximity result shows that, due to considered health risk problem with related to RWH implementation, some central, western and northern part of the study area is less suitable and not suitable having a fuzzification value of less than 0.5. An area located 1.5 km away from settlements, in eastern and central part of the study area is very suitable and exteamey suitable (Figure 40).

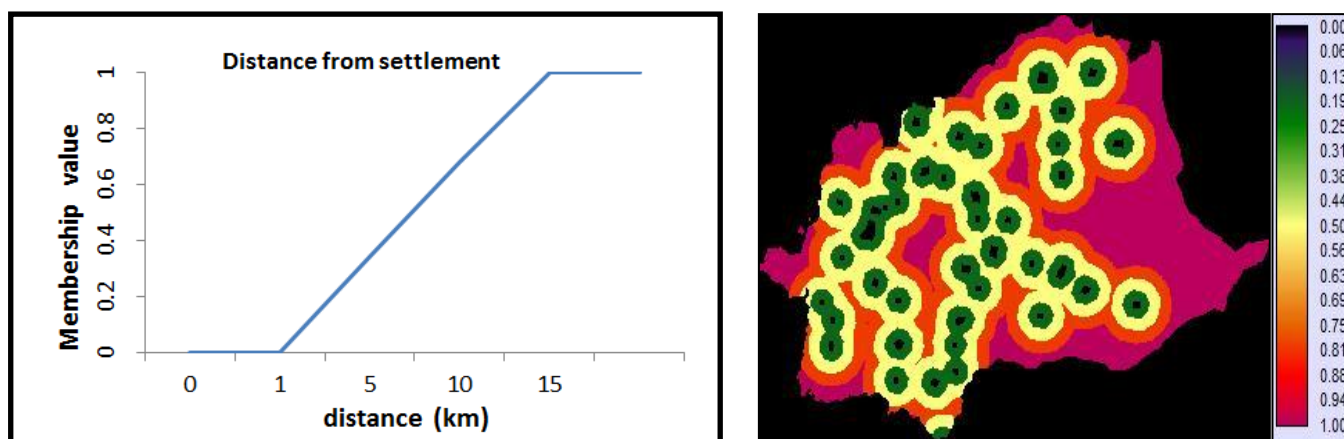


Figure 40: Fuzzified settlement proximity suitability map of the study area.

Lithology

As the result of fuzzified lithology layer map shows, most part of the study area geology is very suitable for RWH. Some eastern, northern and western part of the study area is resulted as suitable lithological class for RWH (Figure 41).

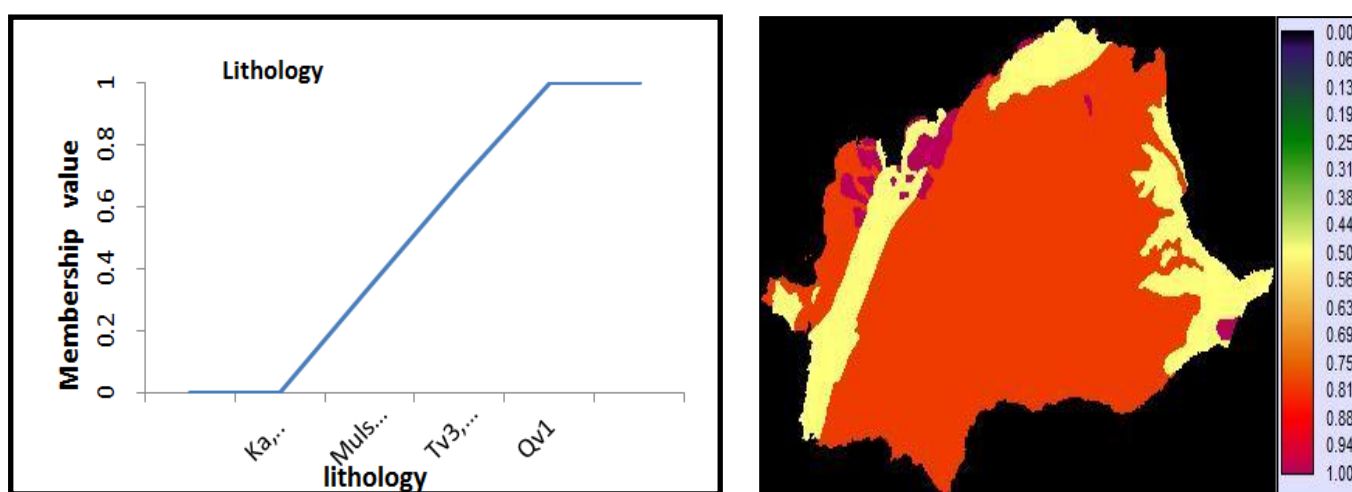


Figure 41: Fuzzified lithology suitability map of the study area.

4.4 Potential RWH Area Map

Using fuzzy AHP analysis that took into account various physical layers, potential site suitability areas for RWH were identified in the spatial extents of the study area. All the factors and group of factors were integrated to produce five suitability classes based on weighted linear combination (WLC) of fuzzy aggregation suitability index values (Figure 42). The potential sites for RWH as identified reflect specific suitability levels of parameters and weight of factors applied in the analysis.

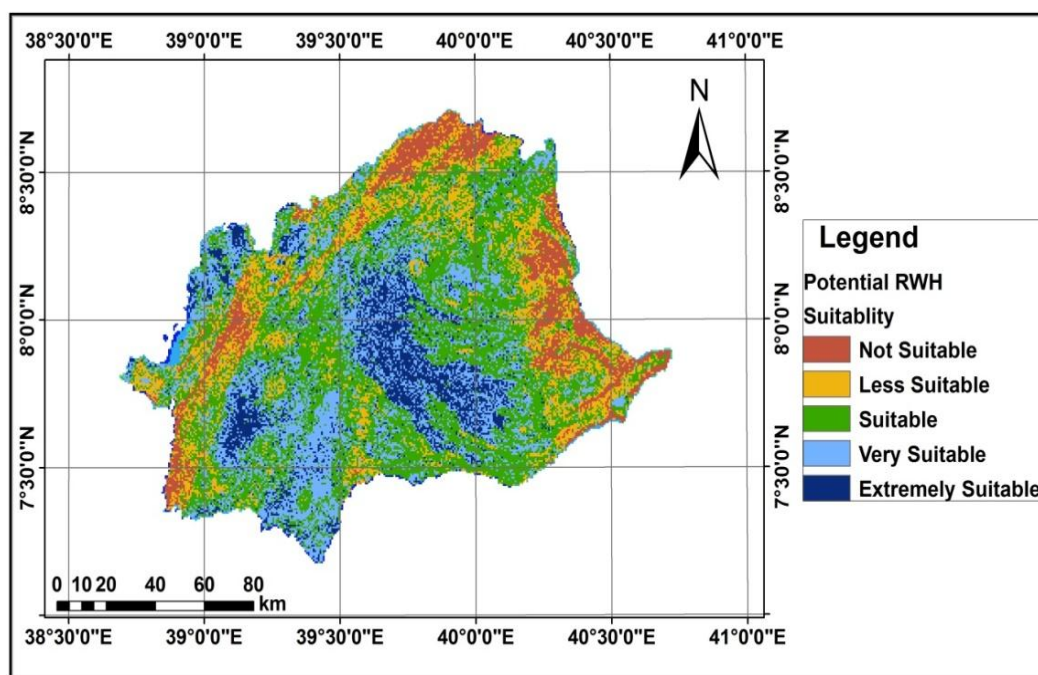


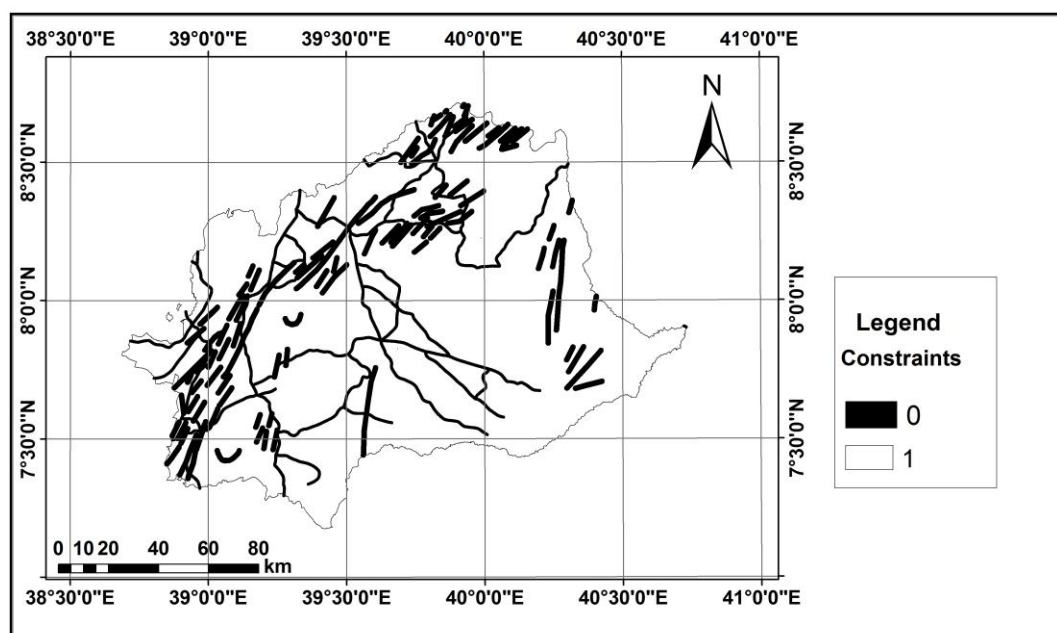
Figure 42: Potential rainwater harvesting suitability map of the study area.

4.5 Constraints Layer Map

The result of constraint set back buffer Zone criteria layers of settlement, major road and faults shows that, it was the combined and transformed constraint layers to Boolean constraint map together (Table 32). The Boolean constraint map of the study area was presented in the constraint map, this layer is divided into two classes, the excluded areas have 0 value (Black color) which indicate not suitable area and the rest of areas have a value of 1 (White color) which is suitable area for RWH (Figure 43).

Table 31: Constraint and restricted area factors.

Factors	Distance (m)	Rank	Classification
Distance to settlement	> 1000	1	Suitable
	$\leq$ 1000	0	Not Suitable
Distance to road	> 500	1	Suitable
	$\leq$ 500	0	Not Suitable
Fault	> 1000	1	Suitable
	$\leq$ 1000	0	Not Suitable

**Figure 43:** Combined constraint map of the study area.

The constraint Boolean layer was multiplied with the final RWH suitability layer with the same resolution of the study area (Figure 44 & 45). As the result of this study reveals, from the total study area 4,540.37 km² (21.94%) of the study area was kept as a constraint. Out of this major roads, faults and settlements cover 2,367.37 km² (52.14%), 1873 km² (41.25%) and 300 km² (6.6%), respectively.

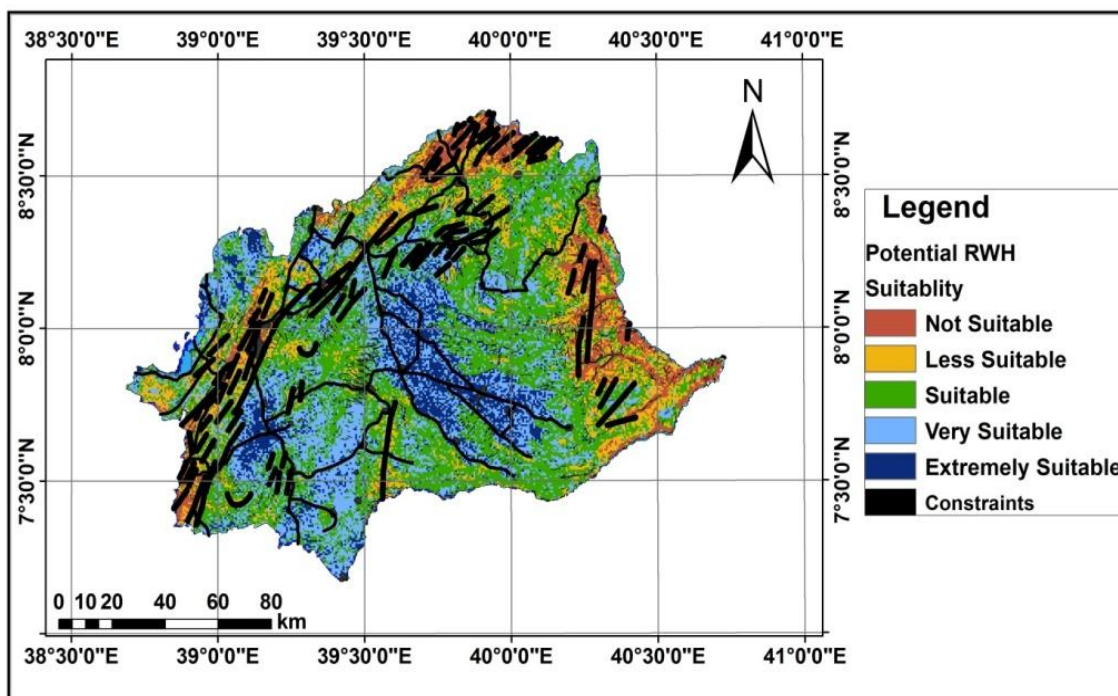


Figure 44: Identified Potential rainwater harvesting Zones of the study area.

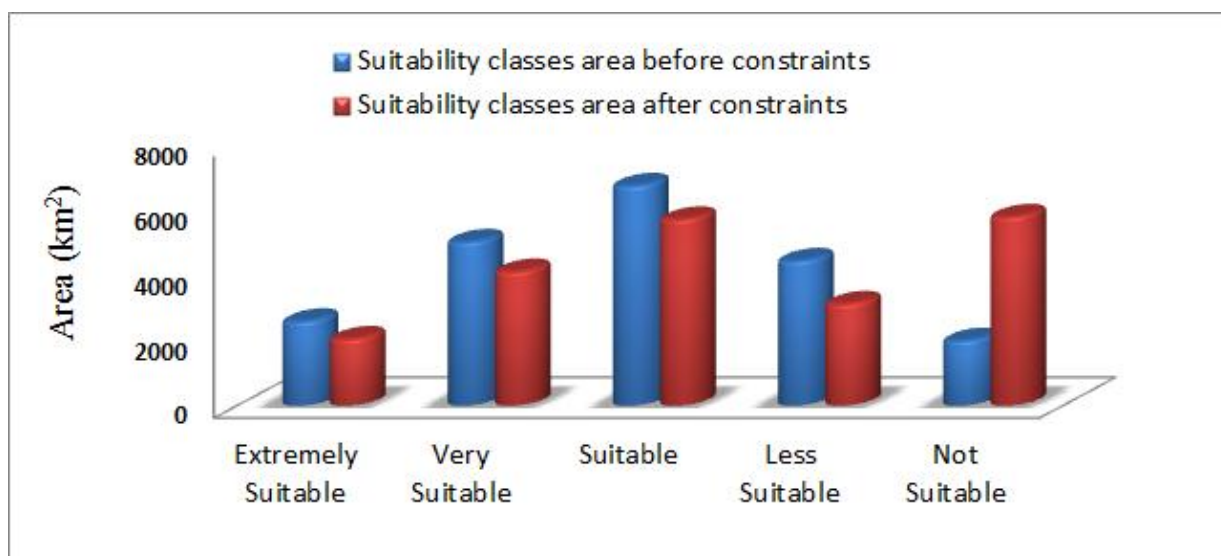


Figure 45: Potential rainwater harvesting suitability area class of the study area.

4.6 Rainwater Harvesting Suitability Sites

Rainwater harvesting suitability results of this research reveal that, 57% of the total area is suitable for farm pond, percolation tank and check dam. Each selected RWH structure for this

research covers an area of: farm pond (16%), percolation tank (9%) and check dam type (32%). The remaining 43% of the study area is less and not suitable for selected RWH structure types (Figure 46).

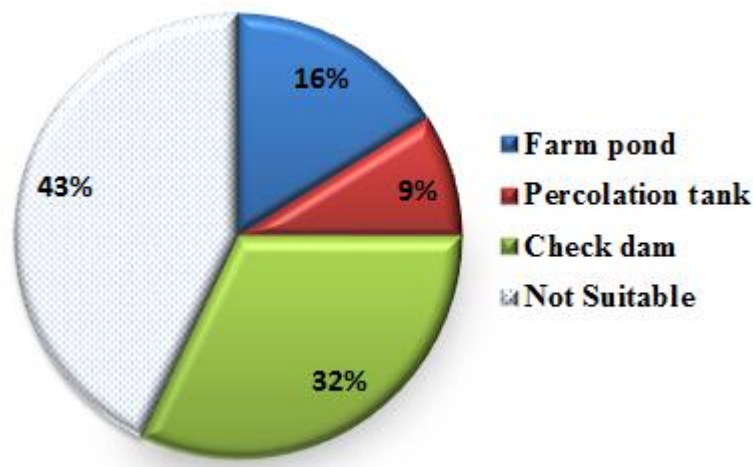


Figure 46: Rainwater harvesting structure type's and area coverage.

Potential RWH Sites for Check Dams

The result of potential RWH proposed sites for check dam shows that, proposed RWH construction sites are located across small streams having gentle slope, hard rock as well on alluvial formation bedrock. Most part of the study area is suitable for check dam construction (Figure 47). From 6,642.86 km² check dam suitable area, 19 RWH check dam sites is proposed for this specific research for supplementing irrigation during dry season.

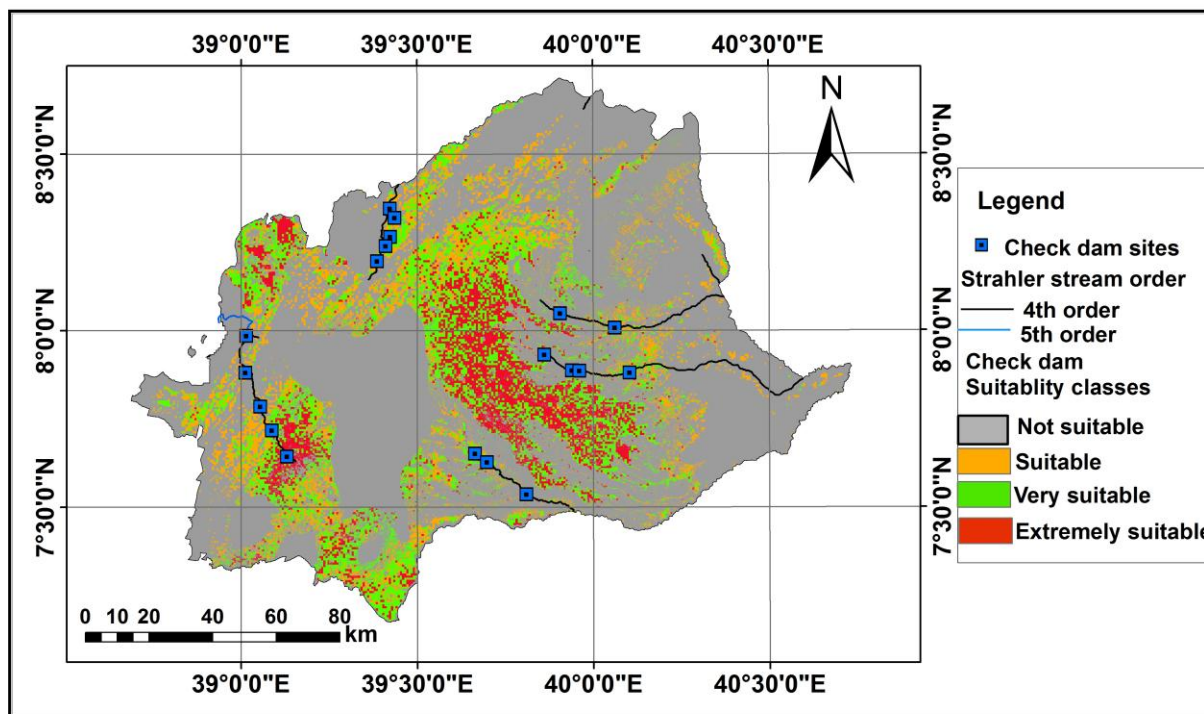


Figure 47: Check dam suitability map and selected proposed sites of the study area.

Potential RWH Sites for Percolation Tanks

The result of potential RWH proposed sites for percolation tank shows that, sites are located on uncultivated, moderate slope, sandy and fracture rocks and across 4th and 5th order stream to provide better water access for the community and also for recharging the groundwater (Figure 48). From 1,838 km² percolation tank suitable area, 21 RWH percolation tank sites are proposed for this specific research.

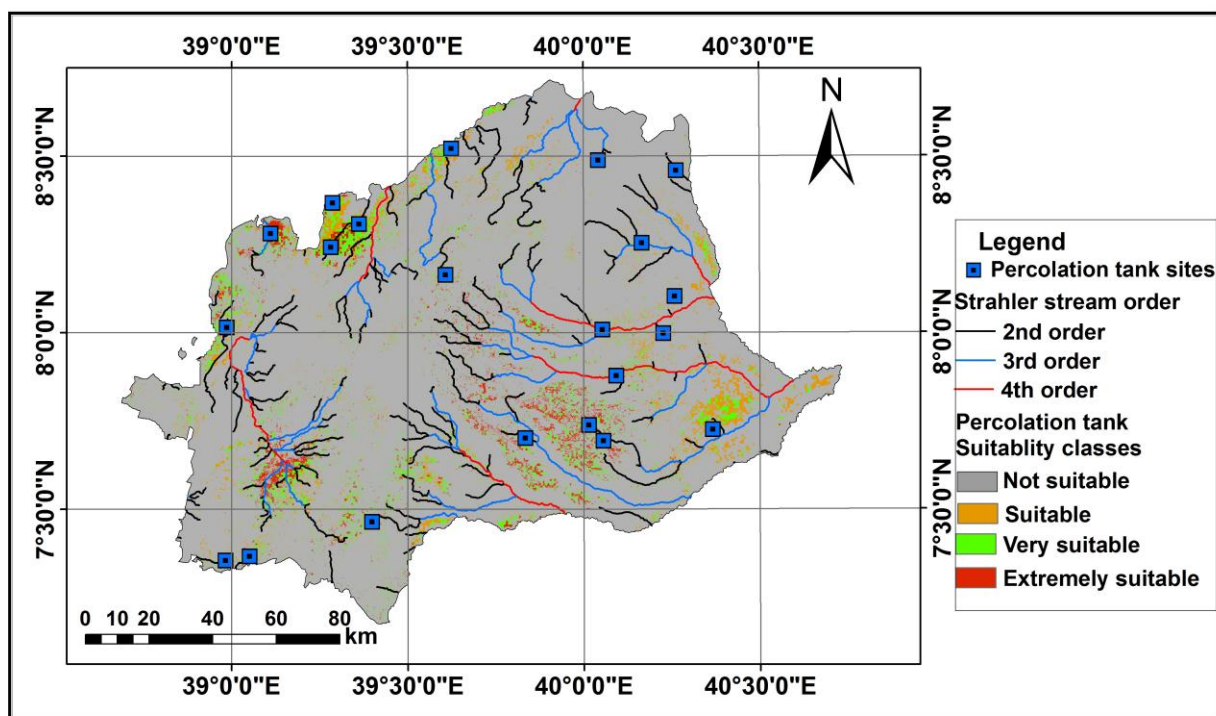


Figure 48: Percolation tank suitability map and selected proposed sites of the study area.

Potential RWH Sites for Farm Ponds

The result shows that, from the total area of Arsi Zone, 3,339 km² area of land is suitable for farm ponds. From this 60 farm pond sites which are mainly distributed in the central plains, where most of the area is agricultural land and nearly level slope area with 2nd and 3rd order streams are proposed as shown in Figure 59.

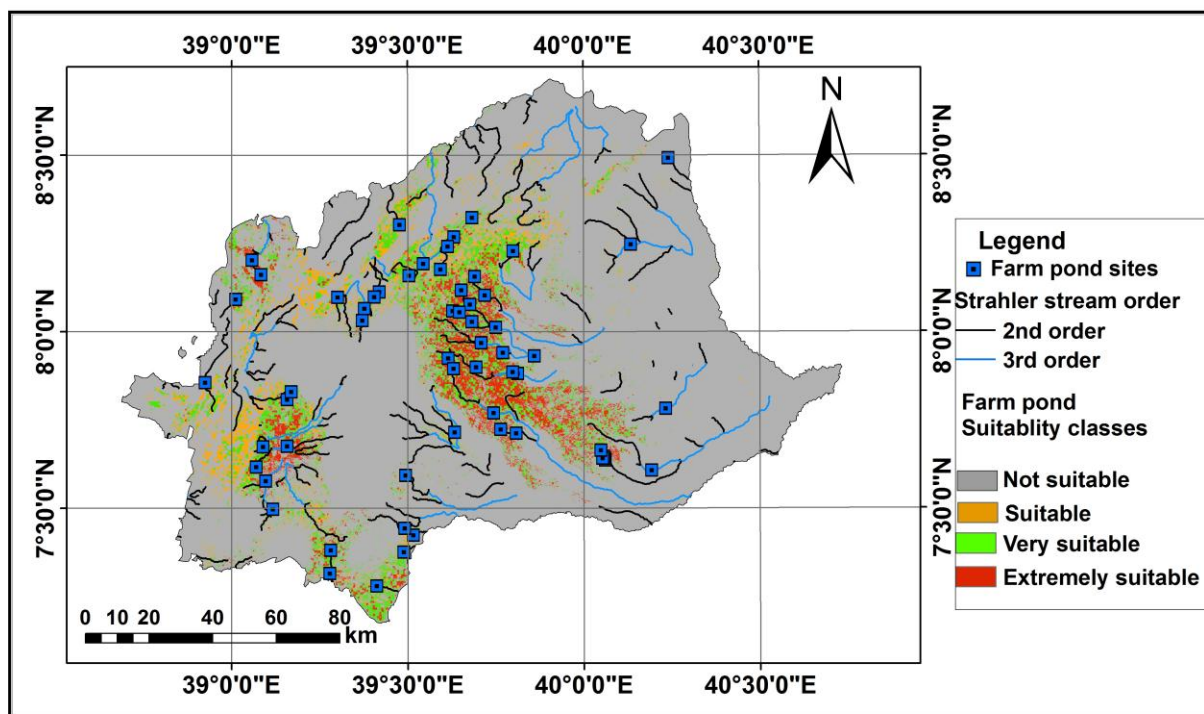


Figure 49: Farm pond suitability map and selected proposed sites of the study area.

4.7 Model Validation

This research was aimed to identify potential site for RWH. Proposed RWH sites may not spatially fit with existing harvesting sites. In addition to that, required amount assessment was not held on the evaluation and potential of existing RWH structures.

Evaluation of the model was done based on the discussions held with farmers, experts, field visit, data collection from literature and assessment performed on existing RWH with the evaluation tool in different projects. Out of 25 woredas of Arsi Zone Limuna Bilbilo, Munesa, Shirika, Digelu tijo woredas (154 kebele) were selected for Agricultural Growth Program II, which include integrated RWH implementation. These four woredas cover 20.66% of total study area. The result of this research proves that 80.72% of the area is under suitable class (suitable = 34.12%, very suitable = 34.68% and extreme suitable = 11.92%) (Figure 50 and 51). This indicates that the developed model is valid for the study area.

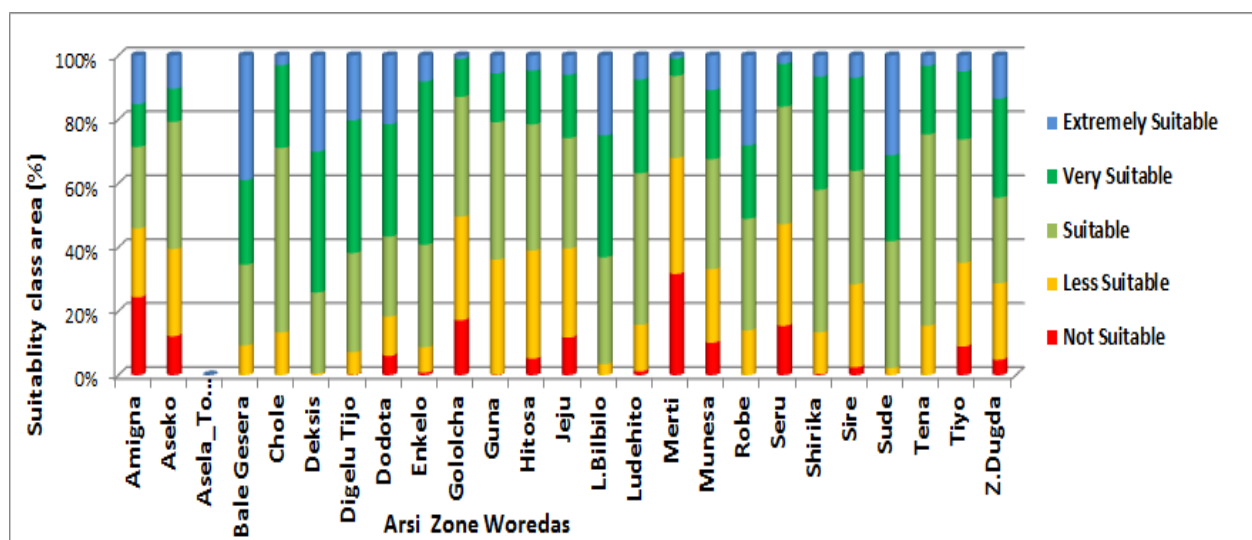


Figure 50 :Percent of rainwater harvesting suitability classes for each Woreda.

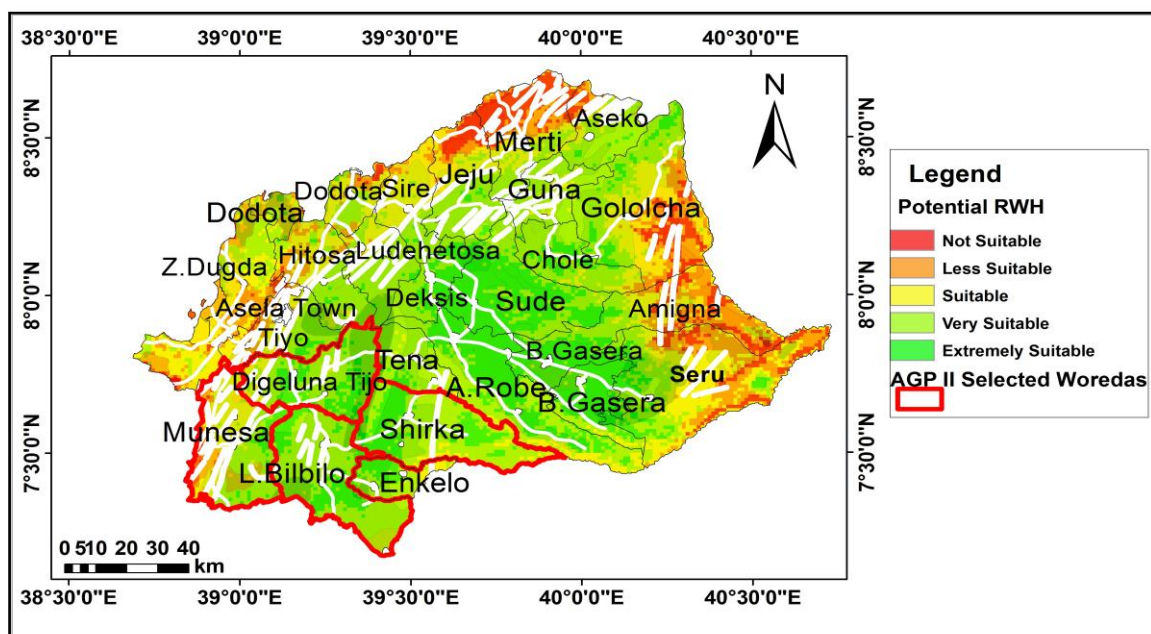


Figure 51: Potential rainwater harvesting sites and AGP II selected Woredas.

Potential RWH site selection done in this and neighboring zone indicates that: Tiyo, Lude hitosa, Digelu tijo, Hitosa, L.bilbilo, Z. dugda and Munesa woredas was classified under very high and high suitability classes covering 645 km² (99%), 229 km² (93%), 872 km² (93%), 536 km²

(90%), 380 km² (75%) and 627 km² (60%) respectively. This implies that above 90% of this research result is positively correlated with referred validation data and reviewed literature. However, detail constraints considered in this research results some variation against referred literatures.

CHAPTER FIVE

5 DISCUSSION

Climate change is bringing tremendous difficulties to the worldwide economy and to social-economic development. Its effects will excessively influence sub-Saharan African nations, where their economies are highly depending on climate conditions such as rainfed agricultural practices. The Ethiopian agriculture is characterized by extreme dependence on the amount of annual rainfall (Tadesse, 2002). Arsi Zone farmers are facing erratic type of annual rainfall and variability in temporal and spatial distribution. In order to increase the availability of water for agricultural and related activities, implementing RWH technologies in suitable location is crucial.

In this study, potential RWH sites selection model was developed through fuzzy modeling approach of fuzzy set theory (Zadeh, 1965) by identifying the more influential appropriate factors for selection of potential RWH sites. Correlation coefficient calculation done between each identified influential factors was near to zero (see appendix for correlation coefficient) for most of factors which indicates that no systematic co-varying exist between the variable, except rainfall-runoff correlation. This indicates that the factors can be used for further analysis (Glass and Hopkins, 1996). Criteria layers were classified to make all layers similarly standardized suitability classes, this are; 1 (not suitable), 2 (less suitability), 3 (suitability), 4 (very suitability), and 5 (Extremely suitability).

From different literature, it is believed several criteria need to be considered while selecting potential sites for RWH. Most of these criteria have been discussed in the literature review chapter. In this particular research, the criteria's were selected based on availability and applicability of data.

Surface runoff is an essential hydrologic criteria used in many water resource and related studies. The rainfall-runoff progression is a non-linear, dynamic and complex process, which is affected by many physical and often interrelated factors. The runoff estimation from conventional methods is difficult, error prone, costly and time consuming due to urban Zones and unreachable areas (Ebrahimian *et al.*, 2009). Munyao (2010) discuss that, runoff depth estimation requires detail and accurate spatial information of the study area. This study provides an integrated

approach to model the spatial-temporal pattern of run-off potential areas using the SCS CN model with remote sensing-derived inputs and ancillary data in GIS. Integrating RS and GIS is most effective solution in the application of in this kind of hydrological studies (Lyon, 2003; Shamsi, 2005). In this study integrated Soil Conservation Service-Curve Number (SCS-CN) with GIS method was used for the estimation of runoff depth based on rainy season interpolated rain gauge records.

All criteria layers identified for the analysis were not equally influential and important to select potential RWH sites of the study area. This difference can be managed by multifactor evaluation of weighted linear aggregation method for Weight calculation to give weight to each criterion to reflect their relative importance. This can be effective because it forces the decision maker/s to give thorough consideration to all elements of a decision problem. By assigning quantitative weights it is possible to make important criteria have a greater impact on the outcome than other criteria. In this research, Integrated Fuzzy logic and AHP (FAHP) (equation 12-17) method was used to get weights to each criteria layers to effectively solves the selection problem imbedding the concept of fuzzy set theory and standardized hierarchical analysis (Chang, 1996; Vahidnia *et al.*, 2008). The criteria layers were Reclassified and standardized and fuzzified having the fuzzy degree of membership between 0.0 which is not suitable and 1.0, which is extremely suitable.

The calculated FCR from Equation 24 was less than 10% (0.1) which indicates that a reasonable level of consistency in the pairwise comparisons and the weights were acceptable. The final weight of each criteria layers gained applying the FAHP was that, weight of runoff depth (26.27%), slope (19.09%), drainage density (11.26%), lithology (11.11%), soil texture (8.61%), elevation (8.18%), lineament density (7.27%), settlement proximity (3.57%), LU/LC (2.07%), major road proximity (1.53%) and fault (1%) as presented in Table 28. Though the selected criteria's are weighted, it is necessary to consider restricted and unacceptable areas for implementation as constraints. In this study, socio-economic and environmental constraint considered was 1 km radius of faults, 1 km radius of settlements and 0.5 km radius of main road (Table 31).

Finally, after weighted criteria and constraints layer were developed, an aggregation stage was applied to overlay the layers from the various criteria and constraint layers. Weighted Linear

Combination (WLC) technique, which was used to aggregate the constraints and factor maps used in this study. Weighted Linear Combination (WLC) technique is most used and preferable technique for better decision making processes and for constraint aggregation (Baban and Wan-Yusof, 2003; Destiny, 2015). The result of this analysis was a continuous scale ranging from not suitable to extremely suitable area, as shown in Figure 45. This research suggests and identifies suitable sites for some commonly used RWH strictures (Check dam, Percolation tank and farm pond), based on common criteria of each structure types (Table 29).

A proposed check dam sites were selected across a drainage channel to lower the speed of concentrated runoff flow for a certain design range of rainy events. Check dams reduce the effective slope of the channel, by minimizing the momentum of flowing water, allowing sediment to settle and reducing erosion. This will support a measurement taking approach for soil and water conservation (Zhang and Zhang, 2010). Proposed Percolation tank sites were also identified downstream of runoff zone with a land slope gradient of 3 to 5%, which allows water to percolate (or seep) through layers. Percolation tank benefits the community to get better clean water, as result of the water continues slow movement to downward and eventually reaches an underground aquifer (Limaye, 2017). In addition to that, proposed farm pond sites were also identified, for irrigation, watering cattle, fish production and related agricultural practices, where the sites with no excessive seepage losses exist and nearly level slope area in order to irrigate with gravity flow (Singh *et al.*, 2009; Chou, 2013). From the total potential RWH areas: 19 check dam, 21 percolation tank and 60 farm pond sites were selected.

To ascertain the reliability of the model that was adopted, validation was done based on existing data and reviewed literature of MoA (2015); KOICA (2008) and Girma (2009) resulting, more than 90% of the model is valid.

CHAPTER SIX

6 Conclusion and Recommendations

6.1 Conclusion

Seasonal flooding risk and adverse drought, which are triggered due to surface runoff volumes increment or the impact of climate change are affecting millions of people in this zone, needs a planned measurement. Implementing RWH techniques provide a means for reducing flooding and ensuring successful drought prevention and mitigation at the same time. The area has sufficient potential to feed on the ever-increasing demand of water, if rainwater is harvested and conserved properly.

The result of this research shows that, the land-use/land-cover within study area was found mainly farmland accounting about 43.30%, while shrubland cover about 36.91% of the study area, settlement area occupy only 0.57%. The curve numbers within Arsi Zone range from 40 to 100. The agricultural/cropland areas was found in central and northern part of the study area that have high curve number especially where hydrologic soil group D dominates, results high runoff generation. In the other hand, forested area was found in eastern part of the study area have low curve number especially where hydrologic soil group B dominates, resulting low runoff generation. Slopes of the Zone were found to range from nearly level to extremely steep. Since, for RWH sites the flat slope is more favorable for most RWH structures. The weight of the RWH factors was determined by the comparison of each layer using TFN-AHP comparison method. From factors used in this research, runoff depth is the dominant factor followed by slope, drainage density, lithology, soil texture, elevation, lineament density, distance from settlement, land-cover, distance from road and distance to fault respectively.

The result of the SCN model analysis showed that a significant amount of annual runoff depth can be harvested in most of the study area, which the area receive excess amount rainfall periodically in rainy season. These enough amounts of water give guarantee to fill the reservoirs in the rainy season. The results also indicate that there was a large difference between the quantity of runoff in the central, western and eastern part of the study area, having the range of 545.17 mm to 1364.8 mm. The minimum runoff depth less than 1000 mm was estimated in the western and eastern part of the study area, whereas the maximum runoff depth greater than 1000

mm was estimated in central part of the study area. In addition, the allocation of weights to the different criteria was done according to literature reviewed and real study area problems, which brings direct positive effects on the quality of the estimated map since the identification and allocation of weights to a high degree influence the fuzzy AHP comparison analysis.

The weighted and fuzzified criteria maps were integrated by using the fuzzy overlay Linear weighted combination to obtain a suitability map consisting of five comparable classes; not suitable, less suitable, suitable, very suitable and extremely suitable. Constraint layer of faults, settlements and major road were excluded from the suitability map of the study area using specific buffer Zone. The RWH suitability map is helpful to decision-makers and planners to easily find out areas that have rainwater harvesting potential than other areas.

The output of this research reveals that, runoff and soil texture in the central and the southern western part of the study area is very suitable for RWH. The suitability of this area for RWH gives a good opportunity to store water and to irrigate the nearby agricultural lands of the study area. The total suitable class that ranges from extremely suitable to very suitable areas covers 29.59%, while the suitable area is 27.52%. The remaining part, representing less and not suitable, is 42.88%. Implementation of RWH should be done in connection with a field survey, because the spatial resolution of the analysis does not guarantee that every site in an area classified as low suitable areas is indeed low suitable areas. There may be spots of suitable areas for rainwater harvesting. On the other hand, any location in an area classified as highly suitable does not guarantee that it is highly suitable because some of these locations may be social restricted areas, small village areas or influenced by social factor preventing implementation of hydraulic structures. Multiple possible proposed sites for locating check dam, farm pond and percolation tank were identified from final suitability map.

Remote sensing, GIS and hydrological modeling tools are less time consuming and cost effective, which offers sufficient support for locating potential RWH sites. The technique will be more effective and helpful; if an accurate data is available, especially where inaccessible area which need RWH practice for better development and water security maintenance. However, both the data quality with regarding to resolution and the allocation of weights are sources of errors in this study.

Even though, application of RWH technologies directly help the community to minimize the water crisis of the Zone but, one should not be forget is the effect of socio-economic and environmental aspects of RWH need detail study. For this study some socio-economic and environmental factors were considered.

6.2 Recommendations

It is recommended that the following should be done in future studies and implementation:

- Detail ground validation studies of the suggested area for RWH for better water resources evaluation.
- Integrated hydrogeological study of the study area is important to evaluate the resource from all points of view (quantity and quality) using high resolution data sources for GIS and RS.
- Better high resolution soil property data for more accurate curve number generation and soil texture.
- Actual RWH implemented by a detail field survey as the spatial resolution of the analysis does not guarantee that every location in an area classified as actual land classification.
- Environmental Impact Assessment (EIA) must be undertaken in order to prevent unintended impact on water resource and to protect environment.
- Involving the community as part of the implementation.
- The design of the RWH structures should be improved from existing 50,000lit holding capacity.
- Rainwater harvesting is not an end by itself, a measurement must be considered like roofing and plastic lined pond for siltation and evaporation problems.

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Appendices

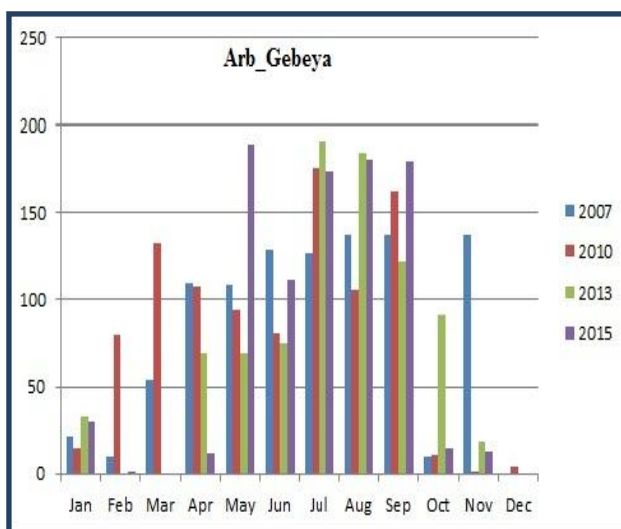
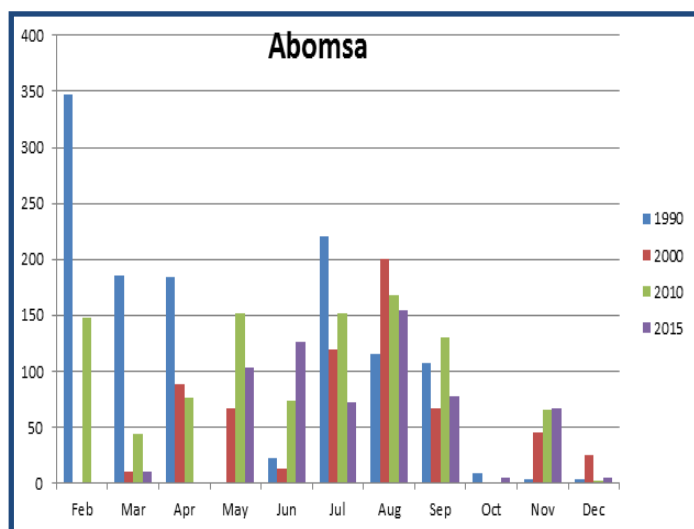
Annex I: Runoff curve numbers for different land-classes (USDA-SCS, 1985)

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

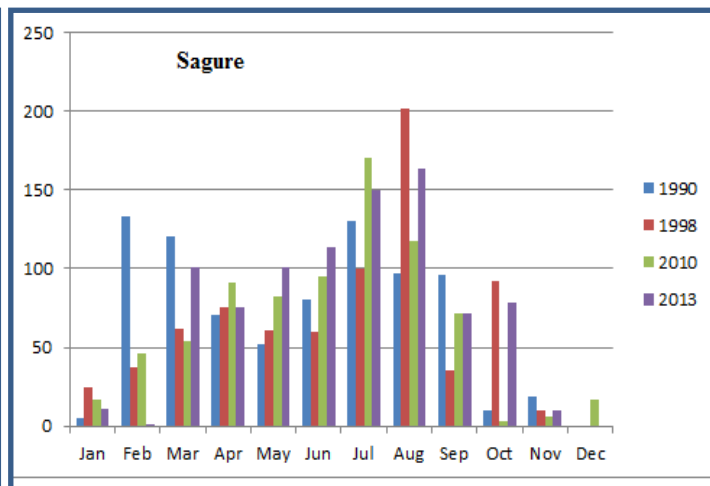
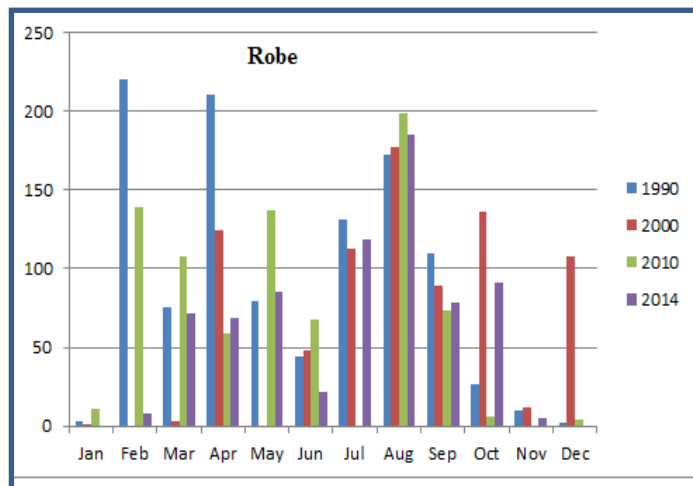
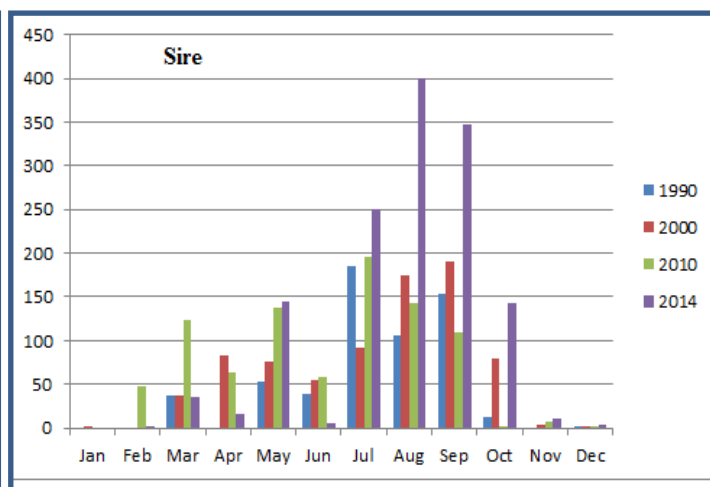
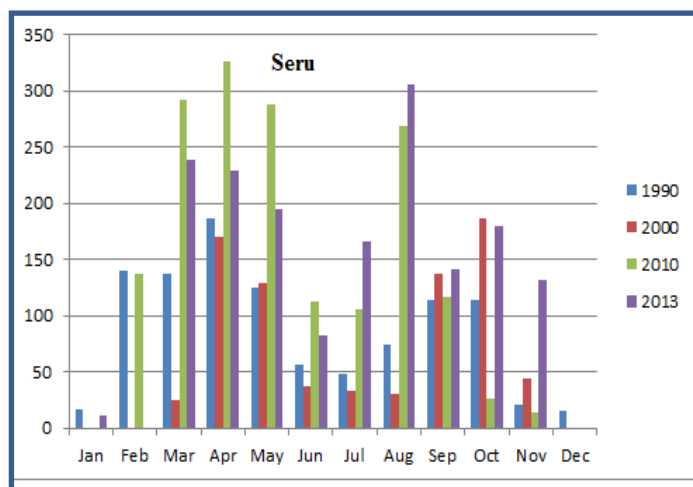
Annex II: Mean monthly annual rainfall for the last 16 years of the study area (1999 –2015).

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1999	20.77	70.39	102.61	122.38	112.12	73.19	143.00	149.72	116.92	57.48	54.88	15.74
2000	9.00	6.18	47.50	40.33	41.95	61.21	182.09	167.96	87.07	48.36	22.60	3.78
2001	9.63	12.48	66.47	84.66	69.84	83.31	175.86	201.46	139.53	54.90	10.62	9.86
2002	30.09	50.08	124.50	158.11	128.06	80.41	122.58	149.64	129.29	134.17	59.98	26.56
2003	10.92	33.09	53.03	81.45	76.92	90.78	138.57	136.66	72.88	37.44	7.52	7.09
2004	22.79	29.27	67.97	106.49	90.39	79.04	143.17	179.20	93.89	57.52	22.37	19.96
2005	30.52	51.54	120.94	69.91	66.24	109.13	193.82	140.70	154.52	72.33	47.68	5.26
2006	9.61	28.97	120.56	142.36	117.62	94.35	134.23	203.57	143.71	80.66	45.32	14.53
2007	17.62	24.58	65.97	73.27	93.37	102.37	224.70	188.49	144.53	45.50	18.08	4.83
2008	18.75	27.53	60.75	101.74	115.75	110.91	170.29	189.06	171.64	74.85	19.77	14.30
2009	24.40	24.03	86.10	132.10	106.98	96.83	197.34	180.59	148.20	79.29	32.15	20.36
2010	19.22	54.30	93.84	121.38	96.44	109.23	186.37	202.93	85.49	61.71	10.21	17.19
2011	24.40	24.03	86.10	132.10	106.98	96.83	197.34	180.59	148.20	79.29	32.15	20.36
2012	19.22	54.30	93.84	121.38	96.44	109.23	186.37	202.93	85.49	61.71	10.21	17.19
2013	17.42	37.82	88.78	114.83	104.38	114.04	179.40	171.41	141.60	58.73	17.39	12.59
2014	28.62	12.22	40.52	72.16	117.77	85.75	188.52	159.83	161.73	83.81	24.20	1.91
2015	28.51	33.62	74.73	85.28	67.78	59.19	159.56	172.51	111.48	68.05	28.86	11.74
Average	20.09	33.79	82.01	103.53	94.65	91.52	171.95	175.13	125.66	67.99	27.29	13.13

Annex III: Monthly rainfall of rain gauge stations for consecutive years.







Annex IV: Correlation Matrix

	1*	2*	3*	4*	5*	6*	7*	8*	9*	10*	11*	12*
1*	1.00000	0.27282	-0.04213	0.15726	0.05469	0.01055	0.39475	-0.05579	0.01825	0.04774	-0.28845	0.30137
2*	0.27282	1.00000	0.03453	0.34601	0.15455	0.26775	0.75215	-0.16035	-0.01327	0.31149	-0.47533	0.989300
3*	-0.04213	0.03453	1.00000	0.31391	0.07470	-0.04421	0.06429	0.01292	-0.06715	-0.27444	0.09296	0.07113
4*	0.15726	0.34601	0.31391	1.00000	0.13467	0.11192	0.39753	-0.00444	-0.04205	0.10277	-0.12810	0.38309
5*	0.05469	0.15455	0.07470	0.13467	1.00000	-0.00481	0.16469	-0.04449	0.02643	0.00461	-0.09260	0.14123
6*	0.01055	0.26775	-0.04421	0.11192	-0.00481	1.00000	0.11697	-0.09073	0.16310	0.17591	-0.17829	0.80177
7*	0.39475	0.75215	0.06429	0.39753	0.16469	0.11697	1.00000	-0.05981	-0.12333	0.19000	-0.37324	0.12520
8*	-0.05579	-0.16035	0.01292	-0.00444	-0.04449	-0.09073	-0.05981	1.00000	-0.17251	-0.03645	0.29806	-0.08915
9*	0.01825	-0.01327	-0.06715	-0.04205	0.02643	0.16310	-0.12333	-0.17251	1.00000	0.02573	-0.09569	-0.07113
10*	0.04774	0.31149	-0.27444	0.10277	0.00461	0.17591	0.19000	-0.03645	0.02573	1.00000	-0.23700	0.16187
11*	-0.28845	-0.47533	0.09296	-0.12810	-0.09260	-0.17829	-0.37324	0.29806	-0.09569	-0.23700	1.00000	-0.37140
12*	0.30137	0.989300	0.07113	0.38309	0.14123	0.80177	0.12520	-0.08915	-0.07113	0.16187	-0.37140	1.00000

1* = Soil Texture, 2* = Runoff depth, 3* = LU/LC, 4* = Drainage density, 5* = Lithology, 6* = Elevation, 7* = Slope, 8* = Lineament density, 9* = Distance from faults, 10* = Distance from Settlements, 11* = Distance from Main road, 12* = Rainfall

Annex V: Lithological description of study area.

Symbol	Lithology	Description
Ka	Upper sand stone	Composed of loosely cemented more or less coarse sand with clay highly permeable.
Qv1	Quaternary basalt	They are relatively fresh, loosely decomposed rocky surface, which are hard and compact
Qr	Rhyolites and trachyte's	
Tv7	Pliocene trachyte	Lava, flow from Chilalo and other mountains, younger post-rift central type flow and slightly weathered, medium grained.
Tv3(1)	Plateau basalt	This basalts are exposed forming major plateau surface. The area is generally tableland and very rarely dissected at horizontal slope: very slightly weathered columnar, massive, dense and compact flow
Tv3(2)	Ignimbrites, ash-fall tufas, gravelly ash-fall	Down faulted during MER and cover vast area in the rift this prolastic includes . At this the thickness varies from place to place. The total thickness reaches up to 250m. The rock is usually massive with minor fracture in most places except at major joints or faults can cut this rock unit.
Tv4	Basalt flow	The lava flows from large plateau area and younger fresh basalts: the basalts are fine grained and columnar jointed.
Mulst	Limestone rocks	Fine to medium grain sized limestone rocks found in valley cuts of river with thickness of 350m.
Musst	Sedimentary structures	Massive bedded in valley altering. Sedimentary structures like bedding, lamination are common
N1g	Alaji basalts	Its vesicular at the top, flows bounded in the middle and massive at the bottom. It is faulted in some places interbedded with red paleosol beds which reduce permeability: grouped as moderate aquifer.
N1a	Arba gugu basalt	Consist of pyrophyritic basalt interbedded with aphanitic basalt. It is jointed and faulted
N2qb	Bofa basalts	Very well developed opening of joints is about 1m. The depth of groundwater is more than 100m. Due to the deep nature of the vertical joints where most of the precipitation infiltrate without meeting on impermeable bed in between.

Annex VI: Problem analysis on Water Harvesting technologies.

No.	Existing Problems
1	Water drain from the cracks in Tank
2	Water drain from the tears of sheet in pond
3	Water infiltrate from the Pond into the ground
4	Water evaporates from Tank.
5	Water evaporates from Pond.
6	Water isn't gathered by the water catchments
7	Water doesn't run in the canal
8	Volume of Tank or Pond reduced by the silt
9	Shallow well's inner wall is delicate
10	Farmers finish Tank's or Pond's water halfway of crop's growth
11	Farmers give less water than crop consumptive use
12	Farmers couldn't cure the crop's disease
13	Farmers couldn't bug the harmful insect
14	Farmers think that Tank or Pond was located in inconvenient area
15	Farmer didn't use the water lifting device
16	Mosquito which is the carrier of Malaria reproduce in Tank and Pond
17	Farmers think that children and livestock fall down in Tank and Pond
18	Farmers think that there is more convenient source

DECLARATION

I the undersigned declare that this thesis is my original work and has not been presented for a Degree in any other university and that all sources of materials used for the thesis have been duly acknowledged.

Getachew Haile Wondimu

Signature _____ Date _____

School of Earth Science

June, 2016

This thesis has been submitted for examination with my approval as university advisor.

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Prof. M. Balakrishnan

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