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FACULTY OF CIVIL AND WATER RESOURCES ENGINEERING

MSc. Thesis on:

Land Suitability Analysis for Agriculture in South Gondar Zone using Remote Sensing and GIS Tools

Program: Irrigation Engineering and Management

By:

Weldehana Aweke Kindie

March, 2023

Bahir Dar, Ethiopia

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Land Suitability Analysis for Agriculture in South Gondar Zone using Remote Sensing and GIS Tools

Weldehana Aweke Kindie

A Thesis Submitted to Bahir Dar University Institute of Technology, School of Graduate Studies in Partial Fulfillment of the Requirements for the Degree of Master of Science in Irrigation Engineering and Management

Advisor: Abebech Abera (PhD)

March, 2023

Bahir Dar, Ethiopia

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Declaration

This is to certify that the thesis entitled "Land Suitability Analysis for Agriculture in South Gondar Zone using Remote Sensing and GIS tools", submitted in partial fulfillment of the requirements for the degree of Master of Science in Irrigation Engineering and Management under faculity of Civil and Water Resources Engineering, Bahir Dar Institute of Technology, is a record of original work carried out by own and has never been submitted to this or any other institution to get any other degree or certificates. The assistance and help I received during this investigation have been duly acknowledged.

Weldehana Aweke		6/7/2015 E.C
Student Name	Signature	Date

Thesis Approval Sheet

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I hereby confirm that the changes required by the examiners have been carried out and incorporate in the final thesis.

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As members of the Board of Examiners, we certify that we have read and evaluated the thesis prepared by Weldehana Aweke and examined the candidate. We recommend that the thesis be accepted as fulfilling the thesis requirement for the Degree of Master of Science in Irrigation Engineering and Management

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Abstract

Ethiopia's national economic development is significantly influenced by agriculture. From the zone level to the national level, agricultural land-use intensification and extensification appear to be necessary to meet the growing population's demand for food and other agricultural products. However, the extent, distribution, or level of the land's agricultural potential have not been well explored and documented. Like other parts of the country, the agricultural land suitability of South Gondar was not studied. Hence, it is urgently necessary to match crop requirements with resources that are currently available through land suitability analysis in South Gondar zone in order to maintain the productivity of agricultural land. This study aimed to address land suitability analysis by using geographical information system-based multi-criteria approach in South Gondar zone. Worldwide data sources, literature reviews, and on-site investigations, were used to evaluate the suitability of agricultural land in South Gondar zone. Seven criteria were identified and the criteria were preprocessed as raster layers on a GIS platform, and the weights of the raster layers were calculated for appropriateness using the analytic hierarchy approach (AHP). A weighted overlay analysis was used to classify the agricultural land as highly suitable, moderately suitable, marginally suitable and not suitable. According to the analysis results, 26% of the land coverage of the zone was found to be highly suitable for agriculture. The moderately suitable and the marginally suitable lands were 70% and 4% respectively.

Keywords: *Analytic Hierarchy Process, Multi Criteria Analysis, South Gondar, Suitability, Weighted Overlay Analysis.*

List of Abbreviations

AHP	Analytical Hierarchy Process
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
DEM	Digital Elevation Model
E	Excessively Drained
ESA	European Space Agency
Esri	Environmental System Research Institute
FAO	Food and Agriculture Organization
GIS	Geographic Information System
LULC	Land Use Land Cover
M	Moderately Drained
MCDM	Multi-Criteria Decision Method
OLI	Operational Land Imager
P	Poorly Drained
RS	Remote Sensing
S1	Highly Suitable
S2	Moderately Suitable
S3	Marginally Suitable
S4	Not Suitable
SRTM	Shuttle Radar Topography Mission
USGS	United State Geological Survey
W	Well Drained
WOA	Weighted Overlay Analysis

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Chapter One

1. Introduction

1.1 Background

The amount of cultivated land available worldwide is limited, and the majority of it has been irreversibly degraded and is no longer suitable for agricultural production (Hamere Yohannes & Teshome Soromessa, 2018). Ethiopia's economic development is heavily reliant on agricultural production, which accounts for 46.6 percent of the national gross domestic product (Hamere Yohannes & Teshome Soromessa, 2018). The majority of agricultural practice has taken place in Ethiopia's highlands (Teshome, 2014). Land is in short supply in this area due to increased demand for food and space as a result of population growth. With yields of less than 1 t ha^{-1}, marginal land has been used for cultivation, and low productivity is still a significant barrier for the agriculture industry (Engda, 2009; Pender & Gebremedhin, 2006). Lack of established procedures for assessing the suitability of agricultural land is one of the obstacles preventing improvement in productivity. As a result, agricultural land suitability analysis has become a critical step to grow crops at its utmost potential in Ethiopia.

A land suitability analysis is an assessment of an area to determine how suitable it is for a specific use of the land (such as growing a crop variety) in a specific location. It is also the examination of a piece of land for its capacity to support a specific agricultural use (Littleboy et al., 1996). Land suitability tools have been widely used to identify better agricultural management practices. Thus, land suitability assessment (LSA) includes soil, topography, rainfall, and temperature analysis with the goal of comparing land characteristics to crop requirements (Wang et al., 2006). The suitability is a function of crop requirements and land characteristics, and it is a measure of how well the qualities of a land unit match the requirements of a specific type of land use (Arifin et al., 2022). Land assessment is a tool for predicting land performance in terms of expected profits, constraints, and environmental problems resulting from productive land use (D. G. Rossiter, 1996). This could be solved by combining GIS and MCE methods. Recently, geographical information systems (GIS) have been discovered to be useful in the task of assessing land suitability (Habibie et al., 2021a; Yalew et al., 2016b).

Remote sensing mapping has the advantage of covering a larger area at a lower cost, resulting in a relatively high efficiency (Demarez et al., 2019). High resolution imagery (Landsat 8 and Sentinel 2) has replaced other data sources as the main ones used to determine crop area in recent years (Dong et al., 2015; Kussul et al., 2016). Geographical information systems can be used to determine land evaluation map analysis procedures (Alemayehu, 2003) and remote sensing (Bandyopadhyay et al., 2009; Pandey & Srivastava). The analytical hierarchy process (AHP) is influential technique used in GIS for decision making process as it has the advantage of incorporating expert opinions to prioritize the criteria according to weight in consistent judgments. AHP using RS and GIS is a common method for spatial decision-making processes, such as cassava land suitability analysis (Purnamasari, 2019); Agricultural land suitability (Yalew et al., 2016b) crop insurance premiums (Islam, 2018); drought hazard inventory (Pandey & Srivastava, 2019); flood hazard mapping (Liu et al., 2019); aquaculture site assessment (Silva et al., 2011); and industrial, landfill and bio digester site selection (Akther et al., 2016; Muhsin et al., 2018).

A variety of criteria must be met when evaluating agricultural land for crop production. Thus, to determine which agricultural lands are ideal for crop production, expert judgment including AHP and the selection of numerous criteria are needed. A multicriteria evaluation of agricultural land suitability is used in the decision-making process and takes into account a variety of factors, including economic and sociocultural conditions, geological and biophysical elements (such as relief, vegetation, soil characteristics, and weather), and geology (Joerin et al., 2001).The selection of the best land used for each defined land unit is the main objective of agricultural land evaluation, which also promotes the preservation of environmental resources for future use (Li et al., 2010). The creation of a standardized framework for the suitable and ideal use of agricultural land has been the focus of numerous studies. Land was divided into four categories by the Food and Agriculture Organization (FAO) in 1976; highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and unsuitable (S4). When choosing potential crops for climate-smart agriculture in

Ethiopia, analyses of agricultural land are necessary to maximize land use and identify environmental resources while ensuring regional food security. Land evaluation in support of rational land use and the appropriate and sustainable use of natural and human resources is part of the solution to the agricultural land use problem (D. Rossiter, 1996). The development of GIS based land suitability analysis using a multi-criteria decision making (MCDM) system in conjunction with expert knowledge (AHP) is crucial to overcoming the limitations of land suitability criteria. Furthermore, multiple years of multi criteria decision making data sets are required. The goal of this study is to evaluate agricultural land suitability analysis based on multiple criteria for a recent period of time in order to ensure the sustainability of crop production in South Gondar zone, Ethiopia. The findings can be used to create a particular approaches or recommendations for offering farmers and the government with technical support in order to expand the practice of agricultural cropping in the study areas (Mardero et al., 2018). Further consideration of the suitability levels can be used to recommend climate smart agriculture and crop diversification.

1.2 Statement of the Problem

Although agriculture is the most primitive occupation of the most civilized men and Ethiopia's main economic activity and source of income for the vast majority of the population, it is not supported by high level of scholars and characterized by low productivity. In South Gondar zone, there is very limited progress in its agricultural information system and the use of satellite remote sensing information and datasets are very low to assess agricultural crop suitability. The crop production and productivity in the study area is poor and not yet supported by proper land evaluation and sutability analaysis. Also the amount, location and degree of suitability of the zone for agriculture is not well studied and/or documented. As a result, agricultural land suitability analysis is critical in South Gondar to thrive for sustainable agriculture. GIS is a powerful set of tools used to collect, store, retrieve, transform and display spatial data from the real world for a specific purpose, and it has been recommended as a decision making and problem solving tool for analyzing crop production land suitability. Satellite remote sensing technologies have a high potential in applications for evaluating agricultural land and can facilitate optimized development for agricultural sector. However, misinformed land selection decisions limit crop yields and increase production related costs to farmers. In this direction agricultural land evaluation using GIS, Remote Sensing and AHP is critical as it provides an insight on the potentials and constraints of land for a specific land use type in terms of crop productivity.

1.3 Objectives

1.3.1 General Objective

- ❖ To determine the lands that are suitable for agriculture in South Gondar zone using various spatial and remote sensing datasets and techniques.

1.3.2 Specific Objectives

- ❖ To evaluate the suitability of the agricultural land of South Gondar zone using selected relevant factors.
- ❖ To produce suitability maps for the various selected factors that affect land suitability of agriculture in South Gondar zone.
- ❖ To generate an AHP method using expert knowledge that determines the land suitability evaluation for agriculture in the South Gondar zone.
- ❖ To produce a composite suitability map for agriculture in South Gondar zone.

1.4 Research Question

This study aims at answering the following questions in order to achieve the above objectives.

1. How much of the land in South Gondar is suitable for Agriculture?

2. What are the required evaluation criteria/ factors to assess the agricultural land suitability?

3. How can suitability maps of the selected factors and the composite suitability map for agriculture be produced?

4. How the expert knowledge is incorporated and possible uncertainties are involved in it?

1.5 Scope of the Study

The scope of the study was focused on analyzing agricultural land suitability and proposing suitable land locations for agricultural production. The research was limited to preparing thematic layers for the selected criteria that will influence the suitability map, as well as generating a suitable agricultural land map in the study area from a composite map.

1.6 Significance of the Study

The significance of the study was in analyzing agricultural land suitability for crop production using GIS and Remote Sensing data sets in conjunction with AHP. The research findings can be used to develop specific approaches or recommendations for providing technical assistance to farmers and the government in order to expand suitable agricultural cropping practice in the study areas. It is also expected to provide valuable information for the government and agricultural sector on land resource management, maximizing crop farming area, and dealing with crop land problems. It also establishes a method for determining the most suitable areas for agricultural production to ensure regional crop production. The study also enables to explore the category of the agricultural land that are marginally suitable, and not suitable which then helps the government and farmers to take measurements with agricultural land suitability problems. Furthermore, this research can provide scientific data for future research.

Chapter Two

2. Literature Review

2.1 History of Agriculture and Land Suitability

The most primitive activity practiced by civilized man, agriculture, has greatly benefited from technological developments, from shifting cultivation to advanced precision farming. As civilization developed, man learnt more about crops and started to cultivate a wide range of crops. Man has settled in one spot and cultivated the same land year after year as a result of the growth in population and the development of civilization. Agriculture is now referred to as commercial agriculture, precision agriculture, and sustainable agriculture because it has developed into a profession. These days, the global population is growing quickly and the farming industry must produce more and more food to meet the rising demand.

The agricultural community should focus on the problem of producing ever-increasing amounts of food with the currently available land because it is impossible to bring more land under cultivation (extensive farming) in the current situations where land is a limiting factor (intensive farming). The farming industry needs to create more nutritious food while using environmentally friendly methods in order to address this issue. Precision farming, sustainable farming, organic farming, and other similar ideas have all been made possible by the necessity for environmentally beneficial practices. The current concern of agriculture are increased productivity, profitability, environmental health and human health. As a result, choosing a crop that is appropriate for a certain region is given a lot of importance (Prakash, 2003). Thus, the suitability of agricultural land is influenced by crop requirements and geographical features. The appropriateness is established by comparing the features of the land to those needed by the crop.

According to the definition (FAO), "Suitability is a measure of how well a land unit's characteristics match the needs of a particular form of land use". Producing high quality products in an environmentally friendly, socially acceptable, and economically efficient manner is what is meant by sustainable agriculture (SA) or farming (SF) (Addeo, 2001), i.e. optimum utilization of the available natural resource for efficient agricultural production. One must cultivate crops where they are most suitable to do so in order to adhere to these SA principles, and the first and most crucial step in this process is to undertake a land suitability analysis (Prakash, 2003). The land suitability analysis must be carried out in a way that ensures the final verdicts adequately reflect local needs and conditions.

2.2 Land Suitability Analysis for Agriculture

In Ethiopia, agricultural land-use intensification and extensification appear to be increasing in order to meet rising population demands for food and other agricultural commodities. However, the amount, location, and degree of agricultural suitability of the area appear to be understudied (Yalew et al., 2016a). Land evaluation is a foundation for sustainable land resource planning and management (Hamere Yohannes & Teshome Soromessa, 2018). Land suitability analysis can be performed using remote sensing and GIS to determine which land types are suitable for crop production. Various parameters determine the characteristics, such as land use type, slope, surface elevation, drainage pattern,rainfall and so on (Bera et al., 2017). All of these factors influence a given area's suitability for agriculture. A number of agricultural land suitability evaluation criteria can be identified from global data sources, literature review, and field investigation, and then preprocessed as raster layers on a GIS (Habibie et al., 2021b; Yalew et al., 2016a; Hamere Yohannes & Teshome Soromessa, 2018). A weighted overlay analysis method can be used to compute categories of highly suitable, moderately suitable, marginally suitable and unsuitable lands for agriculture in the study area (Yalew et al., 2016a; Rajendra Bhausaheb Zolekar & Vijay Shivaji Bhagat, 2015).

2.3 Benefit of Agricultural Land Suitability Analysis

Agricultural land suitability study for land selection with a focus on rain-fed agriculture has gained worldwide importance to address the concerns of food security (Amara et al., 2016; Ambarwulan et al., 2016; Harini et al., 2015; Mathewos et al., 2018). Planning and management of long-term land resources need the evaluation of agricultural land. As a result, in order to maintain the productivity of agricultural land in the research area, it is urgently necessary to match crop requirements with available resources using land suitability analysis (Hamere Yohannes & Teshome Soromessa, 2018). An evaluation of a region's suitability for a particular use of the land, such as the cultivation of a certain crop variety in a specific location, is known as agricultural land suitability analysis. Tools for determining the best agricultural management strategies have been widely used. In order to boost crop yield, an effective method of environmental suitability analysis is needed. Accurate evaluation of regions environmental suitability for agricultural production can be done using a multi factor spatial analysis. However, a comprehensive spatial investigation of the suitability of agricultural land for the study has not yet been finished. To emphasize the importance of this study, it was carried out utilizing GIS based land suitability analysis. Identification, hierarchical organization, standardization, rating, ranking, weighting the selected factors and implementation of the suitability map are the step involved (Enyew, 2021).

2.4 Role of GIS and Remote Sensing in Agricultural Land Suitability

GIS is the tool for input, storage and retrieval, manipulation and analysis, and output of spatial data (Marble et al., 1984). GIS functionality can play a major role in spatial decision-making. Considerable effort is involved in information collection for the suitability analysis for crop production. This information should present both opportunities and constraints for the decision maker (Ghafari et al., 2000). Using the spatial and attribute data that is recorded in GIS, it is possible for it to carry out a range of functions. Numerous geographic technologies including GPS, remote sensing, and others, can be integrated. GIS's primary objective is to support spatial decision-making (Foote & Lynch, 1996). Multiple data layers must be handled in multi-criteria evaluation in order to determine suitability, which is easily accomplished with GIS. Information on the numerous spatial criteria and factors is provided through remote sensing. Information can be accessed from RS on topography, drainage density, land use/cover, and other things. RS will be an effective tool for incorporating and analyzing real-world situations in the most authentic and open way when used in conjunction with GIS. Research by (Liengsakul et al., 1993) shown that in addition to speeding up the process and producing high-quality data, GIS and remote sensing technology can be used to find potential new agricultural locations.

2.5 Methods of Agricultural Land Suitability Analysis

Assessing land suitability is the first stage in developing, promoting, and protecting land use and sustainable agricultural areas (El Baroudy, 2016; Falasca et al., 2012). The main factors for investigating agricultural land suitability for a crop in different parts of the study region are Elevation, Slope, Land use Land cover, Soil depth, Soil drainage, Soil texture and Rainfall (Habibie et al., 2021a; Yalew et al., 2016b). Soil, topography, and temperature analysis is required to determine whether a piece of land is suitable for farming by comparing the features of the land to the needs of the crops (Wang et al., 2006). The various factors were organized in a manner consistent with their importance or weight following the preparation and processing of the data. The order was Rainfall, Slope, Soil depth, Soil texture, Elevation, Soil drainage and LULC. This process is also referred to as rating. Considering the optimum conditions for agricultural land suitability the classes were numbered 0 to 4 with the class of highly, moderately, marginally and not suitable. These ratings, were re classified and this was performed in ArcGIS 10.8 (Habibie et al., 2021a; Yalew et al., 2016b; Hamere Yohannes & Teshome Soromessa, 2018).

2.6 Major factors used for Agricultural land suitability

Assessing the suitability of agricultural land can be done using a variety of effective agro ecological parameters, although doing so complicates long term sustainable management (Akıncı et al., 2013; Bandyopadhyay et al., 2009). To maximize the utilization of a piece of land for a particular purpose, land suitability is assessed using a rational cropping system (Sys et al., 1991). Elevation, Slope, Land use Land cover, Soil depth, Soil drainage, Soil texture and Rainfall were the factors considered for agricultural land suitability.

2.6.1 Elevation

Elevation is an important factor that plays a vital role in the variability of plant cover and causes temperature changes, particularly in highland areas. Areas with higher topographic elevations are more affected by rainfall and soil erosion (Bozdağ et al., 2016). Soil erosion is the alarming condition of agriculture field crop. Also, it is the main problems of agricultural development, such as landslides and flood events; these disasters have been severely influenced by the soil erosion process (Senanayake et al., 2020). Any elevation value below 3700 m asl is considered suitable for agriculture. According to Ethiopia's agro-ecological zoning, elevations above 3,700 m are considered "high wurch" (frosty-alpine) and therefore unsuitable for agricultural purposes (Yalew et al., 2016b).

2.6.2 Slope

The slope affects the quality of the land and is one of the factors used to assess whether crop land is suitable for mechanization. The slope, or degree to which the land is not horizontal, is a measure of how steep the terrain is. The topography of the region, or more specifically, its geomorphological characteristics, has a significant impact on the natural development of soils. With increasing slope, the soil layer's thickness decreases, while with decreasing slope, it increases (Atalay, 2006). The main feature in determining erosion control is slope degree (Koulouri & Giourga, 2007). The amount of material carried away by erosion increases as the slope angle increases. Indirectly, slope limits agricultural productivity by negatively influencing soil qualities; additionally, slope directly reduces agricultural production by limiting the use of machinery and management practices such as soil tillage, irrigation, and drainage. Slope affects an area's potential for agriculture since steep slopes make cultivation more challenging and increase the risk of soil and nutrient loss due to erosion. Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) satellite image used to derive slope map of the study area and the slope of the land was created after filling out the DEM (Halefom, 2020). And then the slope map was reclassified to achieve the required slope status (Solomon, 2020). Based on FAO manual for agricultural watershed management (Sheng, 1990), agricultural land suitability of different slope classes are defined and a slope of 0 -7 % customized as highly suitable, 7 - 15% moderately suitable, 15 – 25% marginally suitable and > 25% not suitable for agricultural land suitability.

2.6.3 Land Use Land Cover

According to FAO (1976), for land evaluation, delineating the current land-use boundary is the crucial step. A land-use type is a kind of land use that is defined by the products and management practices (FAO, 1996). The types of use considered are limited to those which appear to be relevant under the general physical, economic and social conditions prevailing in an area. These kinds of land use serve as the subject of land evaluation. They may consist of major kinds of land use such as rainfed agriculture, irrigated agriculture, grassland, forestry or recreation (FAO, 1976). It is possible to evaluate an area's vegetation, forest, urban presence/settlement, and water bodies using data on land use and land cover (LULC) which the suitability is customized as highly suitable, moderately suitable, marginally suitable and not suitable for agricultural land suitability respectively (Habibie et al., 2021a).

2.6.4 Soil Depth

The amount of water and air in the soil, as well as the root growth, all affected by soil depth. The shallow soils with lithic contact may hampered root growth. Hence, the crops suffer suboptimal conditions in the limited soil volume, which hinders growth and yield of the crop. The depth limitations also vary with the kind of clay mineral present. The type of soils found in the location affects how deep the soils are. The nature of the parent material, on which soils were created, essentially determines the soil depth. Agricultural land with deep soil supports for better agriculture (Bandyopadhyay et al., 2009). These soil characteristics were categorized based on the soil classification and characterization guide for agricultural suitability by FAO for which soil having depth greater than 90, 50-90, 20-50 and 0-20 cm customized as highly suitable, moderately suitable, marginally suitable and not suitable for agricultural land respectively (Sheng, 1990).

2.6.5 Soil Drainage

Soil drainage is an important physical characteristic of the soil. Controlling the movement of salt and water in the soil profile is made easier by considering soil drainage conditions when identifying potential agricultural land in the research area. Drainage ensures that the soil is aerated properly. Excess or standing water can choke crops. Drainage reduces soil and nutrient loss from runoff and can aid in the prevention of soil erosion (Halefom, 2020). Well-drained soils are beneficial to agriculture and other plant growth in general, which moderately drained, poorly drained and excessively drained soils comes next orderly based on their benefit for agricultural use (Hussien et al., 2019) and they are influenced by soil texture, soil type, and soil depth, which affect soil moistures and, thus, plant growth (Abebe, 2020).

2.6.6 Soil Texture

Texture is one of the most important soil properties, influencing crop production, land use, and management. The texture of the soil is directly related to its ability to retain nutrients and drain. The relative proportions of clay, silt, and sand in the soil are reflected in the texture classes. Textural classes are directly related to soil structures, consistency, porosity, and cation exchange capacity when combined with other properties. Because the texture of a soil in the field is not easily changed, it is considered as a permanent soil attribute (Brady & Weil, 2007). Since “these components of soil are largely unalterable, there’s not much anyone can do to change them” (Jaja, 2016). So it is very impractical (expensive) and thus ill-advised to modify a soil’s texture (Berry et al., 2007). In order to know the texture of the soil, its components are classified by their combined percentages into a textural class with the aid of the textural triangle (USDA-NRCS, 1999). The texture of the upper 30cm of the soil, which are important for tillage and water retention (Abebe, 2020). Loamy soil is the most suitable for the majority of crops, generally containing more organic soil matter and retaining moisture and nutrients better than other soil textures which silty clay, clay and water body comes next in order according to the benefit for agricultural uses which then customized as highly suitable, moderately suitable, marginally suitable and not suitable (Radočaj et al., 2020).

2.6.7 Rainfall

Rainwater is an important source of agriculture that falls on the earth's surface and is a climate element that determines the humidity required for crops (Nikolova & Mochurova, 2012). The foremost farming practice over most parts of Sub-Saharan Africa (SSA) is rain fed agriculture. In fact, 97% of the total cropland in Sub Saharan Africa is dominated by rain-fed farming (Bekchanov et al., 2013) and this agricultural practice is expected to remain the major source of staple food production for the majority of people in rural areas (Cooper et al., 2008). Agriculture production is heavily reliant on precipitation which fall in the form of rain (Adnan & Hayat, 2009) and the high period of rainfall is unsuitable for agriculture (Debesa et al., 2020).

2.7 Analytical Hierarchy Process, AHP

The analytical hierarchy process (Thomas & Doherty, 1980) technique integrated with GIS application environments has been used for agricultural land suitability analysis on various case study sites around the world (Malczewski, 2004; M. K. Pramanik, 2016; Zabihi et al., 2015b; Rajendra Bhausaheb Zolekar & Vijay Shivaji Bhagat, 2015). It involves performing a pairwise and weighted multi-criteria analysis on a set of socioeconomic and biophysical drivers. The technique has been widely used for local and regional land suitability analysis for watershed planning (Steiner et al., 2000), vegetation (Zolekar & Bhagat, 2015), and agriculture (Bandyopadhyay et al., 2009; Motuma et al., 2016; Shalaby et al., 2006). Biophysical parameters such as land use land cover, slope, elevation, and soil properties such as depth, texture are frequently used for assessment of agricultural land suitability evaluation (D. Rossiter, 1996; Rajendra Bhausaheb Zolekar & Vijay Shivaji Bhagat, 2015). Through pairwise comparison in AHP, expert opinion is used to weight such factors influencing land suitability.

Chapter Three

3. Material and Methods

3.1 Description of the Study Area

3.1.1 Geographical Location and topography

South Gonder zone is located between 11° 46' N latitude and 38° 8' E longitudes. The zone is bordered on the South by East Gojjam, on the Southwest by West Gojjam and Bahir Dar, on the West by Lake Tana, on the North by North Gondar, on the North East by Wag Hemra, on the East by North Wollo, and on the South East by South Wollo; the Abbay River separates South Gondar from the two Gojjam Zones (Getachew, 2017). Its average elevation is 2,706 meters a.s.l with area coverage of 14,095 square km.

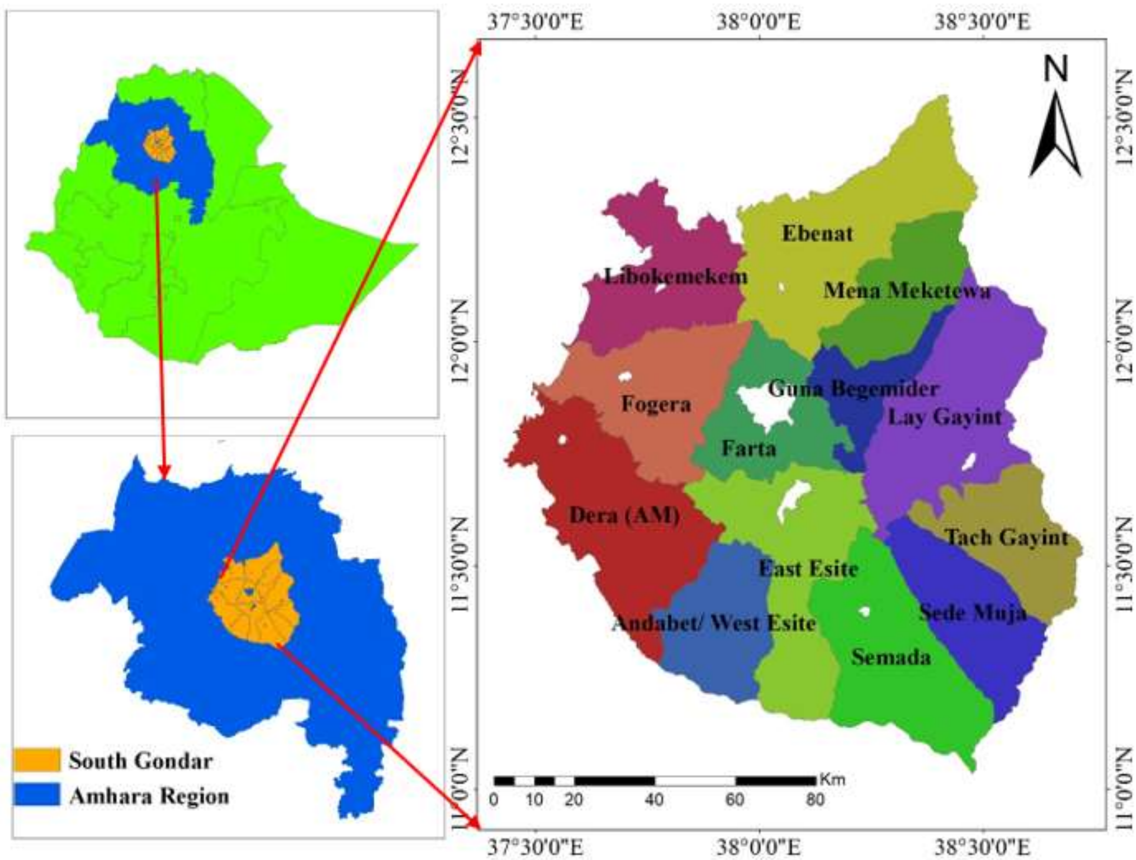

Figure 3. 1 Location map of the study area

3.1.2 Climate

The climate of the zone is more influenced by altitude and latitude than others. Based on the simplified agroclimatic classification of Ethiopia, it lies within four agro climatic zones. Wurch (Alpine) and Kola (tropical) accounts for 2.5% and 16% respectively whereas Woina Dega (Sub tropical) and Dega (temperate) account 27% and 54% of the zone. The zone has bimodal rainfall pattern, summer is the main rainy season with its peak in July (June to August) and the short rainy season from February to April. Rainfall varies from 900 mm to1599mm. The average annual rainfall in the zone is 1300mm. The average temperature in the zone is 17°C (Getachew, 2017).

3.1.3 Agricultural Practice

Various economic activities are undertaken in the study area. Farming is the major economic engagement for crop production such as a teff, barley, wheat, maize, sorghum, potato, triticale, fava bean, field pea. The zone's farming system is characterized by mixed farming. As a result, more than 85% of farm households practice mixed farming systems, and more than 93% plough their land using traditional farming technology(Enyew, 2021).

3.2 Methods

Four stage analysis were applied in this research to achieve the stated goals: First, Digital elevation model, land use land cover, Soil and Rainfall downloaded or received from the appropriate sources as shown below in table 3.1 and were used as the datasets, then vector layers were processed to develop the suitability analysis criteria. Seven criteria were used, which includes; Elevation, Slope, Land Use Land Cover, Soil depth, Soil drainage, Soil texture and Rainfall. The second stage of analysis, was to set the criteria for agricultural land suitability and divided into four categories. Third, develop Analytical Hierarchy Process (AHP) based on expert knowledge. Finaly, perform Weighted Overly Analysis (WOA) on the GIS Environment.

3.2.1 General Approach

The success of suitable agricultural land mapping is largely depend on the selection of appropriate sites and technologies. Suitable agricultural land sites were chosen by identifying and integrating the criteria that influence land suitability for agriculture in the study area. GIS was used in conjunction with a multi-criteria evaluation system (MCES) to identify suitable agricultural sites through three steps: -

I. Selection of criteria and preparation of a spatial datasets.

II. Classification of the suitability level of each criterion.

III. GIS analysis and generation of suitability maps for agriculture.

3.2.1.1 Spatial data sets

Input GIS data used for the analysis of agricultural land suitability are presented according to table 3.1

Table 3.1 Input data

Data type	Resolution	Data type	Source	Output, map for further analysis
DEM	30m	Raster	Shuttle Radar Topography Mission (SRTM) from USGS earth explorer	Elevation Slope
LULC	10m	Raster	Esri 2020 Global Land Cover	LULC
Soil	1:5000	Vector	From Amhara Design & Supervision Works Enterprise	Soil depth Soil drainage Soil texture
Rainfall	1: 5000	Raw data in table	from Amhara Meteorological station	Rainfall

Table 3.2 Software used for data Analysis

Software Name and Version	Purpose
Arc GIS 10.8	Preparation of thematic maps
Google Earth	Ground Verification
XLSTAT 2018	Filling of missing Rainfall data
Excel 2013	For AHP and Rainfall analysis
Word 2013	Writing and documentation
EndNote20	Citation and References

3.2.2 Criteria for Suitability Analysis

Elevation, Slope, Land use Land cover, Soil depth, Soil drainage, Soil texture and Rainfall were the criteria for agricultural land suitability analysis. These criteria were selected based on extensive literature review of potential factors affecting agricultural land suitability.

A. Elevation

Higher topographic elevations are more susceptible to rainfall which exposed to erosion and are therefore unsuitable for agricultural land (Bozdağ et al., 2016). The elevation map was produced using the DEM of South Gondar which lies between 1198 to 4116 m. These datasets were a raster layer and created with two classifications. According to Ethiopia's agro ecological zoning, elevations above 3,700 m are classified as 'high wurch' (frosty alpine) and thus unsuitable for agricultural purposes (Yalew et al., 2016b).

Table 3.3 Elevation class of Agricultural suitability

No	Elevation class	Suitability Class	Rank
1	1198 - 3700	Suitable	S
2	3700 - 4116	Not Suitable	S4

Source: *(Yalew et al., 2016b)*

B. Slope

The slope influences the quality of the land and is one of the parameters used to determine crop suitability. Seasonal plants require flatter land that is only slightly sloped and free of erosion (Zolekar & Bhagat, 2015). The slope map were extracted using the digital elevation model (Demarez et al., 2019) which was downloaded as 30 m resolution. The topography was classified for steepness according to the presence of slopes between 0 and 76%. These datasets were a raster layer and created with four classifications and then resampled to 10m resolution. Because the slope gradient is the main factor controlling soil erosion, when the slope gradient is very steep, soil sediment losses remain at the same high levels after cultivation abandonment (M. Koulouri & Giourga, 2007).

Table 3.4 Slope class of Agricultural suitability

No	Slope %	Suitability Class	Rank
1	0 - 7	Highly Suitable	S1
2	7 - 15	Moderately Suitable	S2
3	15 - 25	Marginally Suitable	S3
4	>25	Not Suitable	S4

Source: (T. Sheng, 1990)

C. Land use / Land Cover

It is possible to evaluate an area's vegetation, forest, urban presence/settlement, and water bodies using data on land use and land cover (LULC) which then customized highly suitable, moderately suitable, marginally suitable and not suitable (Mohajane et al., 2018). The land use/land cover (LULC) map were built using 10 m resolution ESA Sentinel-2 imagery downloaded scenes by the year 2021 and is a composite of land use/land cover predictions for 11 classes with an overall accuracy of 86% on the validation set (Karra et al., 2021) and then processed in ArcGIS. These data sets were a raster layer and created with four classifications, which were vegetation, forest, urban and water. The vegetation class consists of flooded vegetation (4), crops (5), and the range lands (11). The forest class consist of trees (2) and clouds (10). The urban class consist of built areas (7). Finally, the water body consists of areas of water (1) and bare ground (8) (https://www.arcgis.com/apps/instant/media/index.html?appid=fc92d38533d440078f17678ebc20e8e2).

Table 3.5 LULC class of Agricultural suitability

No	LULC_Class	Suitability Class	Rank
1	Vegetation	Highly Suitable	S1
2	Forest	Moderately Suitable	S2
3	Urban	Marginally Suitable	S3
4	Water body	Not Suitable	S4

Source: (Mohajane et al., 2018)

D. Soil depth

The Amhara soil map at a suitable scale were used as the foundation. Soil data of the study area was obtained from Amhara Design & Supervision Works Enterprise which is clipped to the study area and converted to raster format by 30 m spatial resolution which is then resampled to 10m resolution and reclassified into in four classes based on the guide for agricultural suitability by FAO for which soil having depth greater than 90, 50-90, 20-50 and 0-20 cm customized as highly suitable, moderately suitable, marginally suitable and not suitable for agricultural land respectively (T. Sheng, 1990).

Table 3.6 Soil depth class of Agricultural suitability

No	Soil depth_Class	Suitability Class	Rank
1	> 90	Highly Suitable	S1
2	50 - 90	Moderately Suitable	S2
3	20 - 50	Marginally Suitable	S3
4	0 - 20	Not Suitable	S4

Source: (T. Sheng, 1990)

E. Soil drainage

One of the crucial physical properties of soil is drainage. In general, agricultural use and other plant development benefit from well-drained soils. Soil depth, soil type, and texture all have an impact on drainage. Drainage has an impact on soil moisture levels, which has an impact on plant development (Abebe, 2020). The soil data was taken from Amhara Design & Supervision Works Enterprise which was clipped to the study area and transformed to raster format by 30 m spatial resolution before being resampled to 10 m resolution. These datasets were a raster layer and created with four classifications, which were well drained, moderately well drained, poorly drained and excessively drained which then customized highly suitable, moderately suitable, marginally suitable and not suitable respectively which well-drained soil is highly suitable for agriculture (Hussien et al., 2019).

Table 3.7 Soil drainage class of Agricultural suitability

grid_code	Soil drainage Class	Suitability Class	Rank
1	W	Highly Suitable	S1
2	M	Moderately Suitable	S2
3	P	Marginally Suitable	S3
4	E	Not Suitable	S4

Source: (Hussien et al., 2019)

F. Soil Texture

One of the most important physical properties of soil is its texture. Knowing soil texture is useful because it provides a tool for determining the best opportunity for maintaining plants in a healthy and productive soil. Soil data of the study area was obtained from Amhara

Design & Supervision Works Enterprise which then clipped to the study area and transformed to raster format by 30 m spatial resolution before being resampled to 10 m resolution and categorized into four classes which are clay loam, silty clay, clay and water body and rock which then customized highly suitable, moderately suitable, marginally suitable and not suitable (Radočaj et al., 2020). Because they have an even mix of all soil separates, loam soils are generally considered the most productive soil for agriculture. As a result, loam would be favorable for a wide range of crops, including climbers, bamboos, perennials, shrubs, and tubers, as well as the majority of vegetable and berry crops (Jaja, 2016).

Table 3.8 Soil texture class of Agricultural suitability

No	Texture Class	Suitability Class	Rank
1	Clay Loam	Highly Suitable	S1
2	Silty Clay	Moderately Suitable	S2
3	Clay	Marginally Suitable	S3
4	Water body and Rock	Not Suitable	S4

Source:(Radočaj et al., 2020)

G. Rainfall

Rainfall data was recieved from Amhara meteorological stations for 10 years from 2011 to 2020 of 13 stations. May to October is considered the growing season for crop in the South Gondar areas. These 6 months of rainfall data was used for the rainfall pattern analysis. Then, the rainfall data was reclassified with common rainfall criteria. The rainfall data was calculated from the mean of each month to retrieve single raster data. The rainfall was classified according to the presence of rainfall between 1,097mm and 2,012mm. These datasets were a raster layer and created with two classifications suitable and not suitable for which the high period of rainfall is unsuitable for agriculture (Debesa et al., 2020). The highest rainfall usually cuases soil erosion and leaching of nutreints which leads to poor crop productivity.

Table 3.9 Rainfall class of Agricultural suitability

No	Rainfall Class, mm	Suitability Class	Rank
1	1097 - 1600	Suitable	S
2	1600 - 2012	Not Suitable	S4

Source:(Debesa et al., 2020).

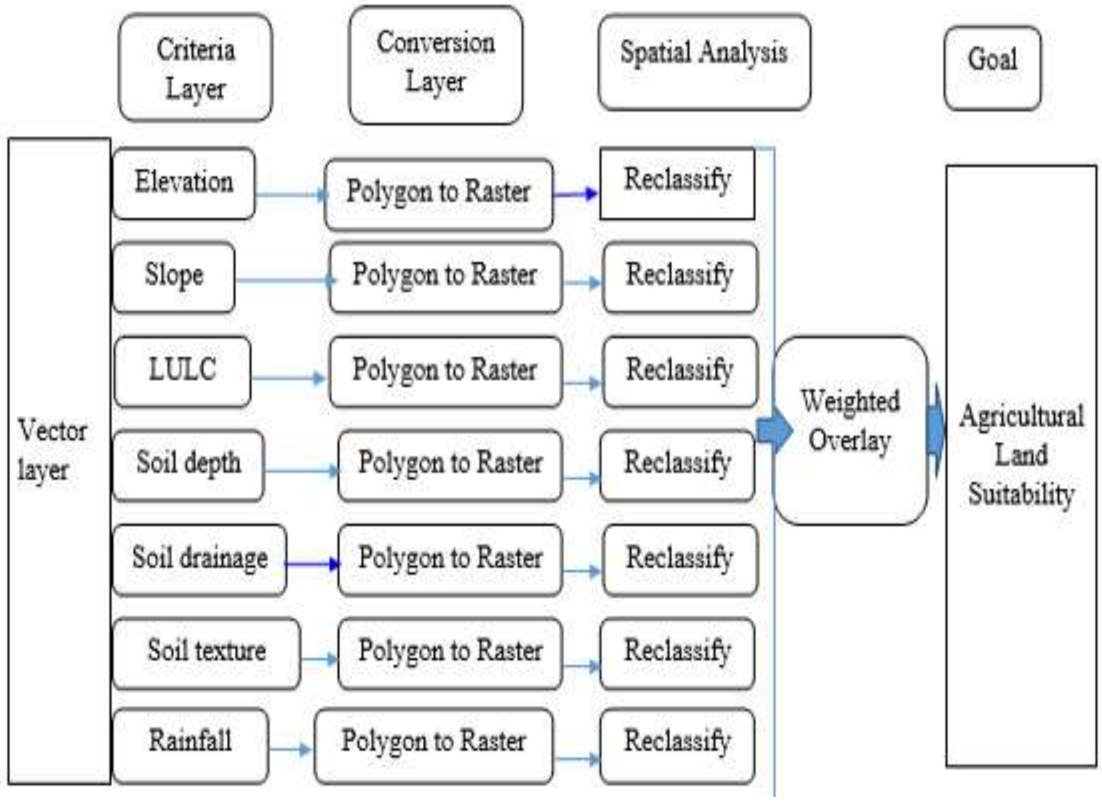

Figure 3. 2 Conceptual frame work for Land suitability Analysis

3.3 Analytical Hierarchy Process, AHP

The first step in an AHP analysis is to create a decision hierarchy. This is also known as decision modeling, and it simply entails creating a hierarchy to analyze the decision. Not all of the criteria will be equally important. As a result, the second step in the AHP process is to determine the relative weights (priorities) for the criteria. It is called relative because the obtained criteria priorities are measured in relation to each other, which is based on verbal judgment in relation to a score of numerical value (Mu & Pereyra-Rojas, 2017). In this study, agricultural land use suitability in South Gondar zone was analyzed using AHP and GIS based weighted overlay analysis (WOA) techniques. Multiple criteria for agricultural land use suitability mapping were derived based on literature reviews, field investigations and FAO guidelines for agricultural land use evaluation (Bandyopadhyay et al., 2009; D. G. Rossiter, 1996; Yalew et al., 2016a; Zabihi et al., 2015a; Rajendra Bhausaheb Zolekar & Vijay Shivaji Bhagat, 2015). In the weighted overlay, the AHP weights, which were also based on expert knowledge, were used to prioritize each criterion layer (Habibie et al., 2021b; Rashid, 2019; Hamere Yohannes & Teshome Soromessa, 2018). The weights were developed from the normalized matrix.

Table 3.10 Saaty scale of rating influence of factors

No	Intensity of influence	Definition	Explanation
1	**1**	Equal importance	Two factors influence equally to objective
2	**3**	Somewhat more important	Experience and judgment slightly one over the other
3	**5**	Much more important	Experience and judgment strongly favor one over the other
4	**7**	Very much more important	Experience and judgment are very strongly to favor one over the other. Its importance is demonstrated in practice.
5	**9**	Absolutely more important	The evidence favoring one over the other is of highest possible validity
6	**2,4,6,8**	Intermediate values	When compromise is needed

Source: (Saaty, 2002)

Table 3.11 Random Index Value

No of Criteria	1	2	3	4	5	6	7	8
RI Value	0	0	0.58	0.9	1.12	1.24	1.32	1.41

Source: (Mu & Pereyra-Rojas, 2017)

3.1.1 Computation of the Weight of the Criteria

The computation of the weights of the criteria were carried out as: -

1. Assign the weight and calculate the summation of values in each column of the pairwise comparison matrix

(See table 3.12).

Table 3.12 Pair-wise comparison matrix

	Rainfall	Slope	Soil depth	Soil texture	Elevation	Soil drainage	LULC
Rainfall	1	3	4	5	6	7	9
Slope	0.3	1	3	4	5	5	6
Soil depth	0.3	0.33	1	2	3	3	5
Soil texture	0.2	0.25	0.5	1	2	3	4
Elevation	0.2	0.2	0.33	0.5	1	2	3
Soil drainage	0.1	0.2	0.33	0.33	0.5	1	3
LULC	0.1	0.17	0.2	0.25	0.33	0.33	1
Sum	**2.20**	**5.15**	**9.37**	**13.08**	**17.83**	**21.33**	**31**

2. Divide each cell in the matrix by its column total.

Table 3.13 Normalized pair-wise comparison matrix

	Rainfall	Slope	Soil depth	Soil texture	Elevation	Soil drainage	LULC
Rainfall	0.45	0.58	0.43	0.38	0.34	0.33	0.29
Slope	0.15	0.19	0.32	0.31	0.28	0.23	0.19
Soil depth	0.11	0.06	0.11	0.15	0.17	0.14	0.16
Soil texture	0.09	0.05	0.05	0.08	0.11	0.14	0.13
Elevation	0.08	0.04	0.04	0.04	0.06	0.09	0.10
Soil drainage	0.06	0.04	0.04	0.03	0.03	0.05	0.10
LULC	0.05	0.03	0.02	0.02	0.02	0.02	0.03

3. Find the summation of each row and averaging to get the weight of the parameters as provided in table 3.14.

Table 3.14 Weight of Parameters

	Rainfall	Slope	Soil depth	Soil texture	Elevation	Soil drainage	LULC	**Criteria weight**
Rainfall	0.45	0.58	0.43	0.38	0.34	0.33	0.29	**0.40**
Slope	0.15	0.19	0.32	0.31	0.28	0.23	0.19	**0.24**
Soil depth	0.11	0.06	0.11	0.15	0.17	0.14	0.16	**0.13**
Soil texture	0.09	0.05	0.05	0.08	0.11	0.14	0.13	**0.09**
Elevation	0.08	0.04	0.04	0.04	0.06	0.09	0.10	**0.06**
Soil drainage	0.06	0.04	0.04	0.03	0.03	0.05	0.10	**0.05**
LULC	0.05	0.03	0.02	0.02	0.02	0.02	0.03	**0.03**

4. Multiply each column cell (assigned numerical value of no 1) by the criteria weight and find the summation of each row to get the weighted sum value and then divide the weighted sum value by the criteria weight to get the ratio.

Table 3.15 Weighted sum value and the ratio

	Rainfall	Slope	Soildepth	Soil texture	Elevation	Soil drainage	LULC	**weighted sum value**	**Ratio**
Rainfall	0.40	0.72	0.52	0.46	0.37	0.34	0.24	**3.06**	**7.64**
Slope	0.13	0.24	0.39	0.37	0.31	0.24	0.16	**1.85**	**7.70**
Soil depth	0.10	0.08	0.13	0.19	0.19	0.14	0.14	**0.96**	**7.42**
Soil texture	0.08	0.06	0.06	0.09	0.12	0.14	0.11	**0.67**	**7.26**
Elevation	0.07	0.05	0.04	0.05	0.06	0.10	0.08	**0.44**	**7.15**
Soil drainage	0.06	0.05	0.04	0.03	0.03	0.05	0.08	**0.34**	**7.07**
LULC	0.04	0.04	0.03	0.02	0.02	0.02	0.03	**0.20**	**7.28**

Summation of ratio $= \mathbf{51.5}$

3.3.2 Consistency

Once a judgment has been entered, it must be reviewed to ensure that it is consistent. In AHP analysis, some inconsistency is expected and allowed. Because the numerical values are derived from individuals' subjective preferences, some inconsistencies in the final matrix of judgments are unavoidable. The question is how much inconsistency can be tolerated. AHP computes a consistency ratio (CR) by comparing the consistency index (CI) of the matrix under consideration (the one with our judgments) to the consistency index of a random-like matrix (RI). In AHP, the consistency ratio is defined as CR where CR = CI/RI. Saaty (2012) has shown that a consistency ratio (CR) of 0.10 or less is acceptable to continue the AHP analysis. If the consistency ratio is greater than 0.1, the judgments must be revised to identify and correct the source of the inconsistency.

$$\lambda \max = \frac{\sum Ratio}{n} = \frac{\sum 51.5}{7} = 7.4$$

Consistency Index, CI = $\frac{\lambda \max - n}{n-1} = \frac{7.4-7}{7-1} = 0.07$

Consistency ratio $CR = \frac{CI}{RI} = \frac{0.07}{1.32} = 0.05$

These is, therefore, the assignment of the weight for each factor and the comparison between them was acceptable (Bascetin, 2007) because this value of 0.05 for the proportion of inconsistency CR is less than 0.1, I can assume that my judgments matrix is reasonably consistent So, I may continue the process of decision-making using AHP. The results of the AHP weights showed that Rainfall was ranked first, the Slope was ranked second, Soil depth was ranked third, and this was followed by the other criteria with lower ranking weights (Table 3.14).

3.4 Reclassification of Criteria

The reclassification was done to interpret the raster data by either replacing a single value with a new value or categorizing ranges of values into a single value. According to FAO guidelines (D. G. Rossiter, 1996) land suitability for agriculture can be classified into five categories: (1) highly suitable, (2) moderately suitable, (3) marginally suitable, (4) currently unsuitable and (5) permanently unsuitable. It was customized and reclassified for each raster layer criteria into four categories with associated suitability score of 1– 4 (1 = highly suitable; 2 = moderately suitable; 3 = marginally suitable; and 4 = unsuitable). The criteria are used to build the agricultural land suitability assessment, which is then reclassified in to four classes.

Table 3.16 Description of agricultural Land Suitability Classes

Code	**Class**	**Characteristics**
S1	Highly Suitable	Land has no limitation for a given use. Limitation that does not reduce appreciable the productivity and benefit. No need for a high level of input.

S2	Moderately Suitable	Land having minor limitation that could reduce productivity or benefits. Adaptive inputs are required to reach the same yield as that of highly luitabil.
S3	Marginal Suitable	Having moderate limitations for certain use, in which the amount of surplus input is only marginally justified.
N	Not Suitable	Land with severe limitations for the land use under consideration. Major factors of the earth soil, climate, and topography.

Source: (FAO, 1976).

3.5 Weighted Overlay Analysis

Weighted overlay analysis (WOA) is performed on an ArcGIS environment after weights for each raster layer are computed using AHP. Weighted overlay is an intersection of standardized and differently weighted layers during suitability analysis (Zolekar & Bhagat, 2015). The weights quantify the relative importance of the suitability criteria that are taken into account. The WOA technique was used to calculate the final suitability map by multiplying the suitability scores assigned to the sub-criteria within each criteria layer by the weights assigned to each criterion.

$$S = \sum_{i=1}^{n} WiXi$$

where S is the total suitability score, Wi is the weight of the selected suitability criteria layer, Xi is the assigned sub criteria score of suitability criteria layer i, and n is the total number of suitability criteria layer (Cengiz & Akbulak, 2009; Pramanik, 2016).

Chapter Four

4. Results and Discussion

4.1 Criterion layer maps

The following thematic maps were essential to identify potential sites for suitable agricultural land in the study area:

4.1.1 Elevation

Based on the analysis result of DEM, the elevation of the area ranges from 1198 to 4116 m. As per the analysis result as shown in Table 4.1 and Figure 4.2 a maximum of 0.3% of the area was found in the not suitable class which has severe restrictions for the proposed land use and the area has elevation > 3700m asl. This implies that, this range of elevation is classified as high wurch which is not suitable for agriculture (Yalew et al., 2016b). 99.7% of the study area which has elevation ranging from 1198 to 3700 m was categorized as suitable and rated as suitable to agriculture since the land has no restrictions on its use and the limitation has no discernible impact on productivity. Therefore, there is no need for a high level of input. Table 4.1 and Figure 4.2 describes the elevation suitability level of the study area.

Table 4.1 Elevation suitability area percent coverage

Suitability class	Suitable	Not Suitable
Area %	99.7	0.3

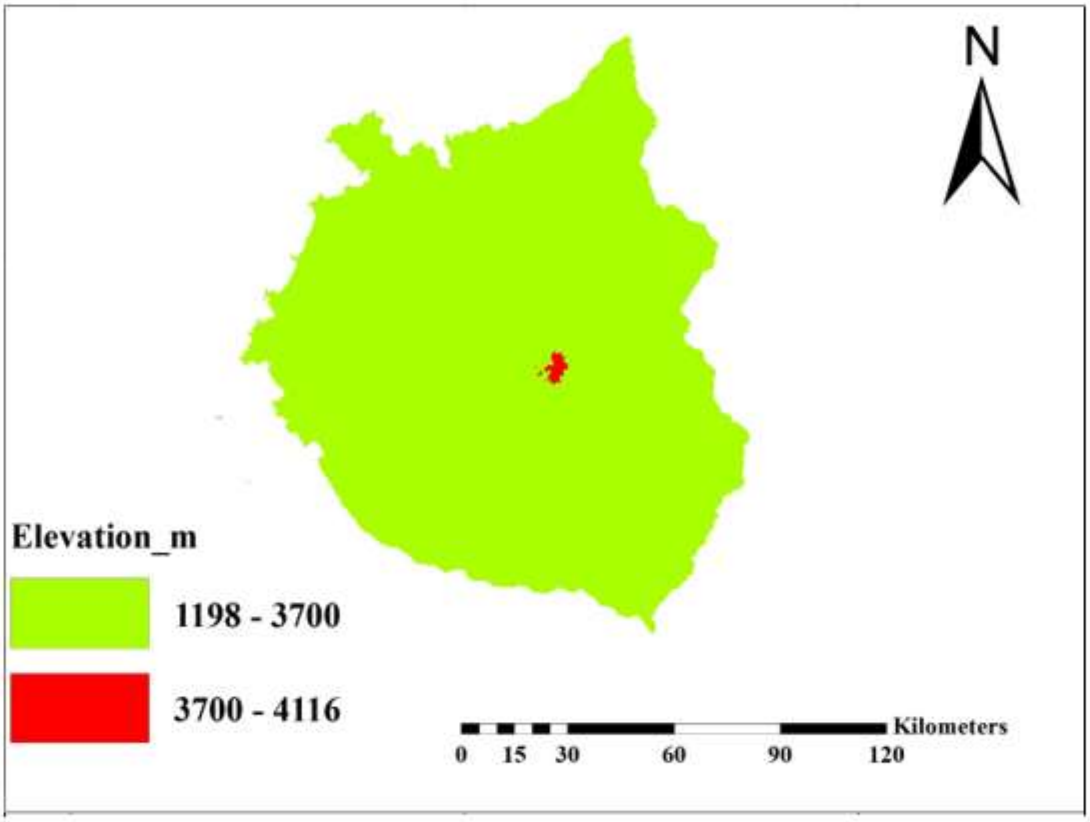

Figure 4. 1 Elevation map

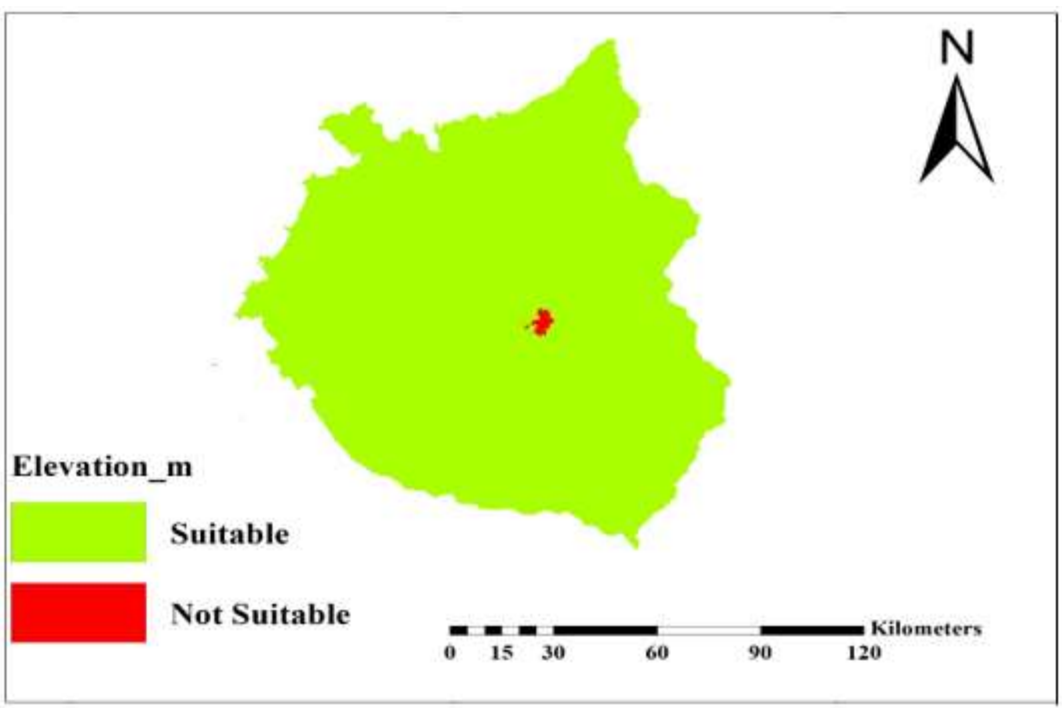

Figure 4. 2 Elevation suitability map

4.1.2 Slope

Based on the analysis result of DEM, the slope of the area ranges from 0 to 76 %. As per the analysis result as shown in Table 4.2 and Figure 4.4 a maximum of 18.2% of the area with a slope >25 was not suitable for agriculture in which the land has major constraints for agricultural use. 29.1% of the study area was categorized as highly suitable since the land has no restrictions on its proposed use and there is no need for a high level of input and the area has a slope of (0 – 7%) and this slope is rated as highly suitable to agriculture (T. Sheng, 1990). About 27.3% of the land is grouped as moderately suitable and this implies that the land has minor constraints that could reduce productivity to achieve the same yield as the land categorized as highly suitable and hence it needs adaptive inputs. 25.4% of the land is grouped as marginally suitable and this implies that the land has moderate restrictions for specific uses of land, where the amount of surplus input is only marginally justified. Table 4.2 and Figure 4.4 describes the slope suitability level of the study area.

Table 4.2 Slope suitability area percent coverage

Suitability class	S1	S2	S3	S4
Area %	29.1	27.3	25.4	18.2

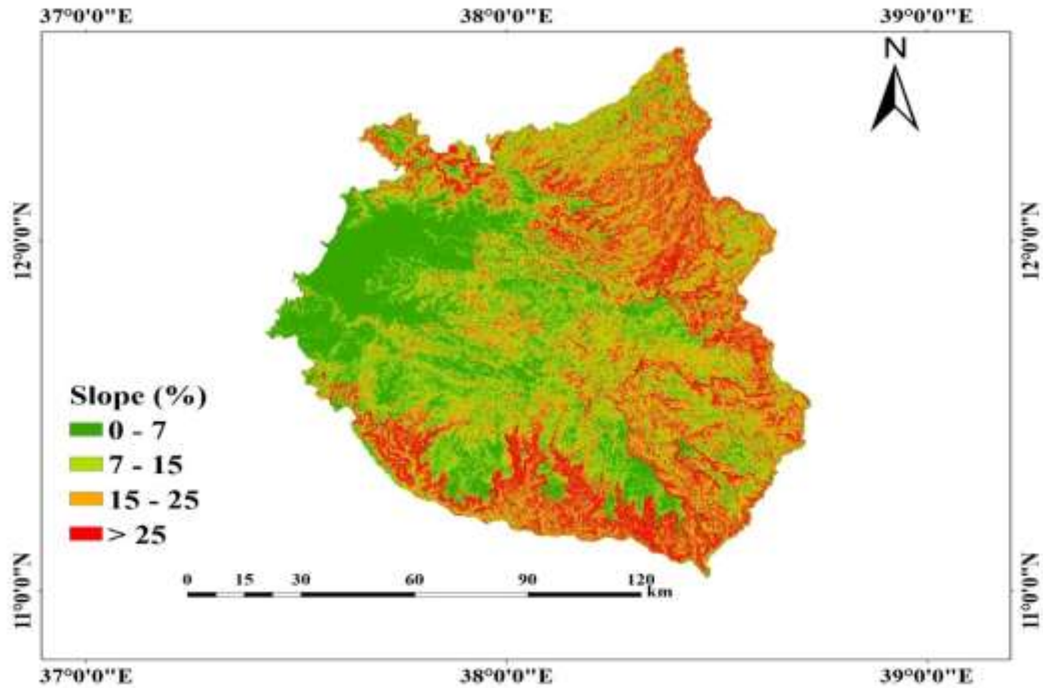

Figure 4. 3 Slope map

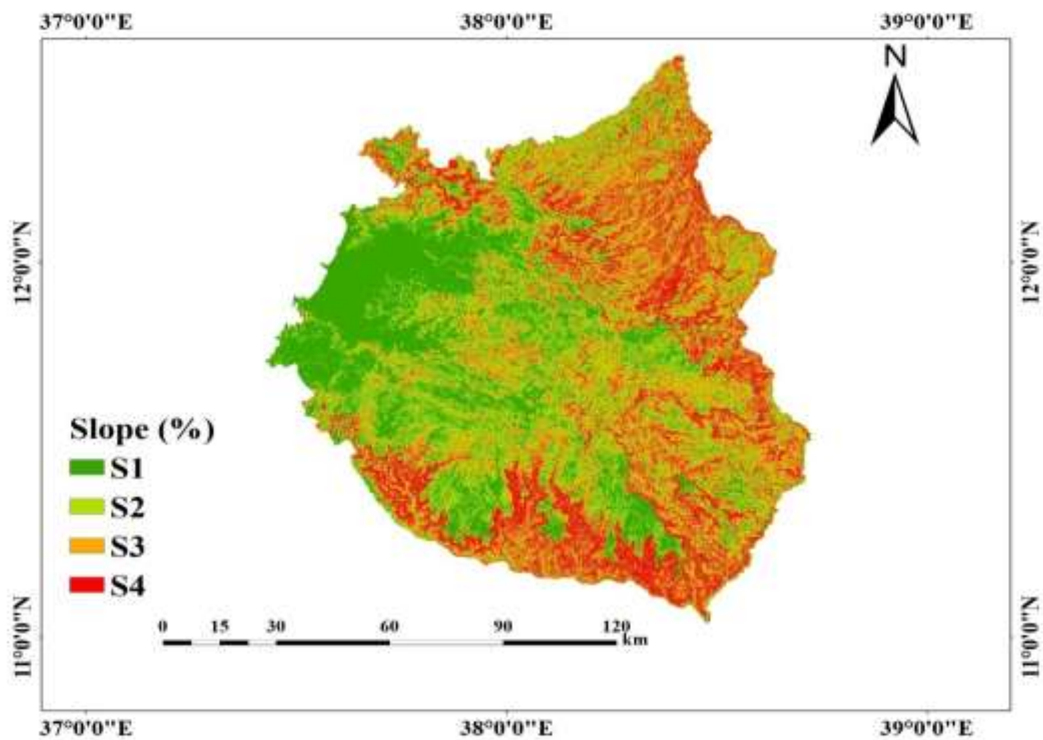

Figure 4. 4 Slope suitability map

4.1.3 Land Use /Land Cover

Land Use/ Land Cover is one of the parameters used to determine the level of land suitability for agricultural crops. As per the analysis results as shown in Table 4.3 and Figure 4.6 a maximum of 0.6% of the area was leveled as not suitable, since this area was water body and bare ground and this category of land has major constraints for agricultural use. Whereas 93.6% of the study area was categorized as highly suitable and has no restriction for agricultural use and the area has vegetation coverage which is rated as highly suitable to agriculture (Mohajane et al., 2018). About 1.5% of the land is grouped as moderately suitable indicating minor constraints that could reduce productivity of the land to achieve the same yield as the land categorized as highly suitable with adaptive input. And 4.4% of the land is grouped as marginally suitable implying that the land has moderate restrictions for specific uses, where the amount of surplus input is only marginally justified.

Table 4.3 and Figure 4.6 describes the LULC suitability level of the study area.

Table 4.3 LULC suitability area percent coverage

Suitability class	S1	S2	S3	S4
Area %	93.6	1.5	4.4	0.6

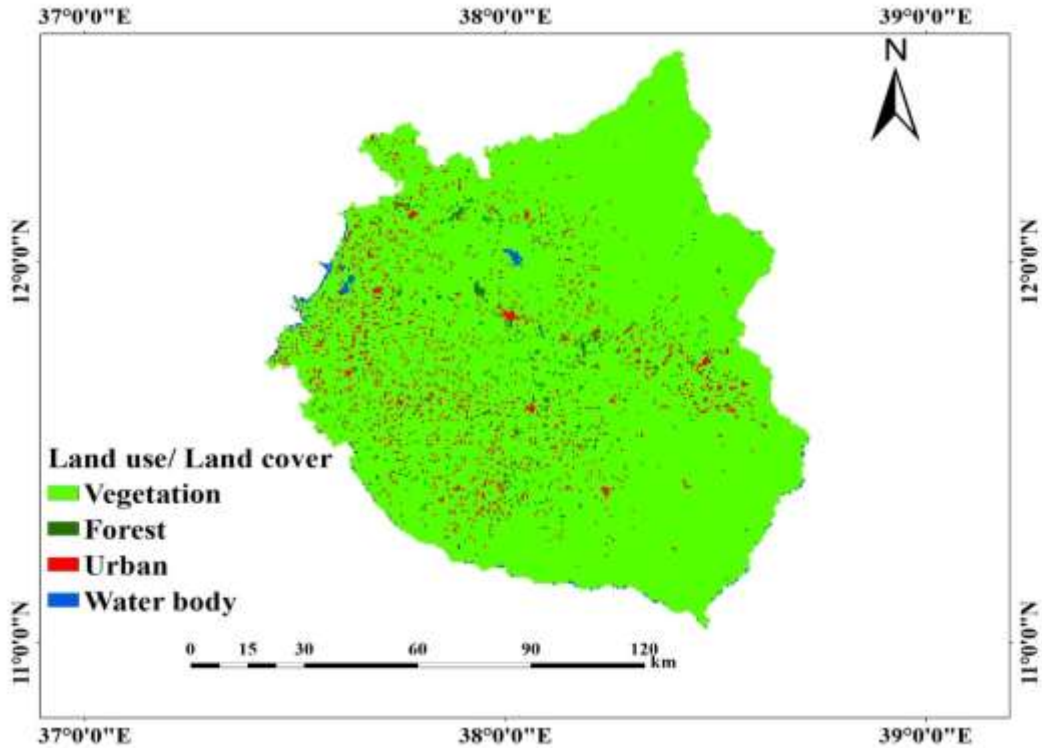

Figure 4. 5 LULC map

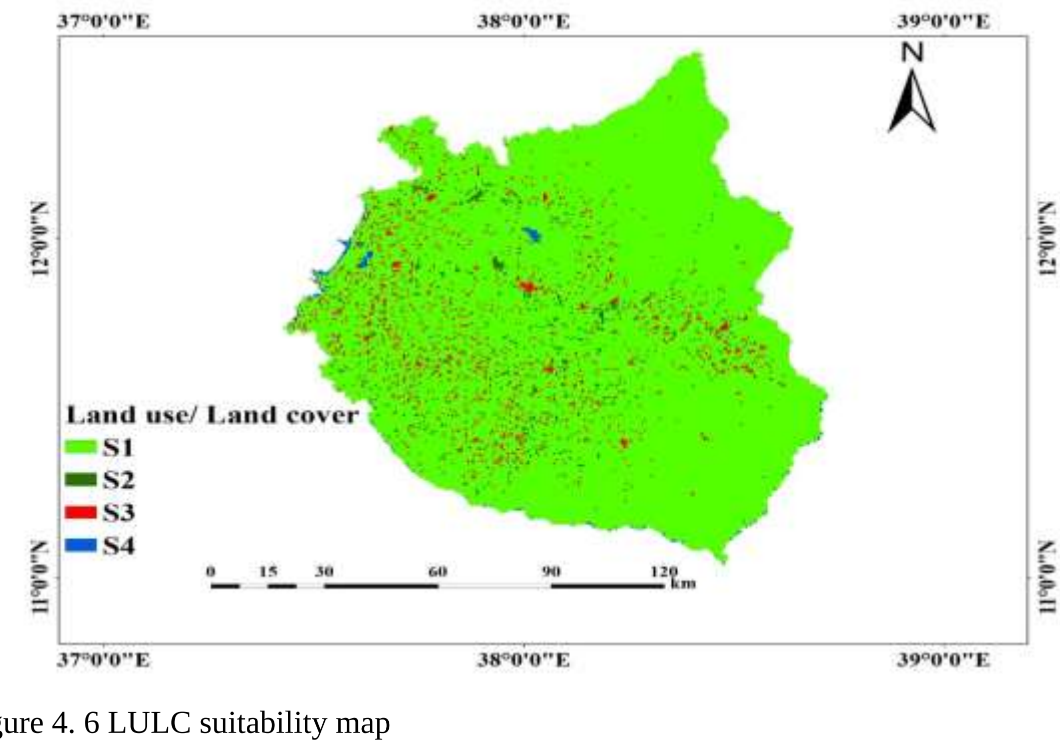

Figure 4. 6 LULC suitability map

4.1.4 Soil Depth

As per the analysis result as shown in Table 4.4 and Figure 4.8, about 6.75% of the area was found to be not suitable, since the area has a soil depth less than 20cm and this category of land has major limitation for agricultural use. 24.5% of the study area was categorized as highly suitable and the land has no restrictions on its proposed use, hence there is no need for a high level of input and the soil depth is greater than 90cm and rated as highly suitable to agriculture (T. Sheng, 1990). About 10.6% of the land is grouped as moderately suitable and this implies the land has minor constraints that could reduce productivity to achieve the same yield as the highly suitable and hence it needs adaptive inputs. 58.1% of the land is grouped as marginally suitable and this implies the land has moderate restrictions for specific uses, where the amount of surplus input is only marginally justified.

Table 4.4 and Figure 4.8 describes the Soil depth suitability level of the study area.

Table 4.4 Soil depth suitability percent area coverage

Suitability class	S1	S2	S3	S4
Area %	24.5	10.6	58.1	6.75

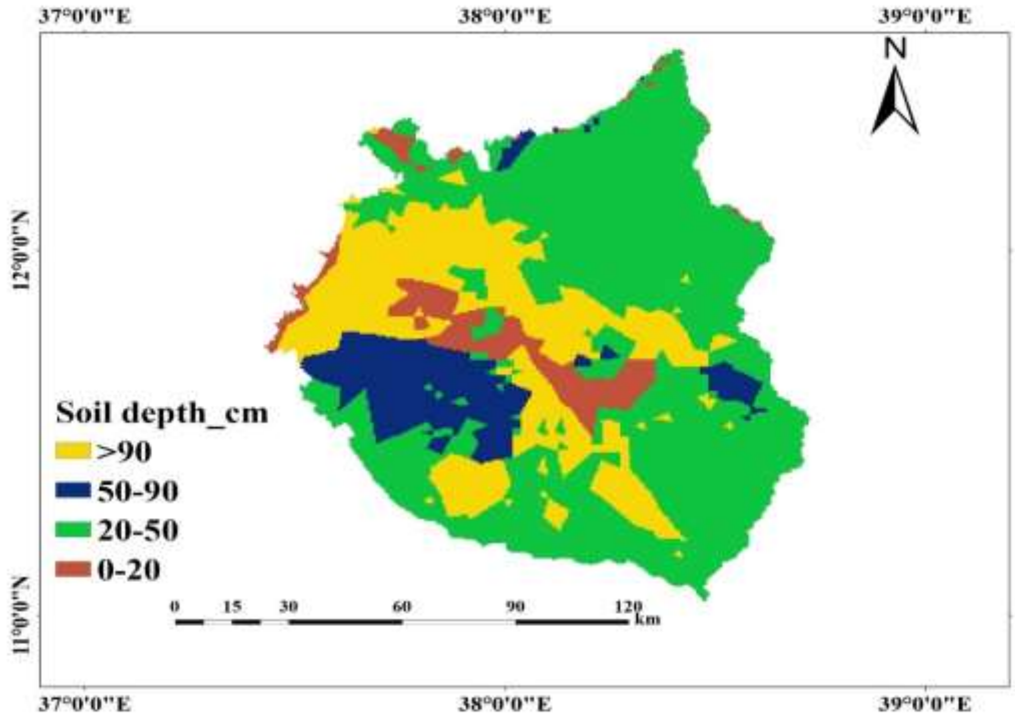

Figure 4. 7 Soil depth map

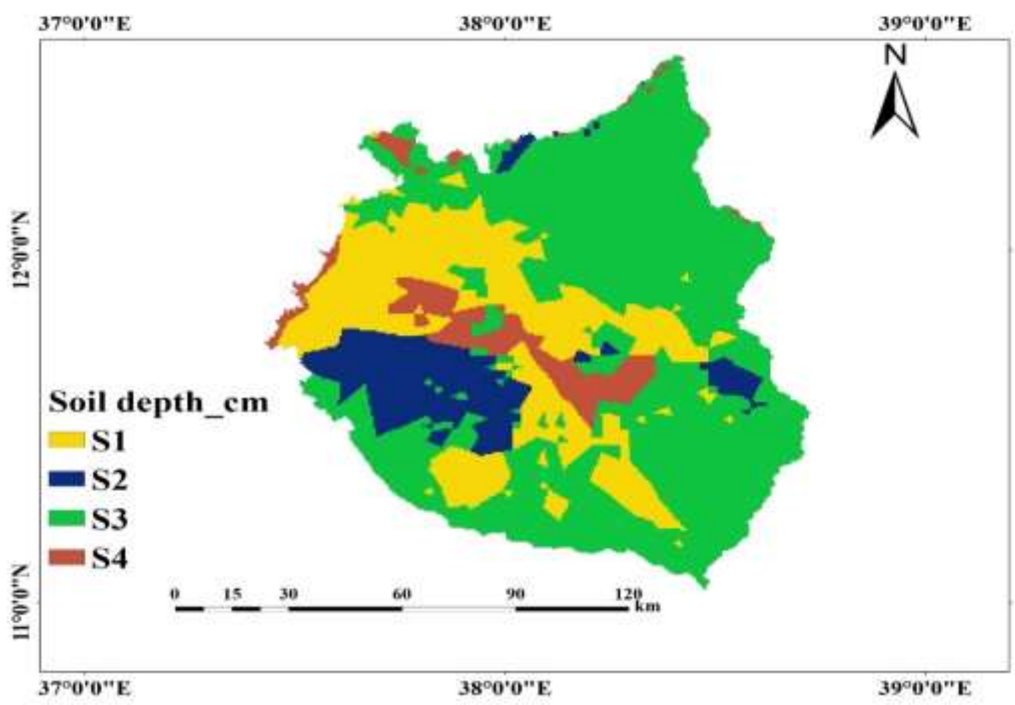

Figure 4. 8 Soil depth suitability map

4.1.5 Soil drainage

As per the analysis result as shown in Table 4.5 and Figure 4.10, about 30.7% of the area was found to be not suitable where the land has major limitations for agricultural use due to excessively drainage. This implies that, water is removed from the soil very rapidly. 12.4% of the study area was categorized as highly suitable where, the land has no restrictions on its proposed use and the area has well drained soil and is rated as highly suitable to agriculture (Ahmed et al., 2016). About 1.4% of the land is grouped as moderately suitable and this implies that the land has minor constraints that could reduce productivity to achieve the same yield as the land categorized as highly suitable and hence it needs adaptive inputs. 55.5% of the land is grouped as marginally suitable which implies the natural land cover is described as it has low saturated hydraulic conductivity, a high-water table, additional water from seepage and the soil drains so slowly which is not suitable for agriculture.

Table 4.5 and Figure 4.10 describes the soil drainage suitability level of the study area.

Table 4.5 Soil drainage suitability area percent coverage

Suitability class	S1	S2	S3	S4
Area %	12.4	1.4	55.5	30.7

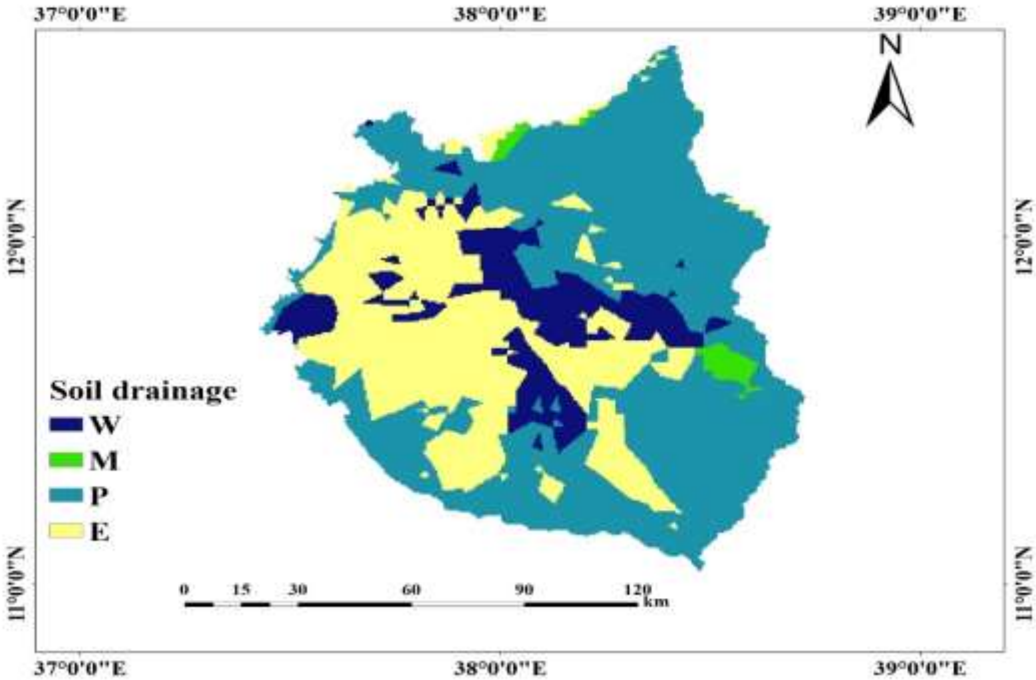

Figure 4. 9 Soil drainage map

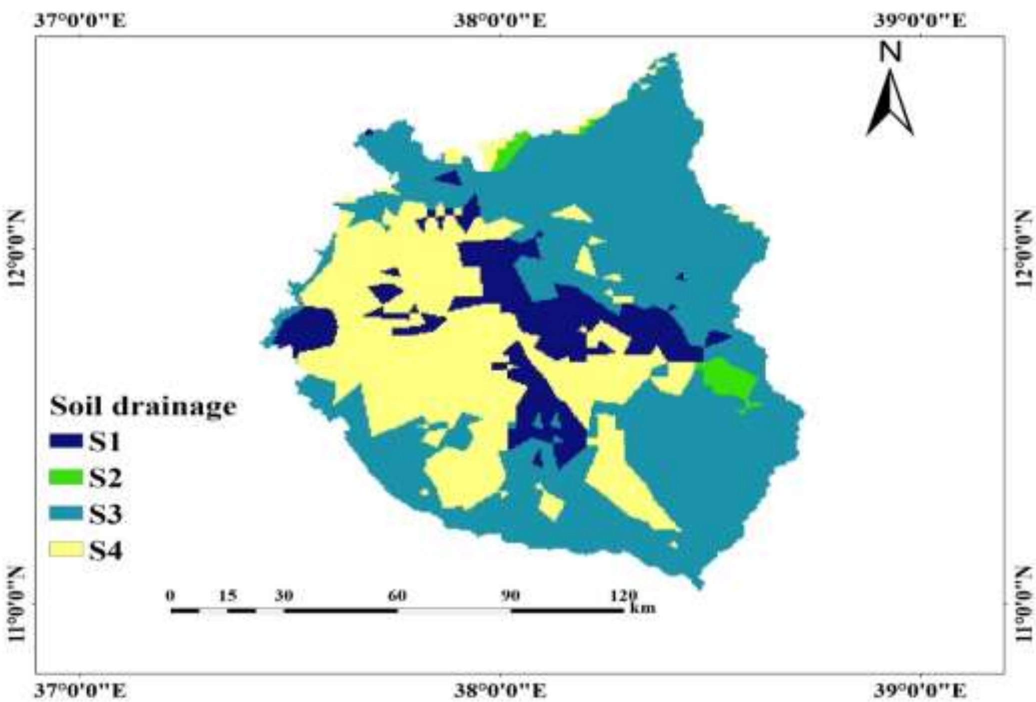

Figure 4. 10 Soil drainage suitability map

4.1.6 Soil Texture

According to the analysis results as shown in Table 4.6 and Figure 4.12, about 1.1% of the area was found to be not suitable which indicates that the land has major limitation for agricultural use. This implies that, 1.1% of the natural land cover of the South Gondar zone is described as water body which is not suitable for agriculture. 54.97% of the study area was categorized as highly suitable where, the land has no restrictions on its proposed use with no need for a high level of input and it is covered with clay loam which is rated as highly suitable to agriculture (Radočaj et al., 2020). About 0.4% of the land is grouped as moderately suitable and this implies that the land has minor constraints that could reduce productivity to achieve the same yield as the land categorized as highly suitable and hence it needs adaptive inputs. 43.5% of the land is grouped as marginally suitable and this implies that the land has moderate restrictions for specific uses.

Table 4.6 and Figure 4.12 describes the Soil texture suitability level of the study area.

Table 4.6 Soil texture suitability area percent coverage

Suitability class	S1	S2	S3	S4
Area %	54.97	0.4	43.5	1.1

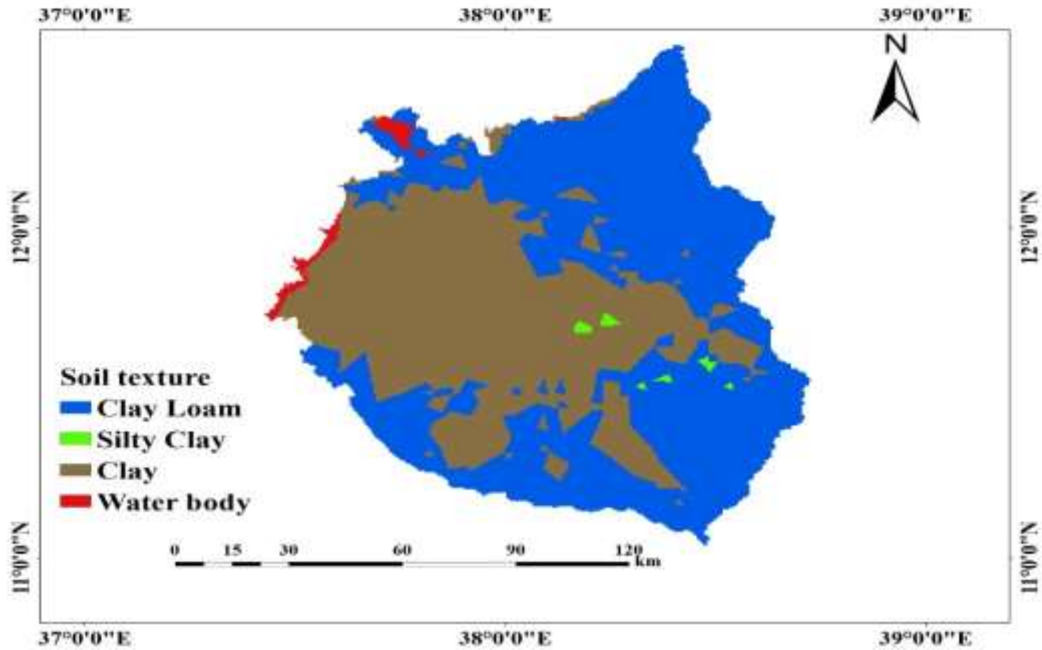

Figure 4. 11 Soil texture map

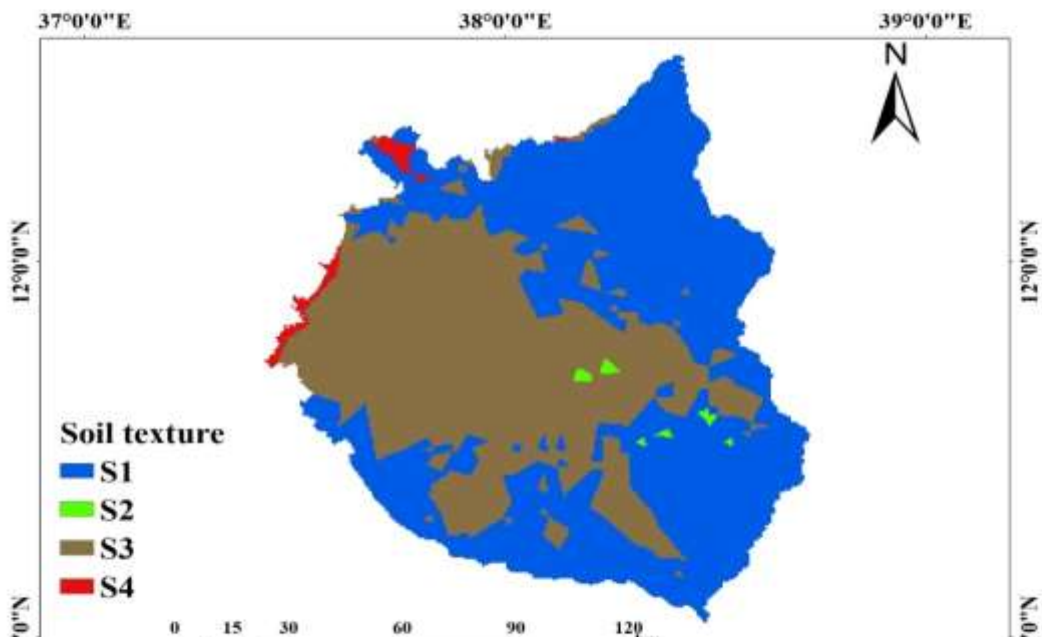

Figure 4. 12 Soil texture suitability map

4.1.7 Rainfall

Based on the analysis results of precipitation, the rainfall of the area ranges from 1,097mm to 2,012mm. According to the analysis results as shown in Table 4.7 and Figure 4.14 about 15.7% of the area was found to be not suitable, since the area has received high rainfall, greater than 1600mm. This implies that, 15.7% of South Gondar zone is described as it is exposed of excess of rainfall which causes erosion and is not suitable for agriculture. 84.3% of the study area was categorized under suitable where, the area has rainfall between 1097 to 1600 mm and rated as suitable to agriculture.

Table 4.7 and Figure 4.14 describes the slope suitability level of the study area.

Table 4.7 Rainfall suitability area percent coverage

Suitability class	Suitable	Not Suitable
Area %	84.3	15.7

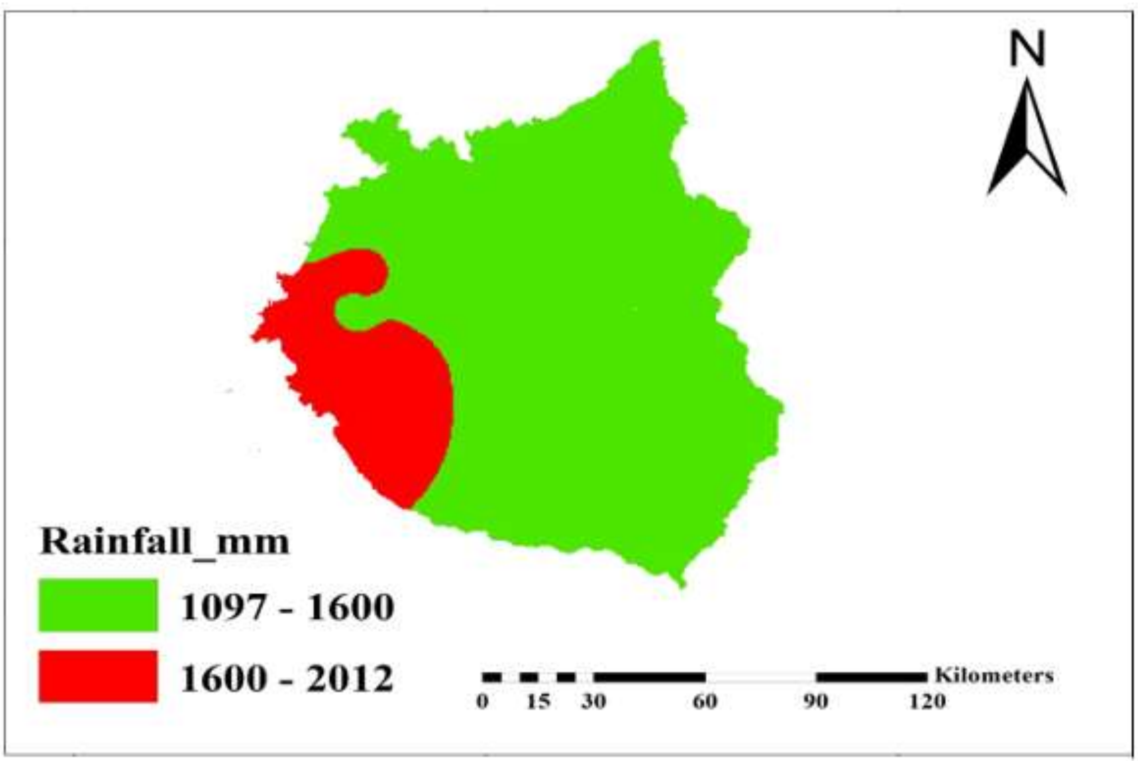

Figure 4. 13 Rainfall map

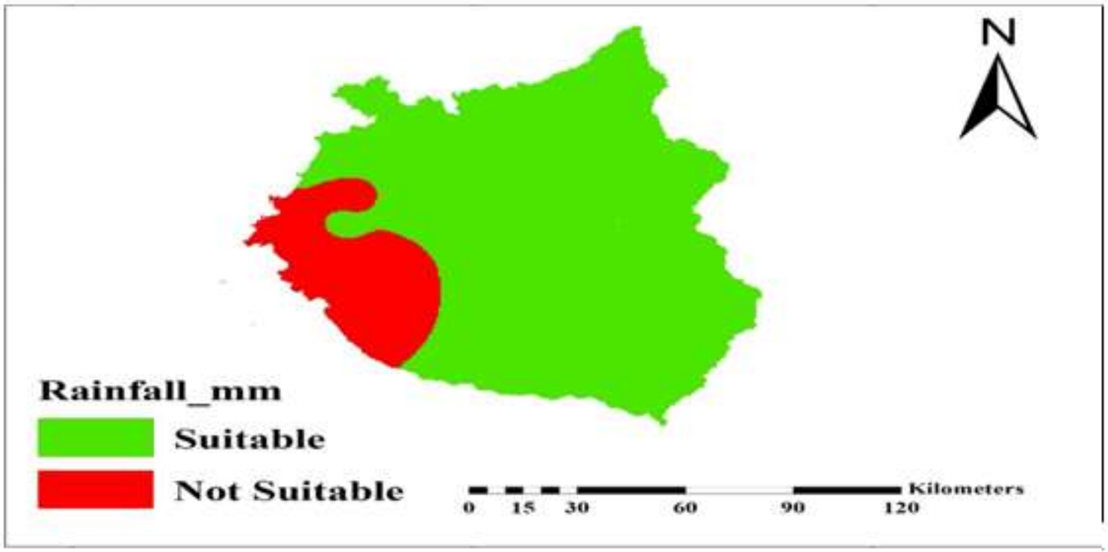

Figure 4. 14 Rainfall suitability map

4.2 Agricaltural Land Suitability Summery

As per the analysis result from Weighted Overlay Analysis (WOA) as shown in Table 4.9 and Figure 4.17, About 28.2% of the study area was categorized under highly suitable since the land has no restrictions on its proposed use and there is no need for a high level of input. About 69.5% of the study area is grouped as moderately suitable and implies that the land has minor constraints that could reduce productivity to achieve the same yield as the land categorized as highly suitable and hence it needs adaptive inputs. 2.3% of the study area is grouped as marginally suitable which implies that the land has moderate restrictions for specific uses, where the amount of surplus input is only marginally justified.

Table 4.8 Summary of Agricultural Land Suitability Map of South Gondar

Suitability Class	Area km^2	Percent %
Highly Suitable	3630	26
Moderately Suitable	9839	70
Marginally Suitable	517	4
Total Area	**13986**	**100.00**

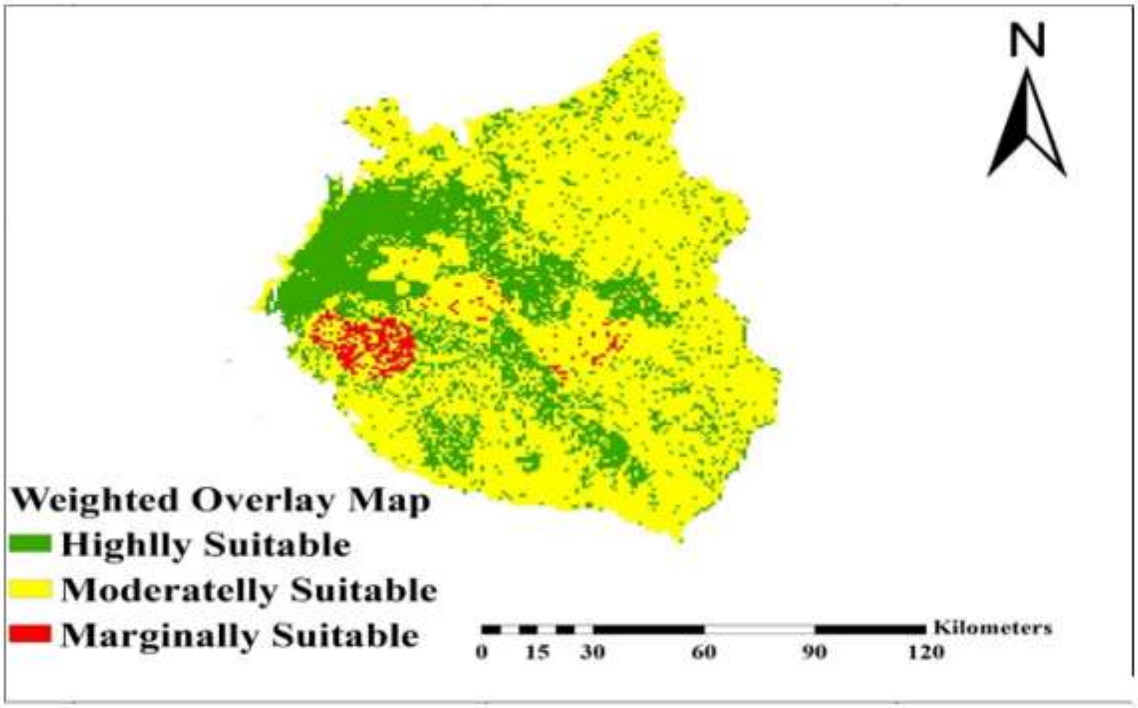

Figure 4.15 Agricultural Land Suitability Map of South Gondar

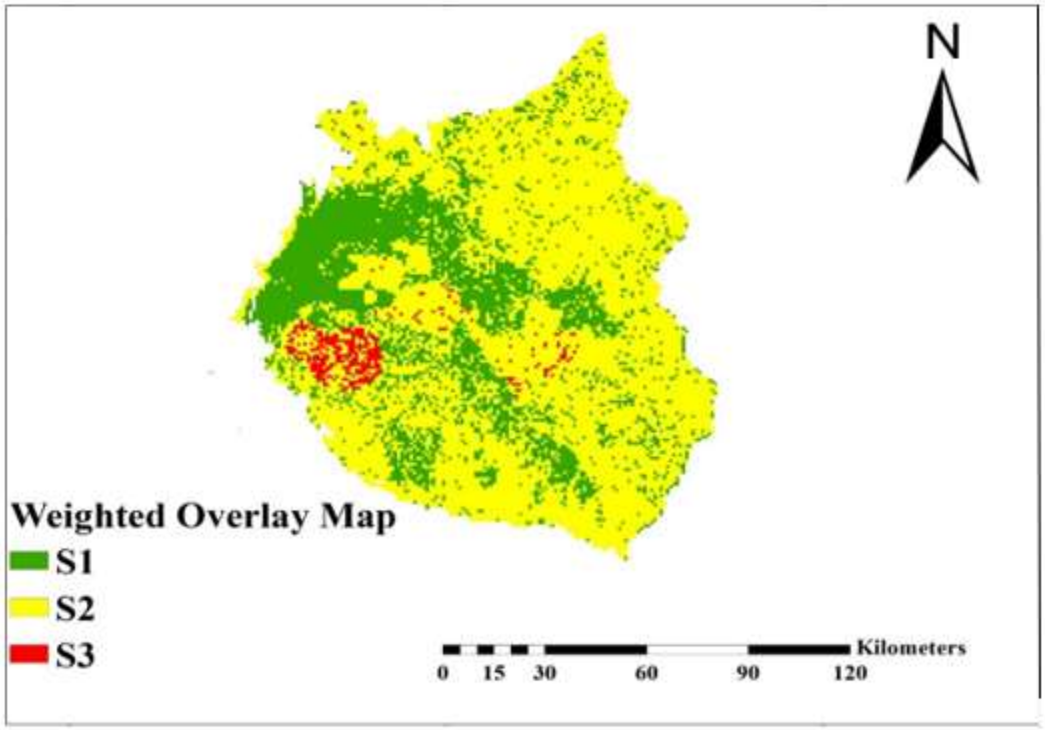

Figure 4.16 Weighted Agricultural Land Suitability Class of South Gondar

Chapter Five

5. Conclusion and Recommendation

5.1 Conclusion

This study established a way to find the most suitable areas for agriculture to ensure regional agricultural production using a multicriteria analysis integrated with GIS, Remote Sensing and Analytical Hierarchy Process, AHP. The multicriteria decision analysis was done for suitability assessment using seven criteria: Elevation, Slope, Land use Land cover, Soil depth, Soil drainage, Soil texture and Rainfall. A composite suitability map was created by the weighted overlay analysis performed using the criteria layers with their corresponding weights. According to this map, it was found that 26 % of the land is highly suitable, 70 % of the land is moderately suitable, 4 % of the area is marginally suitable for agriculture. The result of the research concluded that 3630 km^2 of the land of South Gondar zone is the highly suitable agricultural land. 9839 km^2 and 517 km^2 of the zone are moderately suitable and marginally suitable respectively. This study demonstrates that GIS is a powerful tool for highlighting agricultural land suitability and analyzing cross-tabulations between various thematic map classes in terms of agricultural land suitability, and that can be applied at different scales.

5.2 Recommendation

Since remote sensing (RS) technologies have advanced over time, the agricultural sector now has a diverse range of platforms (from satellites to manned aircraft) and sensors (such as visible, multispectral, hyperspectral, and thermal), as well as methods for gathering various types of agricultural data. With the availability of such sensors and platforms, it is better for the agricultural community to gain a good understanding of the benefits and drawbacks of each technology to ensure that data is used effectively while minimizing the cost and technical challenges associated with data collection and utilization. By using RS data, the agricultural community can identify and quantify suitable agricultural lands, make management decisions that increase farm profits while reducing agriculture-related environmental problems. The GIS is the most widely used, versatile, time-saving, and cost-effective method for determining the suitability of one area over another for agricultural land analysis in large areas.

In the recent years, insufficient agricultural production which leads food insecurity as a result of reduced agricultural investments, increasing costs of production, shortages of agricultural labor, degradation of agricultural resources, water scarcity, climate change and globalization have caused increase pressure on land utilization.

Based on the research findings, this study provides the following recommendation to all stakeholders in the study area who are working to improve agriculture sector.

- The study used seven major factors to analyze land suitability for agriculture. Studieds can be carried out while taking into account all possible factors influencing land suitability analysis for agriculture.
- The complete classification criteria for some major factors considered such as elevation and rainfall are not well documented from literature. Hence, future research should be done to set those criteria especially in Ethiopian context.
- The study was conducted in the South Gondar zone , but the exercise could be applied to the whole Amhara region, and possibly the entire country.
- The government and local administrators are advised to take the possible measures on areas classified as marginally suitable in the zone (North of Libo Kemkem, Farta, North West of Tach Gaynit, South West of Lay Gaynit, East of East Estie) to use the land at its utmost potential.

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Appendixes

Appendix A

Monthly Rainfall of the Station of South Gondar in mm

Addis Zemen Station Monthly Rainfall, mm						
Year	May	Jun	July	Aug	Sep	Oct
2011	108	319	644	738	612	0
2012	22	168	613	675	335	47
2013	78	147	644	247	112	68
2014	19	128	235	296	208	106
2015	170	129	277	285	114	1
2016	139	144	388	291	145	20
2017	258	106	334	296	135	32
2018	10	276	341	305	83	128
2019	102	206	362	405	265	49
2020	81	182	719	489	273	39

Ambesami Station Monthly Rainfall, mm						
Year	May	Jun	July	Aug	Sep	Oct
2011	354	91	455	462	273	37
2012	55	113	559	425	406	26
2013	83	215	714	465	181	231
2014	93	235	885	1056	266	70
2015	288	254	524	469	253	161
2016	327	300	591	409	196	107
2017	121	49	605	445	150	75
2018	73	324	630	541	241	115
2019	98	433	386	498	250	85
2020	123	251	660	699	212	73

Amed ber Station Monthly Rainfall, mm						
Year	May	Jun	July	Aug	Sep	Oct
2011	54	206	382	314	271	82
2012	33	181	403	419	175	39
2013	75	505	490	362	104	266
2014	123	200	270	342	251	155
2015	222	170	433	395	135	76
2016	260	272	558	492	190	26
2017	118	207	449	524	248	34
2018	46	360	281	395	12	5
2019	140	94	195	201	82	0
2020	140	94	195	201	82	0

Aribgebya Station Monthly Rainfall, mm						
Year	May	Jun	July	Aug	Sep	Oct
2011	44	45	772	798	181	14
2012	126	368	451	327	30	43
2013	92	186	1088	741	194	21
2014	279	182	491	965	268	28
2015	172	210	862	1228	206	50
2016	114	231	398	453	214	112
2017	177	143	496	386	398	228
2018	97	373	459	590	242	175
2019	143	397	547	635	483	32
2020	157	372	522	615	332	134

Debretabour Station Monthly Rainfall, mm						
Year	May	Jun	July	Aug	Sep	Oct
2011	176	133	360	392	260	50
2012	57	278	389	448	214	24
2013	165	386	423	439	191	176
2014	206	165	341	454	222	86
2015	176	129	234	284	201	27
2016	193	162	376	399	168	28
2017	176	84	346	291	152	56
2018	56	304	440	423	211	97
2019	85	226	386	564	307	78
2020	157	159	464	601	211	23

Ebinat Station Monthly Rainfall, mm						
Year	May	Jun	July	Aug	Sep	Oct
2011	139	118	263	386	146	0
2012	20	134	378	221	83	17
2013	40	165	372	223	35	77
2014	118	101	253	268	141	98
2015	61	60	184	290	88	47
2016	63	301	1065	819	189	73
2017	155	60	267	299	62	14
2018	15	186	438	297	79	0
2019	128	192	254	919	181	25
2020	120	100	197	165	93	16

Mekane Eyesus Station Monthly Rainfall, mm						
Year	May	Jun	July	Aug	Sep	Oct
2011	128	382	411	388	214	39
2012	65	291	317	271	296	79
2013	77	203	457	305	176	155
2014	129	195	302	305	177	118
2015	380	188	944	375	214	33
2016	176	274	315	418	175	93
2017	154	183	369	329	167	147
2018	156	349	413	338	125	64
2019	55	240	445	1007	337	1
2020	84	203	539	428	88	4

Gasay Station Monthly Rainfall, mm						
Year	May	Jun	July	Aug	Sep	Oct
2011	41	87	430	306	155	22
2012	45	173	383	363	138	9
2013	63	155	529	599	92	133
2014	223	105	456	465	135	63
2015	211	179	293	379	182	69
2016	98	144	476	413	66	46
2017	199	229	180	794	212	32
2018	199	229	180	794	212	32
2019	199	229	180	794	212	32
2020	199	229	180	794	212	32

Hamusit Station Monthly Rainfall, mm						
Year	May	Jun	July	Aug	Sep	Oct
2011	187	158	496	471	387	27
2012	187	158	496	471	387	27
2013	279	167	599	607	74	233
2014	236	383	462	501	437	91
2015	134	207	387	293	187	125
2016	134	207	387	293	187	124
2017	131	108	808	343	163	52
2018	40	249	570	512	403	158
2019	32	408	564	453	274	68
2020	23	223	508	469	23	0

Nefasmewucha Station Monthly Rainfall, mm						
Year	May	Jun	July	Aug	Sep	Oct
2011	76	84	352	267	129	6
2012	27	110	316	308	125	11
2013	38	116	421	355	91	166
2014	212	30	260	260	232	60
2015	124	52	159	335	532	9
2016	193	105	481	328	174	42
2017	207	29	280	295	95	18
2018	20	128	426	360	125	56
2019	176	97	313	345	264	12
2020	147	65	367	400	120	34

Wanzaye Station Monthly Rainfall, mm						
Year	May	Jun	July	Aug	Sep	Oct
2011	168	343	397	438	261	12
2012	50	135	482	350	261	3
2013	26	146	557	373	209	131
2014	168	256	295	301	217	123
2015	117	65	1216	385	188	157
2016	171	226	446	347	185	81
2017	170	158	551	362	163	92
2018	47	230	430	405	148	150
2019	102	322	352	391	180	94
2020	34	211	453	417	127	71

Woreta Station Monthly Rainfall, mm						
Year	May	Jun	July	Aug	Sep	Oct
2011	184	147	315	318	159	22
2012	24	172	381	393	264	16
2013	42	230	421	383	159	122
2014	181	91	290	475	286	11
2015	8	192	1024	1282	356	320
2016	79	412	1255	1662	205	72
2017	83	55	364	404	140	86
2018	22	228	520	336	23	30
2019	0	162	479	358	239	49
2020	101	484	507	481	91	108

Yifag Station Monthly Rainfall, mm						
Year	May	Jun	July	Aug	Sep	Oct
2011	70	127	270	346	207	14
2012	13	95	387	300	166	29
2013	36	150	400	1416	98	100
2014	61	98	268	275	221	135
2015	187	95	277	336	160	6
2016	108	117	332	284	154	36
2017	156	126	465	470	167	87
2018	8	240	452	333	232	109
2019	52	206	452	606	439	80
2020	37	353	950	551	165	3

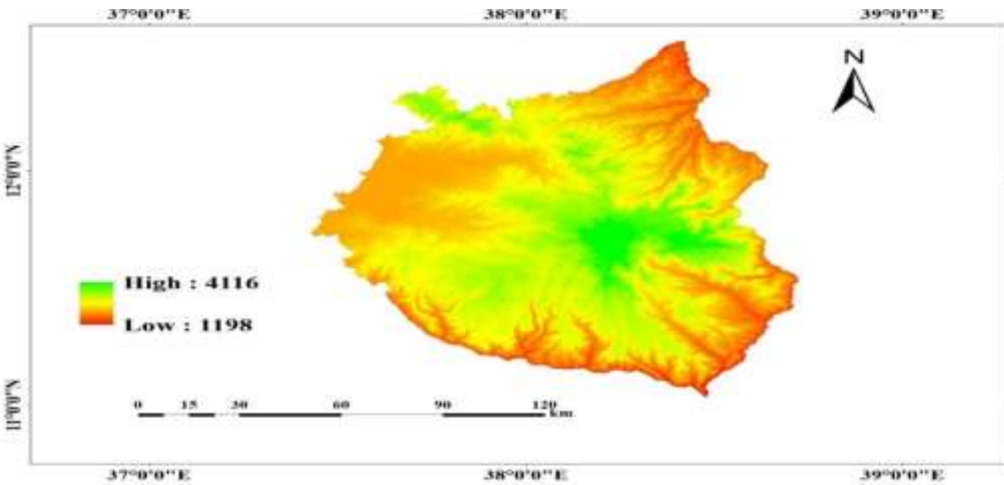
Appendix B

Mean Annual Rainfall of South Gondar in mm

South Gondar Mean Annual Rainfall, mm					
Station	Long	Lat	Elevation	Mean Annual Rainfall	Year of Record
Addiszemen	37.8	12.1	2400	1415	2011-2020
Ambesami	37.62	11.7	2076	1876	2011-2020
Amedber	37.89	11.91	2051	1303	2011-2020
Yifag	37.69	12.07	1940	1411	2011-2020
Woreta	37.7	11.92	1819	1730	2011-2020
Ebinat	38.03	12.07	2212	1130	2011-2020
Debretabor	38	11.87	2612	1377	2011-2020
Nefasmewucha	38.36	11.81	3000	1097	2011-2020
Gassay	38.14	11.8	2789	1431	2011-2020
Wanzaye	37.68	11.79	1821	1494	2011-2020
Hamusit dera	37.56	11.79	1930	1676	2011-2020
Arbgebya dera	37.75	11.64	2228	2012	2011-2020
Mekane Eyesus	38.05	11.61	2374	1529	2011-2020

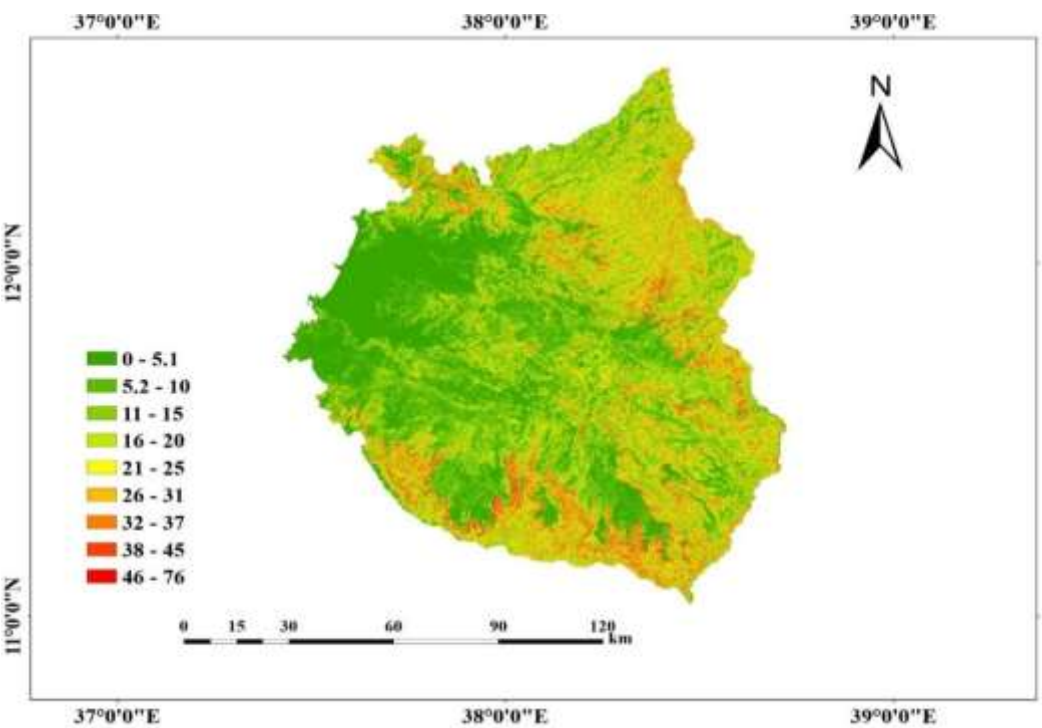
Appendix C

Digital Elevation Map of South Gondar in meter asl



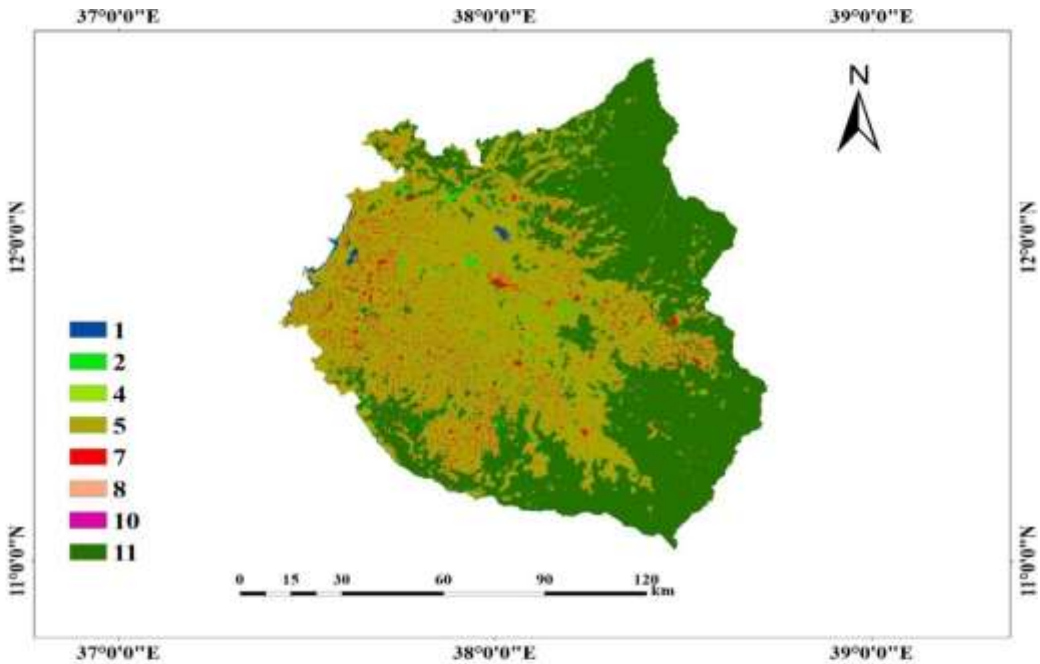
Appendix D

Slope Map of South Gondar in %



Appendix E

LULC Map of South Gondar from Esri 2021



Name of the Codes in the LULC Map of South Gondar

Codes	Name	Classification	Elements
1	Water	Vegetation	4, 5 and 11
2	Trees	Forest	2 and 10
4	Flooded Vegetation		
5	Crops	Urban	7
7	Built Area		
8	Bare ground		
10	Clouds	Water body	1 and 8
11	Rangeland		

1. Water

Areas where water was present most of the year; may not include sporadic or ephemeral water; has little to no sparse vegetation, no rock outcrops, and no built-up features such as docks; examples: rivers, ponds, lakes, oceans, flooded salt plains.

2. Trees

Any significant clustering of tall (15-m or higher) dense vegetation, typically with a closed or dense canopy; examples include wooded vegetation, dense tall vegetation clusters within savannas, plantations, swamps, or mangroves (dense/tall vegetation with ephemeral water or canopy too thick to detect water beneath).

4. Flooded vegetation

Seasonally flooded areas with a mix of grass/shrub/trees/bare ground; examples include flooded mangroves, emergent vegetation, rice paddies, and other heavily irrigated and inundated agriculture.

5. Crops

Human-planted cereals, grasses, and crops that are not at tree height; examples include corn, wheat, soy, and fallow plots of structured land.

7. Built Area

Human-made structures; major road and rail networks; large homogeneous impervious surfaces, such as parking structures, office buildings, and residential housing; examples include houses, dense villages/towns/cities, paved roads, and asphalt.

8. Bare ground

Areas of exposed rock or soil with little to no vegetation throughout the year; large areas of sand and deserts with little to no vegetation; examples: exposed rock or soil, desert and sand dunes, dry salt flats/pans, dried lake beds, mines.

10. Clouds

Due to persistent cloud cover, there is no information on land cover.

11. Rangeland

It is an open area covered in homogenous grasses with little to no taller vegetation; wild cereals and grasses with no obvious human plotting (i.e., not a plotted field); examples: natural meadows and fields with sparse to no tree cover, open savanna with few to no trees, parks/golf courses/lawns, pastures. Mix of small clusters of plants or single plants dispersed on a landscape that shows exposed soil or rock; scrub-filled clearings within dense forests that are clearly not taller than trees; examples: moderate to sparse cover of bushes, shrubs and tufts of grass, savannas with very sparse grasses, trees or other plants.