JIMMA UNIVERSITY

COLLEGE OF SOCIAL SCIENCE AND HUMANITIES

DEPARTEMENT OF GEOGRAPY AND ENVIRONMENTAL STUDIES

LAND SUITABILITY ANALYSIS FOR ARABICA COFFEE (*COFFEA ARABICA)* PRODUCTION USING GEOSPATIAL AND MULTI CRITERIA EVALUATION IN JARDEGA JARTE DISTRICT, WESTERN ETHIOPIA

BY

TEKALIGN ABDISA

NOVEMBER, 2020

JIMMA, ETHIOPIA

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A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES OF JIMMA UNIVERSITY, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE (M.SC.) IN GEOGRAPHIC INFORMATION SYSTEMS AND REMOTE SENSING

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Jimma, Ethiopia

DECLARATION

This is to certify that this thesis entitled **"Land suitability analysis for Arabica coffee (*Coffea Arabica*) production in Jardega Jarte Woreda, Western Ethiopia**," accepted in partial fulfillment of the requirements for the award of the Degree of Master of Science in Geographic Information System and Remote Sensing by the School of Graduate Studies, Jimma University through the College of Social Science and Humanities done by Tekalign Abdisa is a genuine work carried out by him under my guidance. The matter embodied in this thesis work has not been submitted earlier for the award of any degree or diploma.

The assistance and help received during the course of this investigation have been duly acknowledged. Therefore, I recommend that it can be accepted as fulfilling the research thesis requirements.

Major Advisor	**Signature**	**Date**
Co-advisor	**Signature**	**Date**

STATEMENT OF AUTHOR

First, I declare that this thesis is my bonafide work and that all sources of materials used for this thesis have been duly acknowledged. This thesis has been submitted in partial fulfillment of the requirements for an advanced M.Sc. degree at Jimma University and is deposited at the university library to be made available under rules of the library. I solemnly declare that this thesis is not submitted to any other institution anywhere for the award of any academic degree, diploma, or certificate.

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FINAL THESIS APPROVAL FORM

As members of the Board of Examining of the Final M.Sc. thesis open defense, we certify that we have read and evaluated the thesis prepared by **Tekalign Abdisa** under the title "**Land suitability analysis for Arabica coffee (*Coffea Arabica*) production in Jardega Jarte Woreda, Western Ethiopia"** and recommend that the thesis be accepted as fulfilling the thesis requirement for the **Degree of Master of** Geographic Information System and Remote Sensing in Jimma University.

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List of Abbreviation and Acronyms

AHP: Analytical Hierarchy Process

CR: Consistency Ratio

DBMS: Database Management System

DEM: Digital Elevation Model

DSS: Decision Support System

ERDAS: Earth Resource Data Analysis System

FAO: Food and Agriculture Organization

GIS: Geographical Information System

GPS: Global Positioning System

ISRIC: International soil resource information center

ICO: International Coffee Organization

LULC: Land Use Land Cover

MCDM: Multi Criteria Decision Making

MCE: Multi Criteria Evaluation

PCM: Pairwise Comparison Matrix

RI: Random Consistency Index

RS: Remote Sensing

SDSS: Spatial Decision Support System

UTM: Universal transverse Mercator

USRTM: Shuttle Radar Topographic Mission

USGS: United State Geological Survey

WIPR: World Intellectual Property Report

Abstract

Land suitability analysis is a prerequisite for sustainable agricultural production. This study aimed to assess land suitability analysis for Arabica coffee (Coffea Arabica) production in Jardega Jarte district. A GIS and RS technique with a multi criteria evaluation approach was applied for evaluating the land suitability for coffee Arabica production. The evaluation of land in terms of suitability classes was based on the method described in FAO guideline for land evaluation. Factors that were considered for evaluation of the land suitability for coffee Arabica production were climate (rainfall and temperature), topography (slope, elevation), soil (drainage, soil texture, soil depth, soil pH) and landscape (land use land cover). The weight of influence of each factor was computed by pair-wise comparison technique which is one of AHP method. The final coffee Arabica suitability map was created based on the linear combination of factors with their respective weights in ArcGIS overlay extension. This map was classified in to three suitability classes based on FAO Guidelines. The results for coffee Arabica suitability classes show that highly suitable (S1), moderately suitable (S2) and marginally suitable (S3). From the total land of the study area 8979.47 hac (8.4%) is high suitable, 97347.98 hac (90.5%) moderately suitable and 1193.39 hac (1.1%) marginally suitable for coffee Arabica cultivation. The findings for the research indicate that the study area has a potential area for coffee Arabica production.

Keywords: *Arabica coffee; land suitability; GIS and RS; MCDM; Pair-wise comparison*

CHAPTER ONE

1. INTRODUCTION

1.1. Background of the study

Coffee is an extremely important agricultural commodity produced in about 80 tropical countries with an estimated 125 million people depending on it for their livelihoods in Latin America, Africa, and Asia, with an annual production of about 9 million tons of green coffee beans (Krishnan, 2017). There are two most cultivated species of coffee in the world. These are the Arabica coffee (*Coffea arabica)* and Coffea canephora (*Coffea Robusta*) (Dias & Benassi, 2015). Both species have some similar characteristics owing to the fact that the main trunk is vertical and the primary, secondary and tertiary branches are mainly plagiotrophic in nature. They can also grow up to a height of 10 meters if not pruned but must always be controlled for easy harvesting (DaMatta & Ramalho, 2006). Coffee Arabica favored by high altitudes and low temperatures as compared to Robusta coffee which do well in lowlands (Weldon, 2016).

Coffee is the most important beverage worldwide (International coffee Organization (ICO, 2016)). It is most consumed beverages by more than one-third of the world's population (ICO, 2018). Coffee is grown in tropical and subtropical regions of the world are exported in green or roasted beans to more than 165 countries (WIPR, 2017). The crop accounts for 75% of export revenue and provides livelihoods for smallholder coffee producers around the world. According to the statistical report of ICO, (2018), 158.9 million bags of green coffee beans have been produced in 2017/2018.

Ethiopia is the largest coffee producer in Africa and the 5th largest in the world, following Brazil, Vietnam, Colombia and Indonesia (ICO, 2018). Ethiopia is well known not only for being the home of Arabica coffee, but also for it is very fine quality coffee acclaimed for its aroma and flavor characteristics (Deribe, 2019) .Ethiopia has more than 400 coffee exporters, 395 coffee farmers who directly export coffee, and over 30 import-export companies who export coffee and use the foreign currency to import other materials like vehicles and construction inputs (USDA, 2019) .Coffee is the most important crop in the national economy of Ethiopia and the leading export commodity (Deribe, 2019). The coffee sector contributes about 4–5% to the country's

Gross Domestic Product (GDP) and creates hundreds of thousands of local job opportunities (EBI, 2014).

Ethiopia produces Arabica coffee which is considered as superior to Robusta coffee due to its fine aroma (Zewdu, 2016) . According to Central Statistical Agency (CSA, 2017) the estimated area of land covered by coffee in Ethiopia is about 700474.69 ha, whereas the estimated annual national production of coffee is about 469091.12 tons with average productivity of 669.6 kg ha^{-1}. According to Belay *et al.* (2016), in Ethiopia about 25 % of the total populations of the country are dependent on production, processing, distribution and export of coffee. According to Tefera *et al.*(2016) there are an estimated 15 million people of the country's total population who derive their livelihoods from coffee.

Even though the issue of agricultural productivity and food security is widely studied in different parts of the world, the impact of unwise use of land resource and absence of utilization of the land according to its potential suitability is still a serious problem particularly in developing countries (Pirbalouti *et al.*, 2011). In order to increase agricultural production and provide food security, therefore crops need to be grown in areas where they are best suited.

In most high lands of Ethiopia, the competition for land is high due to demand for food and agricultural land as a result of population pressure. This results in degradation of resources in most highland areas of Ethiopian. Therefore, land suitability analysis becomes an important concern for land management planning and implementation in Ethiopia. Agricultural crop production is determined by land characteristics namely elevation, slope, soil (pH, drainage and texture), land cover and climatic factors (Mulugeta, 2010). All these factors collectively determine the suitability of a given area for a particular type of crop cultivation. Thus, in order to build up an efficient crop production system, evaluation of land suitability from time to time is essential.

Outside of the Ethiopia there were a few studies which deal with Physical land suitability analysis for coffee Arabica production that had been studied by Nzeyimana et al. (2014) in Rwanda, Rono et al. (2018) in Kenya, Weldon (2016) in Kericho County. In Ethiopia land suitability analysis for different cereal crops had been studied in different part of Ethiopia (Mulugeta, 2010; Motuma *et al.*, 2016; Debesa *et al.*,2020). Trends of Coffee (Coffea Arabica) productivity, area of production and numbers of holders of coffee in Ethiopia for the period

2006/2007-2017/2018 had been studied by (Gizaw, 2019) .The result of this study indicated the trend of coffee productivity in the country showed non-significant decreasing trend by the factors of -0.176 qt/ha per year for study periods. Therefore, the author of this work has recommended that, land suitability of this crop at which it has been expanded in the country has to study. Hence, this thesis aims to identify the suitable areas for coffee Arabica production using land qualities such as topography, soil, and climate and land use land cover in the study area by using GIS and remote sensing application integrating with multi criteria decision making approach.

1.2. Statement of the problem

Land suitability analysis can help to establish the strategies for the development of agricultural productivity (Steiner *et al.*, 2000), for better land management; mitigation of land degradation and designing land use pattern that prevents environmental problems through segregation of competing land uses (Ziadat & Al-Bakri, 2006). It is the basic information for right decision making (FAO, 1976). However, its practical applicability in Ethiopia is limited. As a result, land degradation, low agricultural productivity and scarcity of farm land are commonly realized in the country.

The growing gap between food demand and supply in Ethiopia is mainly attributed to low productivity of the agricultural sector (Hika & Afsaw, 2019). Majority of the people in the county live in poverty and cannot meet their basic needs (Baye, 2017). This problem is due to the lack of knowledge on the efficient utilization of available and limited resources (especially land and capital), poor and backward technologies, limited use of modern agricultural technologies (lack of transportation and storage facilities, natural calamities and poor agricultural policies (Fekadu & Bezabih, 2009).

Even though the main economic activity in Ethiopia is agriculture, its productivity is very low. To address this issue, Ethiopia has put in place priorities towards producing cereal crop and cash crop by irrigation and rain fed farming (Ethiopia's Progress towards Eradicating Poverty, 2018). To this end, it is necessary to identify suitable areas for agricultural practices, because, mismatched agricultural practice, which is being conducted in many parts without any study is the main reasons that affect sustainable productivity.

Low profitability from coffee was due lack of appropriate technologies for handling crops, weak associativity of producers and decrease of the cultivated area (Ochoa *et al.*, 2017). Other possible contributing factors resulting in low productivity include the improper management of crop plots, and planting in the areas not well suited for coffee production (Blanco & Aguilar, 2015).

In Jardega Jarte district, population growth and limited option of livelihood opportunity together with climate change have led the community to put the scarce available land to uses to which the land is not best fit. This has led to a decrease in agricultural productivity of land. To achieve optimum land utilization for sustainable agricultural productivity, land suitability analysis is important (Zabihi *et al.*, 2015).

As far as the knowledge of the researcher is concerned, there is no single study regarding the land suitability analysis for coffee Arabica in Jardega Jarte district yet. Therefore, the Agriculture office of the district has shown a great interest to have an agricultural land suitability evaluation for cash crops especially, coffee Arabica in the district. So, it is better to assess land suitability analysis for coffee Arabica production by considering parameters such as topography, soil, climate and LU/LC using Geospatial and Multi Criteria Decision making approach in Jardega Jarte district.

1.3. Objective of the Study

1.3.1. Main Objective

❖ The general objective of this study is to conduct land suitability analysis for Arabica coffee (*Coffea arabica*) cultivation in Jardega Jarte District, Western Ethiopia.

1.3.2. Specific Objectives

- To evaluate factors used in land suitability for Arabica coffee production.
- Prioritize the area according to its suitability for coffee Arabica production.
- To develop suitability map for coffee Arabica cultivation in the study area.

1.4. Research Questions

This research intended to answer the following basic research questions:

- ✓ How to evaluate factors used in land suitability analysis for coffee Arabica?

- ✓ Is all parts of the study area is suitable for coffee Arabica production? How can prioritize the area according to its suitability for coffee Arabica production?
- ✓ How suitability map of the study area is developed?

1.5. Significance of the Study

Suitability analysis of land based on GIS that integrate preferences of the decision makers could go a long way in proving sustainable solutions in identifying suitable areas for enhanced productivity (Malczewski, 2006). Land suitability for coffee Arabica in Jardega Jarte District becomes important in the context of land becoming a scarce and non-renewable natural resource. Land use suitability analysis helps development planners to accommodate the economic and environmental needs of people in technical and spatial networks. Land evaluation of the study area for coffee Arabica help in future decision making of land use allocations in accordance to the suitability of the land for crop production. Land utilizations in their selected suitable places will result in an increase of productivity and manage land from erosion or other degradation types. In order to achieve sustainable and rapid agricultural development, it is necessary to identify real development opportunities for each land suitability classes so as to be able to fully utilize them.

1.6. Scope of the study area.

The research study covers the whole of Jardega Jarte District. Integration of GIS ,Remote Sensing and Multi-Criteria Decision Making approach was used to find out the areas which can suitable for coffee Arabica in the study area. Environmental factors such as climate, topography and soil characteristics and land cover type were used in the study to carry out analysis with a view of designing a land suitability which can be used to evaluate land suitability. Appropriate satellite image, Landsat 8 image in particular was used to assist in assessing the present land use and land cover throughout the study area.

1.7. Limitation of the study

As there was no adequate time and budget to collect and analyze the soil physical and chemical characteristics of the Jardega Jarte district, ISRIC soil data which had 250 m resolution was obtained from the International soil reference and information center website were used.

1.8. Ethical Consideration

In the case of ethical consideration the spatial scientists must make every effort to closely follow any guidelines established for human subjects research, and beyond to these every effort to ensure the dignity and welfare of human participants in spatial science research (Grain, 2012).In this study, Privacy and confidentiality was maintained at all times, and all findings were portrayed in a private manner. No personal or identifiable information were recorded or printed in the study. Therefore before data collection, a formal letter that was given to the researcher from Jimma University help to collect the data from concerned organization.

1.9. Organization of the Paper

This research study is organized into five chapters. The first chapter is the introduction which includes background of the study, statement of the problem, objective of the study, research question and others. Chapter two presents the review of previous research works related to land suitability analysis coffee Arabica production. In Chapter three, brief description of the study area, research methodology, methods of data collection were discussed. Chapter four has dealt with results and discussion. Finally, the conclusion of the study and recommendations was described in chapter five.

CHAPTER TWO: LITERATURE REVIEW

2.1. Coffee Plant Overview

Coffee plant is a dicotyledonous plant. It is also a perennial crop, which always does not shade its leaves throughout the year. This makes it an evergreen plant (Weldon, 2016). The genus *Coffea* presents more than 100 species, but commercial trade consists almost entirely of *Arabica coffee (Coffea Arabica)* and Coffea canephora (*Robusta*) (ICO, 2015). Coffee Arabica favored by high altitudes and low temperatures as compared to Robusta coffee which do well in lowlands (Weldon, 2016). 66% of the world production mostly comes from Coffee Arabica *and* 34% from *Coffee canephora* (*Robusta*) respectively.

Ethiopia is the home and cradle of biodiversity of Arabica coffee seeds. More genetically diverse strains of *coffee* Arabica coffee *(Coffea Arabica)* exist in Ethiopia than anywhere else in the world, which has lead botanists and scientists to agree that Ethiopia is the center for origin, diversification and dissemination of the coffee plant (Bayetta, 2001). Arabica coffee is known as backbone of the country's economy, accounting for 22% of the export (Bart, 2018). The country is naturally gifted with a suitable climate and has the potential to produce single origin specialty Arabica coffee beans with a wide range of flavors (Labouisse *et al.*, 2008).

World production in coffee year 2018/19 is estimated at 169 million bags, which is 5.4% greater than in 2017/18. Arabica production rose by 1.7% to 98.33 million bags. Brazil is the world's largest coffee producer. Ethiopia is the first in Africa and 5th in producing coffee Arabica in the world. Ethiopia's output in 2018/19 is estimated at 7.5 million tons , up 0.6% from 2017/18 (ICO, 2018).

2.2. Trend of Coffee Production in Ethiopia

Coffee is grown by over four (4) million small holder farmers in Ethiopia. Farmers engaged in growing and producing stimulant crops such as coffee are greater in number than those growing fruits (CSA, 2017). It employs 15 million people, or roughly 15 percent of the country's population at different points along the value chain. Nearly 95 percent is cultivated on small plots, generally less than half a hectare. Ethiopia is the world's fifth largest coffee producer, accounting for 4 percent of production. It is also the largest producer in Africa, accounting for about 40 percent of continental production (Francom, 2018). Number of coffee producers has increased from 2012/13 to 2016/17 and then declined. Regarding total area of land allocated for the production of coffee, it has increased over the considered years though at different rates. Table 2.1 also indicated that there was a fluctuation in yield of coffee over the last six years in the country.

Table 2.1: Estimated of number of holders, area and yield of coffee over six years

Year	Number of holder	Area(hac)	change area%	Production in quintals	% change in production	Yield(Quintal/hac)	% in change in yield
2012/13	4.217,961	528,751.11	-	3739,406.42	-	7.07	-
2013/14	4,546,785	538,466.80	2	3,920,062.2	5	7.28	3
2014/15	4,723,483	561,761.82	4	4,199,801.5	7	7.48	3
2015/16	5,270,777	653,909.76	16	4,145,964.5	-1	6.34	-15
2016/17	6,455,194	700,474.69	7	4,690,911.2	13	6.7	6
2017/18	5,019,513	725,961.24	4	4,492,298.	-4	6.19	-8

(Source : Degaga ,2020)

2.3. Land Suitability Analysis

Land suitability analysis is a method of land evaluation, which measures the degree of appropriateness of land for a certain use (Kamau, 2015). The suitability is a function of crop requirements and land characteristics and it is a measure of how well the qualities of land unit match the requirements of a particular form of land use (FAO, 1996). Suitability analysis can answer the question – what is to grow where?

Land Suitability Analysis (LSA) implies the assignment of values to alternatives that are evaluated along multiple decisions or criteria (Bozda *et al.*, 2015; Pereira & Duckstein, 1993). These criteria are detrimental to land suitability analyses for different land use types. Land suitability analysis evaluates many alternative land use types under various criteria from various disciplines. Analyzing suitability is mainly based on the land qualities such as erosion resistance, water and nutrient availability, rooting condition, drainage and flood hazard. The value of land quality is the function of the assessment and grouping of land types into orders and classes in the framework of their fitness. Generally, land suitability is categorized as suitable (S) and not suitable (N). Whereas S features lands suitable for use with good benefits, N denotes land qualities which do not allow considered type of use, or are not enough for suitable outcomes (FAO, 1976; FAO, 1993) . Suitability orders could be further subdivided. Accordingly, three classes (S1, S2 and S3) are often used to distinguish land that is highly suitable, moderately suitable and marginally suitable for a particular use. Two classes of not suitable can usefully distinguish land that is unsuitable for a particular use at present, but which might be useable in future (N1), from land that offers no prospect of being so used (N2). The FAO framework identify four categories of increasing detail as shown table 2.1

Table 2.1: FAO (1993) structure of Land Suitability Classification

No	Categories	Explanation
1	Land suitability order	Reflecting kind of suitability
2	Land suitability class	Reflecting of suitability within orders
3	Land suitability sub class	Reflecting kind of limitation within class
4	Land suitability unit	Reflecting minor difference in required management within sub class

2.4. Criteria that are affecting land suitability for coffee arabica production.

Coffee production is sensitive to biophysical factors such as climate, topography, soils, and Topography, genetics and farming practices(Camargo, 2010; Haggar *et al.*, 2011; Silva *et al.*, 2013; Wang *et al.*, 2015). Topography, soil, land cover, and climate are the factors which requires for the growth of coffee (Weldon, 2016).

2.4 .1.Climate

2.4.1.1. Rainfall

Rainfall is the most important factor governing the distribution of coffee farming and wild coffee forests in Ethiopia (Hailu *et al.*, 2015). The distribution of rainfall varies greatly across Ethiopia, according to season, altitude and physical features of the landscape. Clear annual patterns are evident, although rainfall is extremely variable. Arabica coffee requires rainfall ranging between 1000 and 2000 mm per annum (Block *et al.*, 2005). If the rainfall pattern is well distributed hence favoring the growing of coffee. Annual rainfall in the coffee growing regions of the Ethiopia country varies from 1,500-2,500mm (Alemayehu, 2015). Where precipitation is less, as in the eastern part of the country (about 1,000 mm), coffee is supplemented with irrigation. It is not only the total rainfall which is important for good production of coffee but also its eight-month distribution.

2.4.1.2 .Temperature

According to J. Moat *et al.* (2017) the ideal average minimum temperature for Arabica coffee is 12–14˚C, which in most cases occurs .The ideal average temperature is 18–22˚C, with an ideal average maximum (daytime) temperature of 25–27˚C. Maximum temperatures of 30–32˚C are not lethal if they exist for short periods (hours), and if there is sufficient water available in the soil. Extreme temperatures for coffee beyond 32˚C up to 34˚C, and perhaps even a high as 38˚C, can be tolerated by Arabica plants for very short periods (a few hours), but only if there is adequate water in the soil. If the soil is not wet enough, then extreme maximum temperatures for plant survival will be lower; for example, temperatures around 30˚C could be lethal within less than 24 hours if the soil is too dry. According to Alemayehu (2015) and Block *et al.* (2005) Coffee does well under temperatures of 14 to 26°C). These temperatures prevail in most of the country's coffee growing areas.

2.4.2. Topography

Slope defines the vulnerability of a site to erosion and determines the potential for mechanization. Thus, flat or low slopes are optimal, as steep slopes require major soil conservation practices and reduce the efficiency of farming practices (Descroix *et al.*, 2004). The coffee growing areas have undulating landscape with hill slopes and gentle slopes. This has ensured well drained and aerated soils with good Cation Exchange Capacity (CEC) which dictates the soil fertility (Block *et al.*, 2005).

According to Winston *et al.*(2005) an elevation greater than (1000 m) above sea level is required for Arabica coffee. Low elevation Arabica coffee does not possess the quality required by the world markets. For premium coffee, areas above (1300 m) clearly produce superior quality coffee. High elevation improves the quality of the bean and potential cupping quality. Due to a delay in ripening brought about by cooler weather associated with higher altitudes, the inherent characteristics of acidity, aroma and bold bean can develop fully.

According to Alemayehu (2015) coffee grows at various altitudes, ranging from 550-2,750m above sea level In Ethiopia. However, the bulk of Arabica coffee is produced in the altitudes ranging from 1,300 - 1,800 m.a.s.l (above mean see level).

2.4.3. Soils

Soil is the main platform where other activities are carried out. In coffee, like any other agricultural activity, soil contributes a larger percentage of influence towards the crop. It is in the soil where we have soil texture. Soil texture refers to the soil porosity or impermeability contributed by the percentage components of silt, clay and sand. Their ratio in soil makes the soil to be either sandy loam, loamy sand, clay or loam. Normally, particles of clay are less than 0.002mm in size that of silt ranges between 0.002 mm-0.06 mm, while that of sand is in the range 0.06 mm – 2 mm. Soil texture affects multiple soil properties that influence soil fertility and crop productivity. Since coffee productivity is sensitive to nutrient and water supply, sandy and heavy clay soils are avoided for their limitations in water and nutrient holding capacity and drainage.

Soil pH also is an inevitable factor that influences soil productivity. This refers to the degree of acidity or alkalinity of the soil. It is dictated by the amount of hydrogen ions in the soil. Soil pH is affected by decomposition of organic matter, rainfall, soil depth, crops being grown, nitrogen fertilization and parent materials which made the soil. The pH and cat ion exchange capacity are critical indicators of nutrient availability in the soil. Coffee plants prefer slight to medium acidic soils (5.0-6.2) with a high cat ion exchange capacity. Unlike soil texture, pH and cat ion exchange capacity can be modified by farming practices, such as chemical fertilization, the addition of organic matter, burnings (Osman, 2013).

2.5. Criteria of Decision Making

Decision making has always been taken by many people as a very simple occurrence in life. Kościelniak & Puto (2015) defined the word decision to mean a resolution or settlement which enables people to solve problems. Human life is governed by a multitude of actions which are always anchored in the ability to make choices or decisions. Decision alternatives are evaluated on the basis of a set of criteria, which include attributes and objectives (Malczewski & Rinner, 2015). Each criterion must be comprehensive and measurable. A set of criteria should be complete (it should cover all aspects of a decision problem), operational (the criteria can be meaningfully used in the analysis), decomposable (the set of criteria can be broken into parts to simplify the process), non-redundant (to avoid the problem of double counting), and minimal (the number of criteria should be kept as small as possible).

Decision making is the process of making choices by setting goals, gathering information, and assessing alternative occupations, it has also been discovered that an effective decision making process must undergo seven steps (Cabala, 2010). These are: Identifying the decision to be made, Gathering relevant information, Identifying alternatives, weighing evidence, choosing among alternatives, taking action, Reviewing decision and consequences.

The ability to choose the best alternative from a set depends on the ability and expertise of the decision maker. It means that limitations of the decision maker affect the ultimate choice of the best alternative. The limitations are attributed to the power to precisely define the objectives requirements and ability to determine the achievements generated by the alternative choice (El Amine *et al.*, 2016).

In the determination of land suitable for a particular use, rigorous processes of decision making are involved. Elements that entail biophysical, socio-economic, cultural and institutional factors are put into consideration. The factors being explored in the land suitability analysis are mostly independent in nature although they concurrently affect land suitability. However, each of the factors may affect land use potential in a certain way (Saaty, 1990) .Hence to be able to precisely determine land suitability, decision making becomes the pivot or common denominator in the process.

Decision making processes are expected to yield best alternatives which are devoid of biases. It is fundamental therefore to use systematic and comprehensive procedures which may be revisited and applied in future when good results are realized. Some of the methods in common use currently are Multi-Criteria Decision Making Analysis (MCDMA) and Multi-Criteria Decision Making (MCDM).

2.6. Multi-Criteria Decision Making (MCDM)

Multi Criteria Decision Making has become a familiar approach used by decision makers in the daily business of making best choices in business or administrative levels of diverse organizations. It has proved to be a reliable technique which performs its functions by incorporating a multiple set of methods. All the methods that constitute this technique are geared towards assisting decision makers executing their roles of decision making (Greene *et al.*, 2011). As MCDM took the center stage in decision making problems, numerous methods have been formulated to augment the technique. Some of these very important methods include Multi-Attribute Utility Theory (Greene *et al.*, 2011; Humphreys, 1977) , Analytical Hierarchy Process (Saaty, 2008).

2.6.1. Analytical Hierarchy Process (AHP)

This method is one of the popular techniques used in an environment where decision making involves searching for the best choice from numerous alternatives. It is employed by Multi-Criteria Decision Making (MCDM). In some literature, it is referred to as Saaty Method. This is because it was first designed by Thomas Saaty in 1970. The major characteristic of the AHP method is the use of pair-wise comparisons.

AHP is a theory of measurement through pairwise comparisons and relies on the judgments of experts to derive priority scales (Saaty, 2008). Its use of pairwise comparisons can allow decision makers to weight coefficients and compare alternatives with relative ease.

Complex problems always require rigorous decision making process which having a capacity to break the problems in to manageable levels. There are generally three main levels in any problem solving process. These are the goals, criteria and alternatives. A problem is deemed to have been completely solved if the best consideration and choice is used to realize the stated goal. By use of hierarchical approach or arrangement towards solving any problem, every element that may be involved in the process is considered and given a chance to contribute some impact (Promentilla *et al.*, 2006; Saaty, 2008).

In any AHP process, it is possible to disintegrate or simplify a decision involving numerous criteria through a six-step process(de FSM Russo & Camanho, 2015). The first step deals with the definition and choice of the problem as well as considering any assumptions taken during the process. This entails breaking the problem into parts which are then putt in a hierarchical arrangement beginning with the goal, then criteria, sub-criteria and any alternatives in the lowest level of the hierarchy. It is very important to arrange or structure decision problem as a hierarchy whenever AHP is intended to be used (Bushan & Rai, 2004).

The second step is designing the hierarchical structure for AHP is that of collecting data from experts or decision-makers. It is done by putting all elements in a pairwise comparison of alternatives and assigning scores as per a qualitative scale which was first designed by Thomas Saaty during his time of discovering this analytical method. The scale has been named as Saaty scale just after its founder. Thirdly, the pairwise comparisons are then arranged in a square matrix. During the analytical process, criteria are subjected in a gradation scale where from comparison each pair of the criteria, sub-criteria or alternatives, categorization is done.

The fourth step in the application of AHP involves computation of Eigen vector whose values are referred to as principal Eigen values. It is out of the Eigen values where weights of the criteria or sub-criteria are obtained through normalization of the Eigen vector. A rating of the alternatives is also done using the weights.

2.7. Role of GIS and Remote Sensing In Land Suitability Analysis

GIS can be defined as a decision support system involving the integration of spatially referenced data in a problem solving environment (Thapinta & Hudak, 2003). GIS is conventionally set of tools for input, storage, retrieval, manipulation and analysis, and output of spatial data. The system also contains a set of procedures to support decision making activities Use of geospatial technology in agricultural production has brought a lot of revolution towards better achievements. Information and communication technology, which has been incorporated and provided in the Geographic Information System (GIS), is valuable and effective geospatial information for the decision makers in improving their decisions in planning and development (Chandio *et al.*, 2013). GIS (Geographic Information Systems) technology, together with other Multi-Criteria Evaluation (MCE) methods in carrying out suitability analysis has created an avenue of doing land planning. This has made it possible to assigned development activities to appropriate sites (Weldon, 2016).

The integration of GIS using the multi criteria decision analysis approach provides an environment to the decision makers in citing areas using land suitability analysis procedures (Chandio *et al.*, 2013).Use of GIS technology, together with other Multi-Criteria Evaluation (MCE) methods in carrying out suitability analysis has created an avenue of doing land planning (Weldon, 2016) .This has made it possible to assigned development activities to appropriate sites. Integration of GIS, remote sensing and Multi Criteria Modeling to analyze topography, soil, land cover, and climate factors by matching them with the requirements for the growth of coffee. GIS includes scientific tools that enable the integration of data from different sources into a centralized database from which the data is modeled and analyzed. GIS based tools and processes address the challenges of suitability analysis based on the collection, processing and analysis of spatial data.

Remote sensing provides the information about the various spatial criteria/factors under consideration. Remote sensing can provide the information like land use/cover, drainage density and topography. Many of the non-spatial parameters can also be inferred by looking at the various spatial parameters. Remote sensing in combination with GIS will be a powerful tool to integrate and interpret real world situation in most realistic and transparent way. Integrated GIS and Remote Sensing technology apart from saving time and yielding good data quality have the ability to locate potential new cropland sites.

CHAPTER THREE: MATERIALS AND METHODS

3.1. Description of the Study Area

3.1.1. Location

The study area is located in Horo Guduru Wollega Zone of Oromia National Regional State at 367 km from Adisabeba. Alibo is the capital town of Jardega Jarte district located about 55 km away from the zonal capital Shambu. Astronomically, Jardega Jarte District is located at 9°40'0" N to 10°0'0" N latitude, and 36°53'0" E to 37°23'30" E longitude in terms of absolute location (figure 3.1). Similarly, it is bounded from the north by Amhara regional state, from the South by Abe Dongoro District, from south East by kiramu District and Horo district in the west. The district occupied a total area of 286,536km^2 (Jembere, 2014).

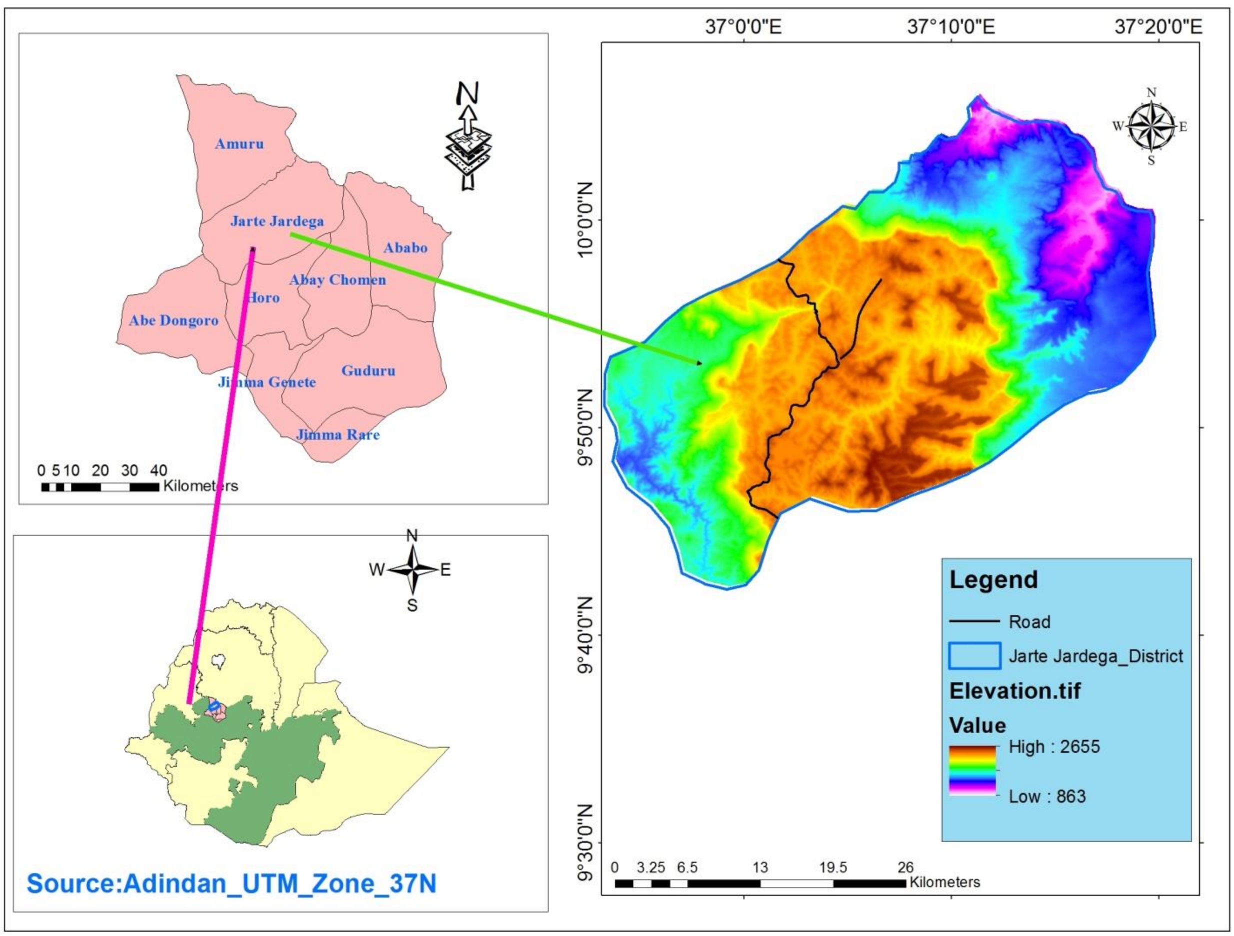


Figure 3.1: Map of Study area

3.1.2. Physical Characteristics

3.1.2.1. Topography

Jardega Jarte District is characterized by different land forms prominently high lands and low lands. It is highly dominated by rugged topography that greatly affects the constructions of roads to connect the district with the neighboring. The elevation of Jardega Jarte District ranges between 1200 m to 2645 m above sea level. The district has mountains like Car, Oku, Dhinsa, Okote and plateaus like Platos Bada Sire, Barji, Siree Baqo and Daban. It also rivers like Cago, Angar, Asatti, and Dimtu are also found in the study area (Jembere, 2014).

3.1.2.2. Soil Type

The most dominant soil type of the district constitutes loam soils, sandy soils and clay soils which are fertile. The farmers practice traditional method of maintaining soil fertility like fallowing, crop rotation and manuring (Jardega Jarte District Agricultural and Rural Development Office Report, 2017).

3.1.2.3. Climate

Due to the rugged topography the district experiences three agro-ecological zones such Dega, Woina Dega and Kola covering 17%, 66%, and 17% of the total area respectively .Dega zone gets the maximum rainfall annually whereas kola gets the minimum rainfall for shorter period of time. Similarly the distribution of the rainfall varies from season to season as other parts of the country. The study area gets rainfall twice in a year i.e. bio-modal, belg rainfall (February to April) and summer (Mehar rainfall or kiremt) June to October).

Based on the meteorological data collected for 28 years (1990-2017) rainfall and temperature records from Alibo station, the mean annual rain fall of the district range between 1346 and 1750 mm, while the mean annual temperature of the study area ranges between 17.5° and 23.5° mm (Alibo Metrological Station, 2018)

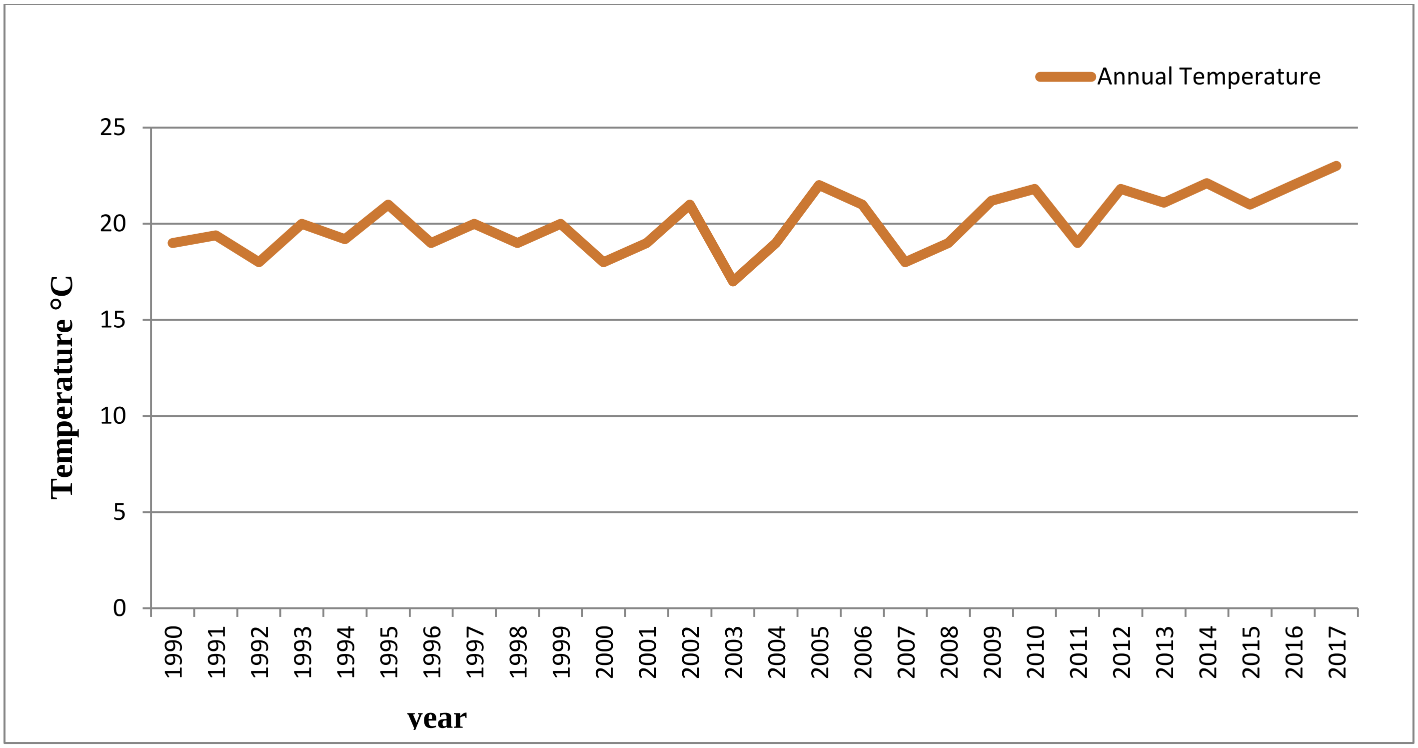


Figure3.2: Mean annual temperature of Jardega Jarte district (1990-2017)

(Source: NMA 2017, own processing)

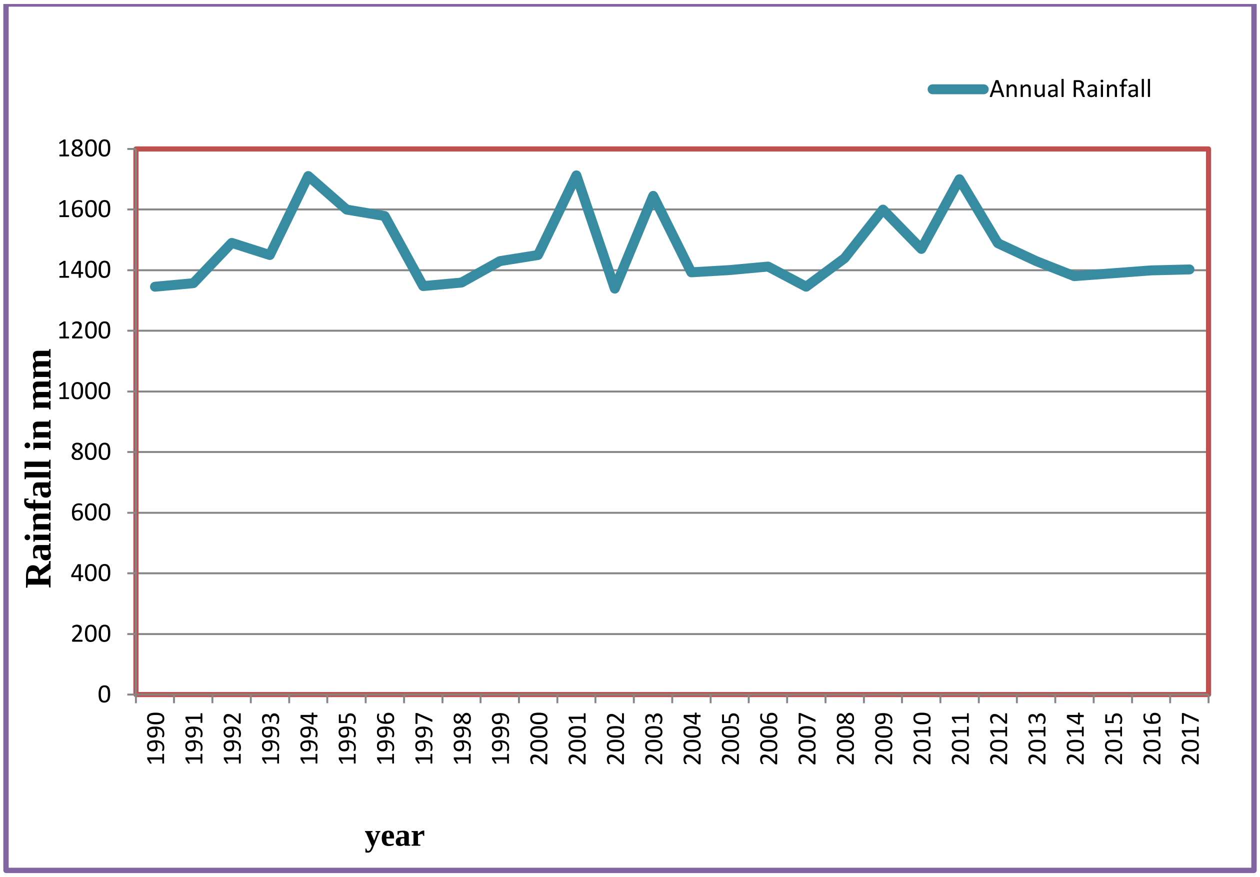


Figure 3.3: Mean annual Rainfall of Jardega Jarte district (1990-2017)

(Source: NMA 2017, own processing)

3.1.3. Socio Economic Characteristics

3.1.3.1. Population

According to Population Projection of CSA, 2017 the total population of Jardega Jarte District is 63876 where 31617 are males and 32059 females. Out of the total population 11.25% are residing in urban areas, whereas 88.74% is rural dwellers.

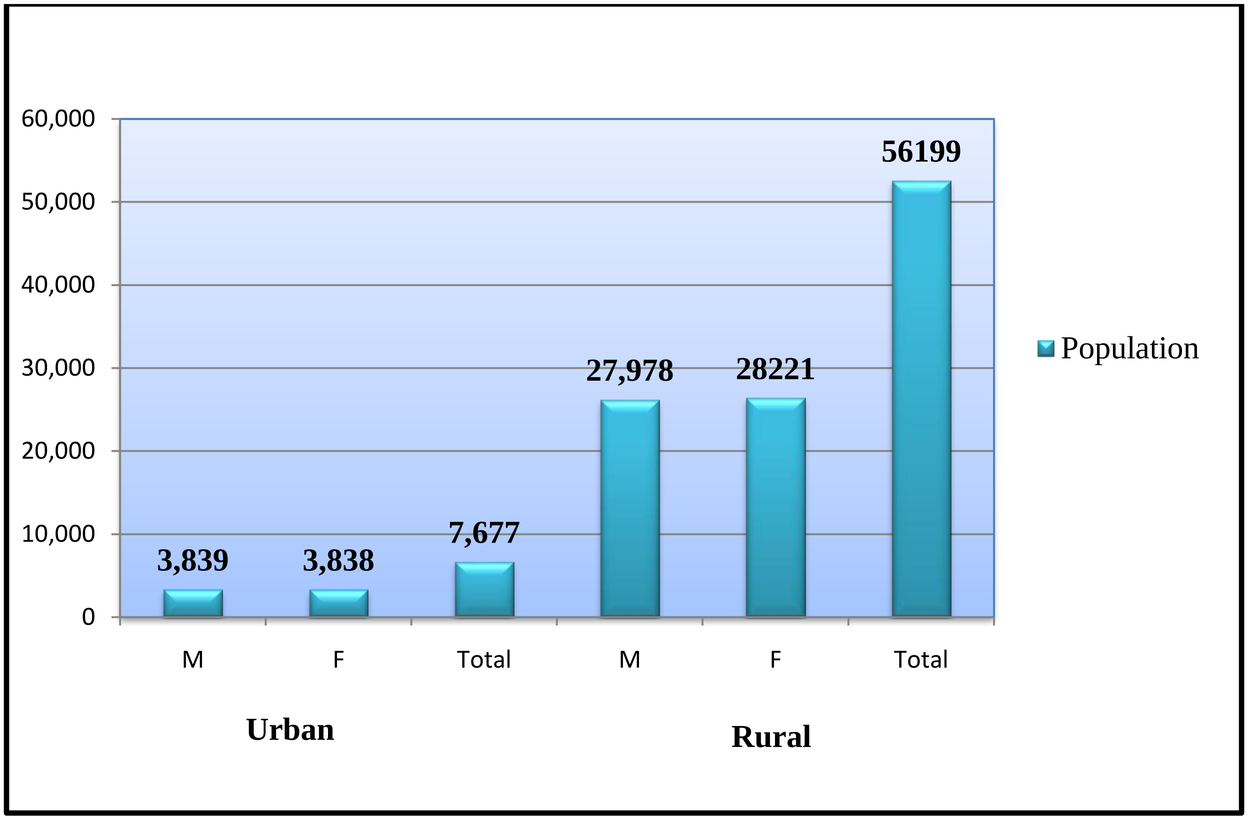


Figure 3.4: Population of Jardega Jarte District (CSA,2017)

3.1.3.2. Land Use

Potential arable land accounts for about 35,048 hectare, which is currently under annual crop cultivation. On the other hand forest land constitute 27,962 hectare, grazing land 12,456 hectare, Wetland 2486 hectare, Bush land 7219 hectare and Other land use 13,663 hectare. The major crops produced in the study area are cereals such as teff, wheat, Barley, maize, millet and some amount of pulses and oil seeds. The production of these crops depends on rain fed agriculture on seasonal basis. Land clearing is commonly practiced from March to April which is the beginning of the raining season. The rain starts at the middle of March and ends in October.

Table 3.2: Land use land cover of Jardega Jarte (Agricultural and Natural resource office , 2018)

Land Use type	Area in(ha)	Area in %
Crop Land	35,048	16%
Forest Land	27,962	12%
Grazing Land	12456	5%

Wet Land	2486	1.10%
Bush Land	7219	3.30%
Other Land Use	133663	61%
Total	218,834	100%

3.2. Research Design

There are different types of research approaches. However, for the purpose of this study the mixed research approach was used .The purpose of mixed method is to collect data from different sources and applied triangulation method to enhance and improve the quality of the data during the analysis and interpretation. As indicated in Powell *et al.*(2008) quantitative or technical and qualitative phases occur one after the other, with the quantitative/technical phase being given higher priority and mixing occurring at the data interpretation stage. In this study, the quantitative research approach was employed to measure and quantify collected data while the qualitative design approach was used for field observation and other data obtained from different sources.

3.3. Data and Materials used

The GIS-based suitability analysis method and multi-criteria evaluation techniques were used in this study. Some software was applied in this study for data acquisition, design, analysis and presentation of the final research results: ArcGIS 10.3 for map making and different analysis like mapping, reclassification, and accuracy assessment; ERDAS Imagine 2015 was employed for satellite image processing and classification; in this case Landsat 8 (OLI multispectral bands) has been used. Table 3.4 shows the dataset and source of data that were used for this study.

Dataset	Data Format	Data Source	Resolution	Application/use
Climate data(Rainfall and temperature)	Excel	NMA		Temperature and Rainfall map
Topography data(DEM)	Tiff	Alaska Satellite Facility (https://asf.alaska.edu/	12.5 m	Elevation and slope map

Soil Data (pH, texture, drainage depth)	Tiff	ISRIC website (https://www.isric.org/explore/isric soil-data-hub)	250 m	Soil (texture, depth, pH, Drainage map)
Land Sat 8 (OLI)	Tiff	USGS website (https://earthexplorer.usgs.gov/)	30 m	LU/LC map

Table: 3.3 : Dataset and source of data that were used in the study area

3.4 .Data Collection Techniques

To get the relevant information in order to meet the stated objectives of study, different technique was used. The data collection techniques used for this study were; GPS data and own observation. GPS data collection has been applied for accuracy assessment on classified land use land cover map of the study area. To collect reference data, a random sampling technique is the best technique for the relatively small and accessible area. In this case, all feature classes have been easily selected and the collected data could be more representative for accuracy assessment. The expert involvement in this process was needed to convert subjective relative importance of given criteria into a linear set of weight. Field observation also applied for identifying and understanding potential coffee Arabica cultivation located in the district.

3.5. Method of Data Analysis

3.5.1. Climate Data (Temperature and Rainfall)

Four meteorological stations that are found inside and around the study area (Shambu, Abe Dongoro, Alibo and Kiramu) with mean annual rainfall and temperature of 28 (1990-2017) years were obtained from National Metrological Agency of Ethiopia in Excel format. In the MS Excel file containing the climate data, spatial data in terms of latitudes and longitudes of the locations of weather stations were entered into corresponding climate data. The results were exported to the ArcGIS 10.3 software for further manipulation and then producing raster image from the data input in ArcGIS. The interpolation technique was processed in ArcGIS with the use of Geo-statically analyst tool an Inverse Distance Weighted technique has been made to estimate overall rainfall and temperature distribution of the area. The resultant raster image was extracted to the study area by use of the district boundary.

Finally mean temperature map was reclassified according to land suitability analysis classification of FAO (1984) and Rainfall map was reclassified according to land suitability analysis classification of Nzeyimana et al.(2014) for coffee Arabica Production.

3.5.2. Topography Data (Elevation and Slope)

Elevation, also called altitude, is the height of a place above (or below) a reference level, such as mean sea level. Elevation and slope factors are the major factors that influence land suitability of coffee Arabica Production (Estrada *et al.*, 2017).

A digital elevation model (DEM) of high resolution (12.5 m) was download from ASFDAAC(Alaska satellite facility archive active center) by path and row search of the study area. DEM which obtained from this website was extracted by using study area boundary. The extracted study DEM was resampled to 30 m spatial resolution before derivation of slope map of the *woreda*. This was done by using Arc GIS 10.3 software. From the datasets, it was found out that elevation in study area ranges from 863 m to 2655 m above sea level.

Slope is the incline or gradient of a surface and is commonly expressed in percent or degree. Slope is important for soil formation and management because of its influence on runoff, soil drainage, erosion and choice of crops. Those experiencing little variation are gentle slopes while those experiencing extreme variations are steep slopes (Mihret & Yohannes, 2015)

From the elevation data, slope was derived by using ArcGIS 10.3 software surface analysis. The slope of the study area which was derived from DEM was given in percent.

Finally, Elevation was reclassified based on coffee Arabica requirements according to land suitability analysis classification of on (FAO, 1984) and derived slope map was reclassified according to land suitability analysis classification of (Nzeyimana et al., 2014).

3.5.3. Soil Data

Soil data (soil depth, soil pH, soil drainage and soil texture) which had 250 m resolution of the study area were obtained from ISRIC website (https://www.isric.org/explore/isric-soil-data-hub). Data were obtained in raster format. The obtained soil data was then extracted by study area and resampled to 30 m resolution in Arc GIS 10.3. Finally soil maps were reclassified based on coffee Arabica requirements according to land suitability analysis classification of on (FAO, 1984).

3.5.4. Land use /Cover (LULC)

Landsat 8 image of 2020 (OLI) which has 30m resolution was downloaded from USGS(https://earthexplorer.usgs.gov/) website. The image had 30 m of spatial resolution. It used to prepare current land use/ cover map of the study area through ERDAS Imagine 2015 image processing software.

Table 3.4: Land Sat 8 (OLI) satellite data characteristics.

Index	Sensor	Path _Row	Resolution	Acquisition date	producer	Used bands
Around 2020	OLI	170-053	30	02/02/2020	USGS	1-5,7,8

For the preparations of current land use or cover map of the study area the following main steps were followed:

3.5.4.1. Pre-Processing of Satellite Image

The Landsat 8(OLI) image has eleven bands. The seven bands with the exception of band six (6) all layer were stacked together. The band six was excluded because of it have relatively high atmospheric effect. The stacked layers were calibrated through calibrate tool in ERDAS Imagine 2015. False color composite that is red 5, green 4 and blue 3 were used to develop the land cover map of the study area.

3.5.4.2. Land Use/Cover Classification

For an each single class an enough training sites were taken to create signatures. After established training sites each training sites were stored in signature editor and color desired for the particular feature class. Classify image pixel to belonging spectral class the supervised technique were employed. The classification scheme had to have classes that used for the study and discernible from the available data. For this purpose (Anderson, 1976) classification scheme was applied for the land use land cover classification. Supervised classification maximum likelihood algorithm in ERDAS imagine was applied in this study to classify land cover using multispectral satellite data obtained from Landsat 8 for the period of 2020 .The study area classified into five major Land cover classes. These were Agricultural land ,water bodies, Forest land, Grass land and Settlement.

Table 3.8: Land use / cover categories of Jardega Jarte Woreda

Land cover class	Description
Forest land	Land covered by relatively dense collection of trees which have closed canopy and eucalyptus plantation.
Agricultural land	This category involves all cultivated land. It Includes holding areas for livestock; land ploughed and made ready for sowing.
Water body	This category involves Rivers, streams, reservoirs
Settlement	Scattered rural settlements and Sparsely located settlements, Residential, commercial and services, recreational sites, public installation, infrastructures.
Grass land	Areas with permanent grass cover used for grazing and are usually communal.

3.5.4.3. Accuracy Assessment

The accuracy assessment reflects the real difference between classification and the reference map or data (Disperati & Virdis, 2015; Tsutsumida & Comber, 2015).If the reference data is highly inaccurate, assessment might indicate that classification results are poor.

Random selection of reference pixels was used to reduce the biases of using same pixels for testing classification. 102 Ground control points or reference points were collected randomly from the study area by GPS. 35 points from agriculture, 30 points from forest, 17 points from grass land 8 points from settlement and 12 points from water body were collected randomly from the study area.

Producer's accuracy is the map of accuracy from the point of view of the map maker (the producer). This is how often are real features on the ground correctly shown on the classified map or the probability that a certain land cover of an area on the ground is classified as such. It is also the number of reference sites classified accurately divided by the total number of reference sites for that class (Anand, 2017).

$$\text{Producer Accuracy} = \frac{\text{Number of correctly classified pixels in each category}}{\text{Total number of classified pixels in that category column total}} * 100 \text{.....equation (1)}$$

User's accuracy is the accuracy from the point of view of a map user. The User's accuracy essentially tells us how often the class on the map will actually be present on the ground. The User's accuracy is complement of the commission error; User's accuracy is equal to 100%-commission error. The User's accuracy is calculating by taking the total number of correct classifications for a particular class and dividing it by the row total (Anand, 2017).

$$\text{User Accuracy} = \frac{\text{Number of correctly classified pixels in each category}}{\text{Total number of classified pixels in that category (row total)}} * 100 \ldots \ldots \text{..Equation (2)}$$

Overall accuracy was used to calculate a measure of accuracy for the entire image across all classes present in the classified image. The collective accuracy of map for all the classes can be described using overall accuracy, which calculates the proportion of pixels correctly classified (Anand, 2017).

$$\text{Overall Accuracy} = \frac{\text{Total number of correctly classified pixels (diagonal)}}{\text{Total number of reference pixel}} * 100 \ldots \text{...Equation (3)}$$

Kappa coefficient

The Kappa coefficient, which measures a classification agreement, can also be used to assess the classification accuracy. It expresses the proportionate reduction in error generated by a classification process compared with the error of a completely random classification(Congalton, 1999). Kappa value greater than 0.8 denotes a strong agreement, value between 0.4 and 0.8 denotes a moderate agreement and a value below 0.4 represent poor agreement. The Kappa coefficient (K) is calculated using equation given by (Congalton, 1999).

$$\text{kappa coefficient} = \frac{(\text{total} * \text{sum of correct}) - \text{sum of all the(Row total} * \text{culemn total})}{\text{total squared} - \text{sum of the (Row total} * \text{culemn total})}$$

3.6. Criteria Determination

For land suitability Analysis of Coffee Arabica production, there is no uniform standard in the overall procedure of the operations; rather, it is applied based on nature, situation and available resource in a given geographic area. Criteria were established from the literature review, coffee experts knowledge and agronomists expert of the study area. The casual factors were chosen based on the four main criteria by considering the data availability, local expert knowledge and literature inputs (FAO, 1984; Nzeyimana *et al.*, 2014; Ochoa *et al.*, 2017). Hence, four main criteriaand nine factors namely: topography (elevation and slope), climate (temperature and rainfall), soil (texture, depth, drainage and pH) and landscape (land use land cover) were selected considering the nature of the study area and the available information, time and resource. Table: 3.8 show general criteria and sub criteria/factors that were used in the study.

Table 3.5: General criteria and factors that were used in the study

No	General Criteria	Sub criteria	Suitability range	Suitability class	References
1	Topography	Slope	0-4%	S1	(Nzeyimana *et al.*, 2014)
			4%-12%	S2	
			12%-25%	S3	
			25%-50%	N1	
			>50%	N2	
		Altitude	<1100 m and>2200m	N1	(FAO, 1984)
			1100 m-1500 m	S1	
			1500 m-1800 m	S2	
			1800 m-2200m	S3	
2	Climate	Rainfall	1200 mm-1400 mm	S2	(Nzeyimana *et al.*, 2014)
			1400mm-1600mm	S1	
			1600 mm-2000mm	S3	
			> 2000 mm	N1	
		Temperature	<17.5 and >25	N	(FAO, 1984)
			17.5-20	S2	
			20-22.5	S1	
			22.5-25	S3	
3	Soil	Soil Texture	Loam	S1	(Nzeyimana *et al.*, 2014)
			clay loam	S2	
			clay	S3	
		Soil Drainage	Good drainage	S1	
			Moderate Drainage	S2	

			marginally drainage	S3	(FAO, 1984)
			very poor drainage and excessive drainage	N1	
		Soil pH	<4.5 and >6.7	N1	(FAO, 1984)
			4.5-5.0	S2	
			5.0-5.5	S1	
			5.5-6.7	S3	
		Soil Depth	75 cm -100 cm	S3	(FAO, 1984)
			100 cm -150 cm	S2	
			150 cm-200 cm	S1	
4	Landscape	LU/LC	Agricultural land	S1	Local Expert knowledge
			Forest area	S2	
			Grazing land	S3	
			settlement	N1	
			Water body and	N2	

3.7. Criteria standardization and rating

Data are measured on different units as well as on different scales of measurements. Thus, it is necessary to standardize the factors before combination and assure they are transformed, if necessary, so that all factor maps are positively correlated with suitability (Yohannes & Soromessa, 2018). Linear scale transformation is the most frequently used GIS-based approach for criteria standardization (Malczewski, 2004). Thus, criteria have been standardized for this study, by using reclassify spatial analyst tool, to make sure that each criterion had an equivalent measurement basis. Simultaneously during reclassification, factor ratings were also assigned for suitability analysis from 1 (most suitable) to 5 (to least suitable). To have a reasonable comparison, common standard is required so as to apply weighted overlay over each of the input criteria (Mishra *et al.*, 2015).

3.8. Method of Land Suitability Evaluation

Land evaluation is formally defined as the assessment of land performance when used for a specified purpose, involving the execution and interpretation of surveys and studies of land forms, soils, vegetation, climate and other aspects of land in order to identify and make a comparison of promising kinds of land use in terms applicable to the objectives of the evaluation (FAO, 1993).

For land suitability evaluation, degrees of suitability classes have been applied in this study for analyzing land evaluation for the coffee Arabica production based on FAO, (1993) guidelines. The suitability map of the Coffee Arabica classified based on their land use quality priority for specified land use requirements. According to FAO (1993), based on land suitability classes that reflect the degrees of suitability, a land can be divided in to five classes. These include very suitable (S1), moderately suitable (S2), marginally suitable (S3), not suitable (N1) and permanently not suitable (N2).

Table 3.6: Land suitability classification (Source: FAO, 1993)

	Suitability	**The land can support the land use indefinitely and benefits justify inputs**
S1	Highly suitable	Land without significant limitations.
S2	Moderately suitable	Land that is clearly suitable but which has limitations that either reduce productivity or increase the inputs needed to sustain productivity compared with those needed on S1 land.
S3	Marginally suitable	Land with limitations so severe that benefits are reduced and/or the inputs needed to sustain production are increased so that this cost is only marginally justified.
N	Not suitable	Land that cannot support the land use on a sustained basis, or land on which benefits do not justify necessary inputs
N1	Permanently	Land with limitations to sustained use that cannot be overcome

	not suitable	

3.9. Assigning Criterion Weights

A weight is a value assigned to an evaluation criterion that indicates its importance relative to the other criteria under consideration (Malczewski & Rinner, 2015). There have been a number of methods used for assessing criterion weights. Pairwise comparison method is based on the assumption of spatial homogeneity of preferences and assigns a single weight to each criterion (Malczewski, 2006).

Pair-wise comparison of AHP method introduced by Saaty (1980) was used to calculate the required weighting factors for this study. Pairwise comparison matrix has been computed in excels. The process of converting data to such numeric scales is most commonly called standardization. This method used, to derive ratio scales from paired comparison. The pair wise comparison technique developed by Saaty in the context of a decision making process is a ratio (reciprocal matrix) where each aspect is compared with the other criteria, relative to its importance on a scale. Criteria are subjected in a gradation scale as shown in table 3.10.

Table 3.7 : Scale for pairwise comparisons (Saaty, 1980)

Intensity of Importance	Description
1	Equal importance
3	Moderate Importance
5	Strong Importance
7	Very strong Importance
9	Extreme Importance
2,4,6,8	Intermediate Value
Reciprocals	Value for inverse compression

The ratio scales derived with the help of Principal Eigen Vectors and the consistency index derived through Principal Eigen Value. In order to make some decisions compare one or more alternatives with one or more criteria to make some conclusion, this based on this comparison. Some of the criteria have more importance than others and according to their importance, assigned their weights. For this study criteria weight was calculated based on the following formula:

$$w_k = \frac{\sum_{p=1}^{n} c_{kp}^*}{n} \text{ ..... Equation (5)}$$

Where:

w_k = is criteria weight

c_{kp}^*= normalized entire matrix

n = number of criteria

Then, the consistency ratio (CR) is computed to check the consistency of comparisons. It was calculated as follow

$CR = \frac{CI}{RI}$, CR <0.10 ………….Equation (6)

$CI = \frac{\lambda_{max} - n}{(n-1)}$ ………………...Equation (7)

Where:

CR = Consistency Ratio

CI = Consistency index

λ_{max} = is the Principal Eigen Value

RI = Random Consistency Index

n = is the number of factors

3.10. Weighted overly analysis

Weighted overlay applies a common scale of values to diverse and dissimilar inputs to create an integrated analysis (Kamau *et al.*, 2015). The weighted overlay function weights the individual input raster on a defined scale. The more favorable locations for each input criterion were reclassified to the higher values. In the weighted overlay tool, the percentage influences assigned to all the input raster must equal to 100 percent. In this study, different map layers characterizing land suitability was weighted using the weights derived from the AHP process described in previous section. Aggregation of the weight and standardized rated criterion map, weighted overlay method was used to combine standardized rated criteria and weighted criteria to map the suitable land.

In this study, weights and the standardized criterion maps are aggregated by means of a weighted linear combination, an empirical contribution of (Malczewski, 2006) in Arc GIS weighted overlay extension tool . This was competed as the following formula:

$$S = \sum wixi \text{……………………………………equation (8)}$$

Where:

S – Is suitability

Σ - Is sum

wi– Weights assigned to each factor

xi– Factor scores (cells)

The figures 3.4 are flow charts showing the overall process of carrying out a land suitability analysis for coffee growing. A number of factors are considered in the process and their combined effect on the crop is represented in a suitability map.

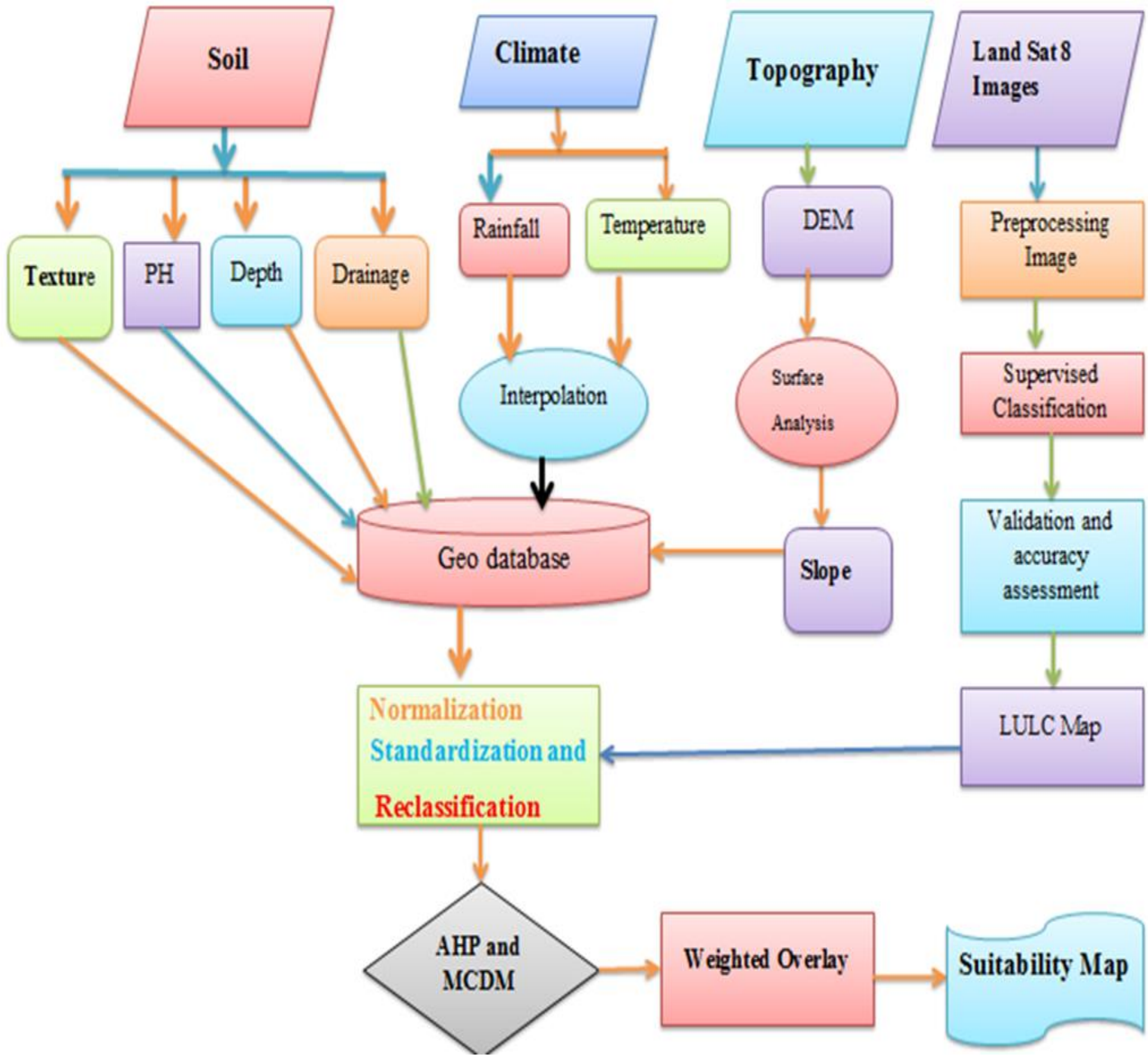


Figure 3.5: Flow diagram of the method used for suitability analysis

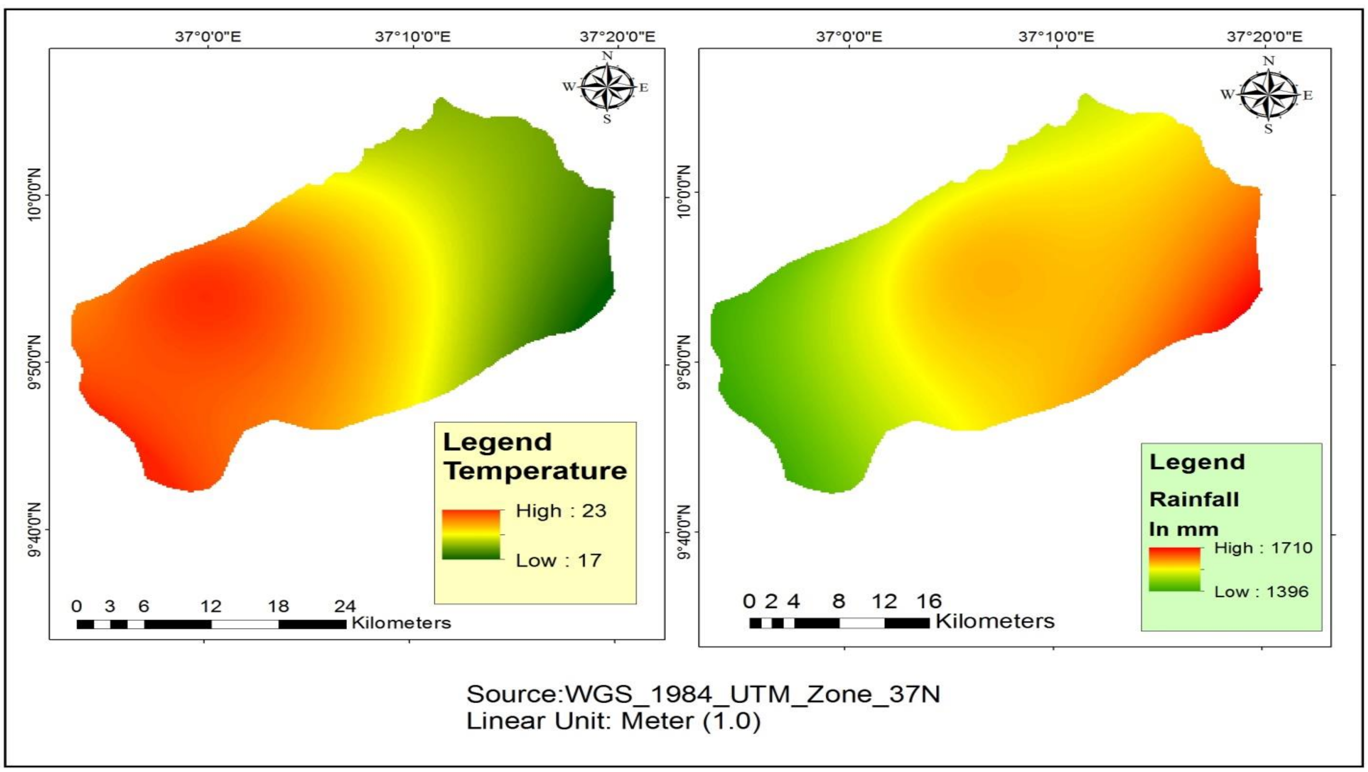
CHAPTER 4: RESULTS AND DISCUSSIONS

4.1. Preprocessing of Data and Reclassification Results

Physical and chemical factors of the land as well as climate are the major factors that determine crop suitability of a given land (Kassam *et al.*, 2012). For this paper, soil pH considered from chemical factors to analyze the land suitability for coffee Arabica production. The physical land properties of the study area, which were evaluated include topography (slope and elevation), soil (drainage, texture, depth) and land use land cover. Climate (Temperature and Rainfall) of the study area was also used for coffee Arabica suitability analysis.

4.1.1. Climate Data (Rainfall and Temperature)

The area has annual temperature of between 17 °C and 23°C. Similarly, rainfall ranges between 1396 mm and 1710 mm annually. This is as per average temperatures computed for over 28 years. It is also apparent that rainfall increase proportionately with decrease in temperatures.



(**A)** Figure 4.1: Mean annual temperature map. (B) Figure 4.2: Mean annual rainfall map

4.1.1.1. Rainfall Suitability Evaluation

Rainfall distribution plays a significant role in optimizing agricultural production. Thus, the average rainfall distribution together with its variation in both frequency and extent entails its agronomic importance. Crops need specific requirements of temperature and rainfall for growth. Based on rainfall requirement of coffee Arabica, rainfall of the study area was classified in to three suitability classes according to land suitability analysis classification of (Nzeyimana *et al.*, 2014). Its suitability ranges from high suitable to marginal suitable.

The result in the (Table 4.1 and Figure 4.3) revealed that the rainfall ranges between 1400 and 1600 mm (82.12%), 1300 and 1400 mm (17.7%), 1600 and 1710 mm (0.1%) were classified as highly suitable, moderately suitable and marginally suitable for coffee Arabica production respectively in the study area.

Table4.8: Rainfall suitability class

Rainfall (mm)	rainfall suitability class	Area(hectare)	Area%
1400-1600	S1	95293.53	82.12
1300-1400	S2	20621.8	17.7
1600-1710	S3	120	0.1

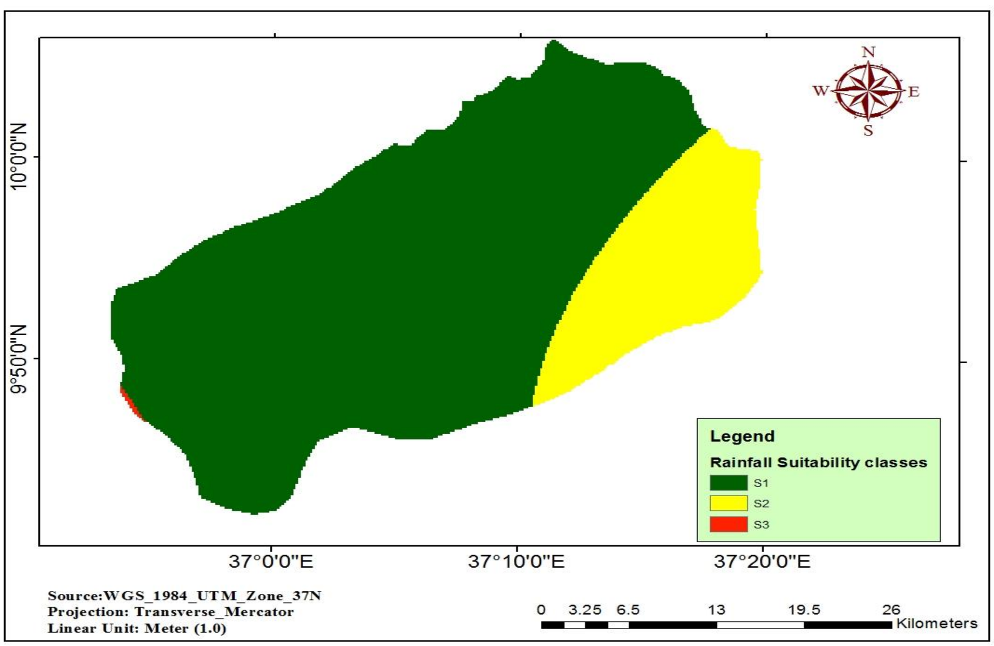


Figure 4.3: Rainfall suitability class map of the study area

4.1.1.2. Temperature Suitability Evaluation for Coffee Arabica

Temperature is one of the limiting factors for crop production (Debesa *et al.*, 2020). Based on temperature requirement of Coffee Arabica production, temperature of the study area was reclassified in to three suitability classes according to land suitability analysis classification of (FAO, 1984). These were highly suitable, moderately suitable and marginally suitable. Temperature that ranges between 20° and 22.5°, 17.5° and 20° and 22.5° were classified as highly, moderately and marginally suitable respectively for coffee Arabica production. The result in the (Table 4.2 and Figure 4.4) revealed that 87.9 % of total area of the woreda was highly suitable for coffee Arabica production with respect to temperature whereas, 6.5 % and 5.4% of total area of the study area was moderately and marginally suitable for coffee Arabica cultivation respectively with respect to temperature. The result is as shown Table 4.2 and Figure 4.4

Table 4.9: Temperature suitability class

Temperature in °C	Temperature suitability class	Area(hectare)	Area%
20-22.5	S1	48847.86	87.9%
17.5-20	S2	36617.49	6.5%
22.5-23.3	S3	30264.21	5.4%

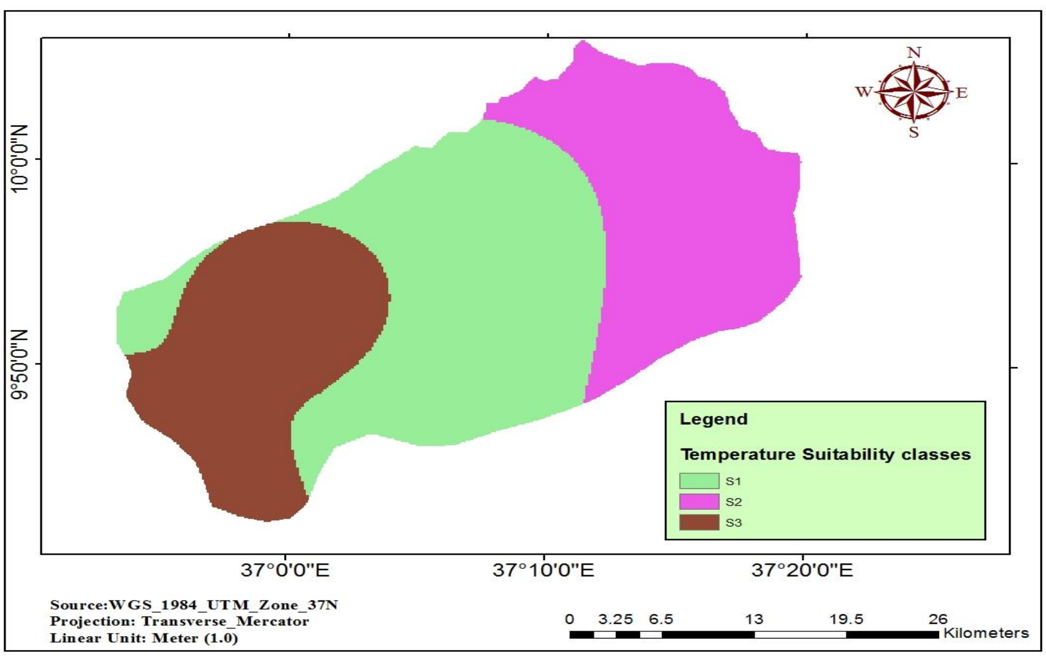


Figure 4.4: Temperature suitability class map of the study area

4.1.2. Elevation and Slope

4.1.2.1. Elevation

Elevation, also called altitude, is the height of a place above (or below) a reference level, such as mean sea level. Elevation and slope factors are the major factors that influence land suitability of coffee Arabica Production (Estrada *et al.*, 2017).

A digital elevation model (DEM) of high resolution (12.5m) which obtained from the earth data website was extracted by using study area boundary. The extracted study DEM was resampled to 30 m spatial resolution before derivation of slope map of the *district*. From the datasets, it was found out that elevation in study area ranges from 863 m to 2655 m above sea level. The result was as shown in Figures 4.5

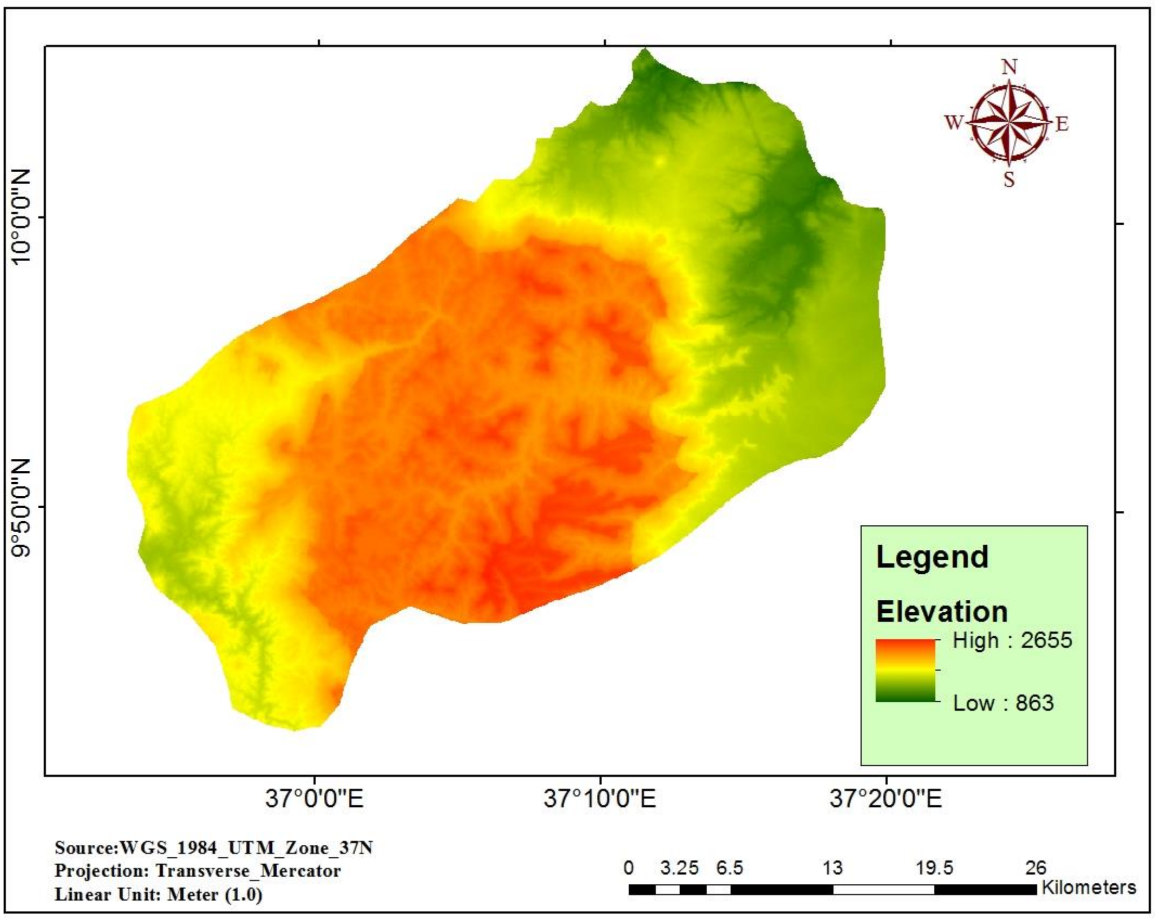


Figure 4. 5: Elevation map of the study area

4.1.2.2. Elevation suitability evaluation for coffee Arabica cultivation

Some of earlier studies suggested that elevation is the major factor that influence land suitability of coffee Arabica production (Nzeyimana *et al.*, 2014; Ochoa *et al.*, 2017). The Elevation of the study area was reclassified in to four classes according to its land qualities and characteristics of the altitude for the selection of the land for suitability of coffee Arabica production. The elevation was classified according to land suitability analysis classification of (FAO, 1984) . Its suitability ranges from high suitable to not suitable. The result in the (Table 4.3 and Figure 4.6) revealed that the elevation range between 1500 and 1800 m (20%) is reclassified as highly suitable for coffee Arabica production. Elevation ranges between 1100 and 1500 m (18%), 1800 and 2200 m (16%) were classified as moderately and marginally suitable for coffee Arabica production respectively; whereas, Elevation range between 863 and 1100m and 2200 to 2655 m classified as not suitable for coffee Arabica cultivation.

Table 4.10: Elevation suitability class of the study area

Elevation in (m)	Elevation suitability class	Area(hectare)	Area%
1500-1800	S1	24036.39	20%
1100-1500	S2	21060	18.1%
1800-2200	S3	19345.95	16.6%
863-1100 and 2200-2655	N1	51631.65	44%

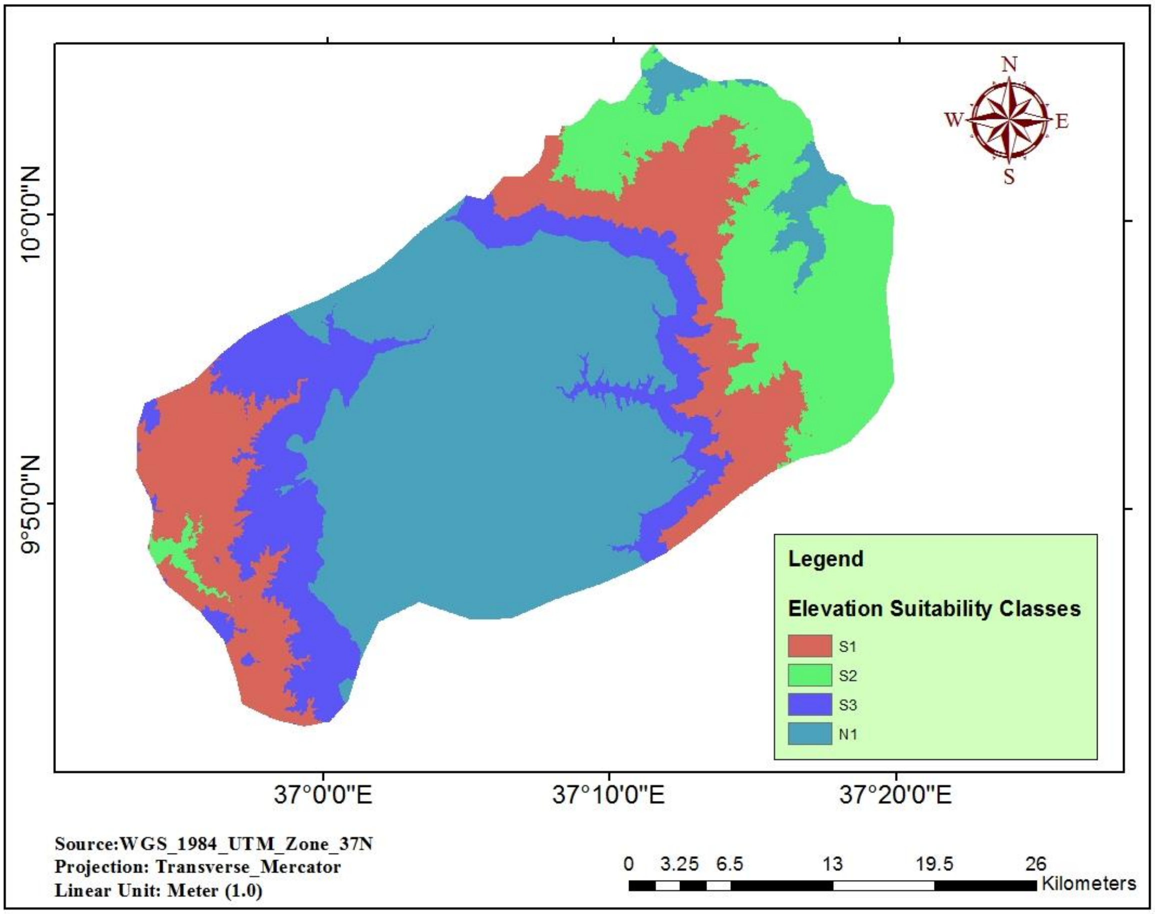


Figure 4. 6: Elevation suitability class of the study area

4.1.2.2. Slope

Slope is the incline or gradient of a surface and is commonly expressed in percent or degree. Slope is important for soil formation and management because of its influence on runoff, soil drainage, erosion and choice of crops. Those experiencing little variation are gentle slopes while those experiencing extreme variations are steep slopes (Mihret & Yohannes, 2015)

Slope of the study area was drive from digital elevation model. The slope of the study area which was derived from DEM was given in percent. It was found between 0% to 72% .The result obtained after the evaluation was that 11.4% of the area of the study area was below 4%, 23% of the area was between 4% and 12%, 23% of the study area was between 4-12% and 37% of the study area was between 12% and 25 %, 19.6% of the area was between 25% and 50% and 9% of the study area was greater than 50%. The result is as shown in the (table 4.4, figure 4.7).

Table 4.11: Slope class of the study area.

Slope Class	% Range	Area %
Nearly level	0-4	11.4
Gently sloping	4-12	23
Moderate sloping	12-25	37
Strongly sloping	25-50	19.6
Steep	>50	9

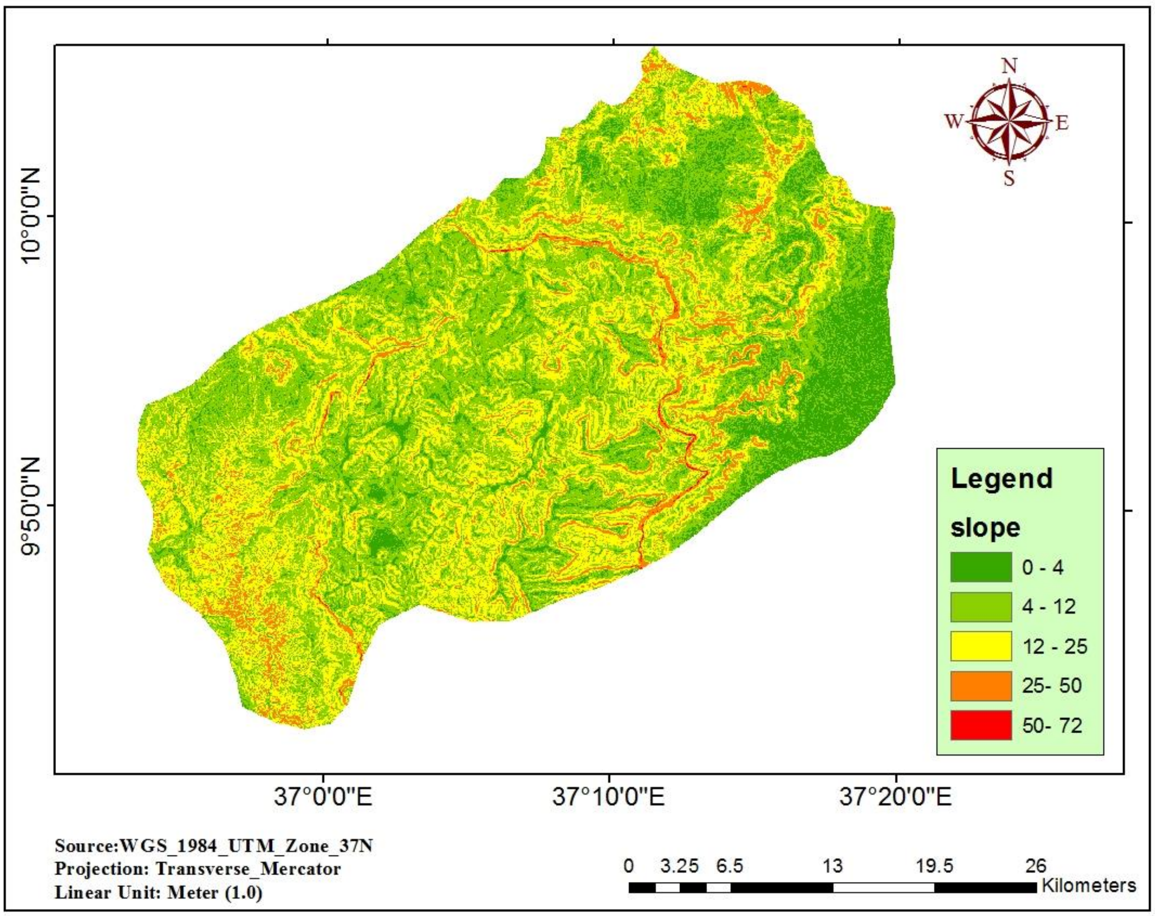


Figure 4.7: Slope map of the study area

4.1.2.3. Slope Suitability Evaluation

Slope has been considered as one of the evaluation parameters in coffee Arabica suitability analysis (Nzeyimana *et al.*, 2014). The slope of the study area is expressed in percentage. The Slope of the study area was reclassified in to five classes according to land suitability analysis classification of (Nzeyimana *et al.*, 2014). The classes include very suitable (S1), moderately suitable (S2), marginally suitable (S3), not suitable (N1) and permanently not suitable (N2). Slope ranges between 0 and 4 %, 4 and 12%, 12 and 25% were classified as highly, moderately and marginally suitable for coffee Arabica production respectively, whereas slope range between 25% and 50 % and greater than 50% were classified as not suitable and permanently not suitable for coffee Arabica production. The result is as shown (Table 4.5 and Figure 4.8).

Table 4.12: Slope suitability class of the study area.

Slope Class	% Range	Slope suitability class	Area(hectare)	Area %
Almost flat	0-4	S1	6345.45	5.40%
Undulation plain	4-12	S2	27796.95	23%
Hill to rolling	12-25	S3	43984.17	37%
Steep	25-50	N1	31214.79	26%
Very steep	>50	N2	6733.53	5.80%

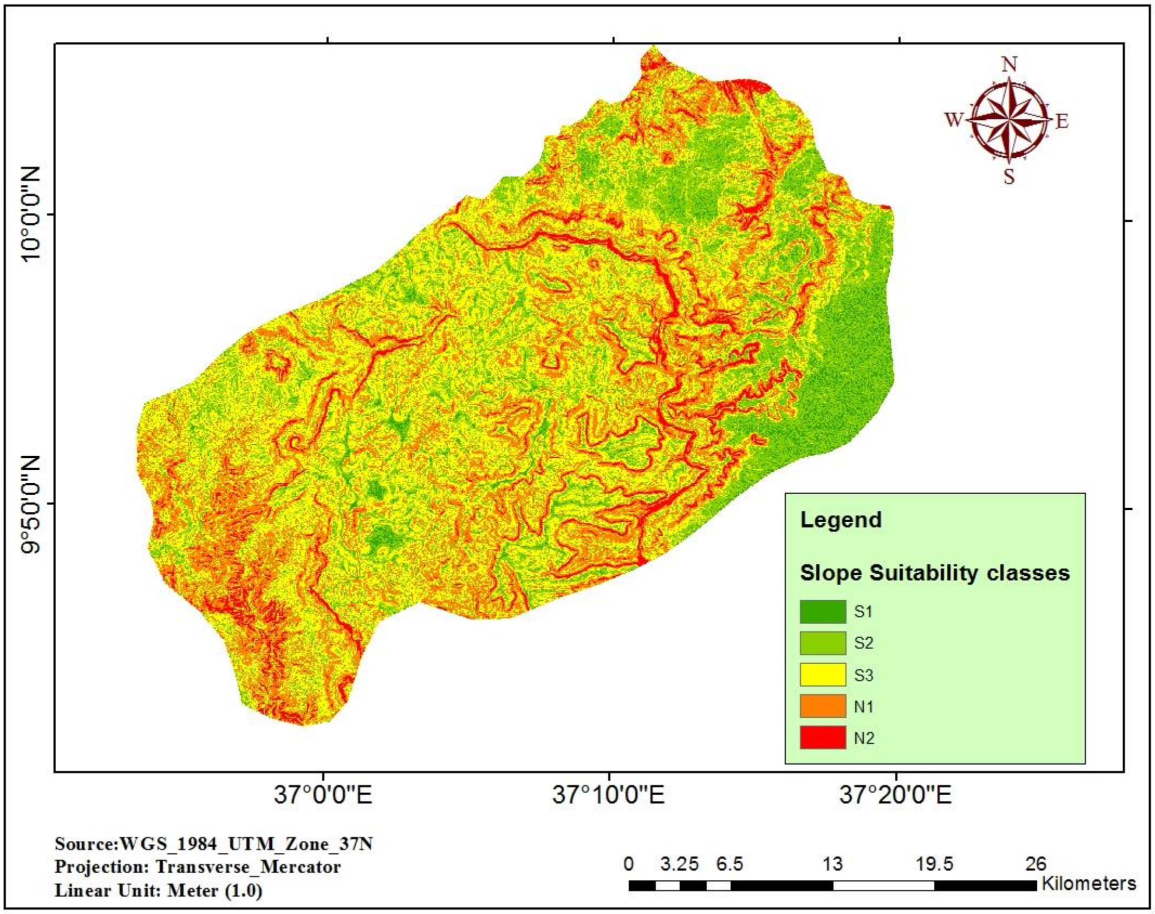


Figure 4.8 : Slope suitability class map

4.1.3. Soil Depth

A soil depth variation from place to place determines the growth of plants and also affects the growing of plant roots. The thickness of the soil materials, which give structural support, nutrients and water for crops, is referred as soil depth. Soil depth of the study area which was obtained from ISRIC data was extracted by study area boundary and resampled to 30 m. It ranges between 75 cm to 200 cm. The soil depth of the study area was classified in to three classes according to land suitability analysis classification of (Mulugeta, 2010). Bedrock between 70 and 100 cm was described as moderately deep. 100 - 150 cm were deep and if it is greater than 150 cm it was very deep. Table 4.6 shows the soil depth class of the study area.

Table 4.13: Soil depth class of the study area

Soil Depth Class	Depth in cm
Very Deep	>150
Deep	100-150
Moderately Deep	75-100

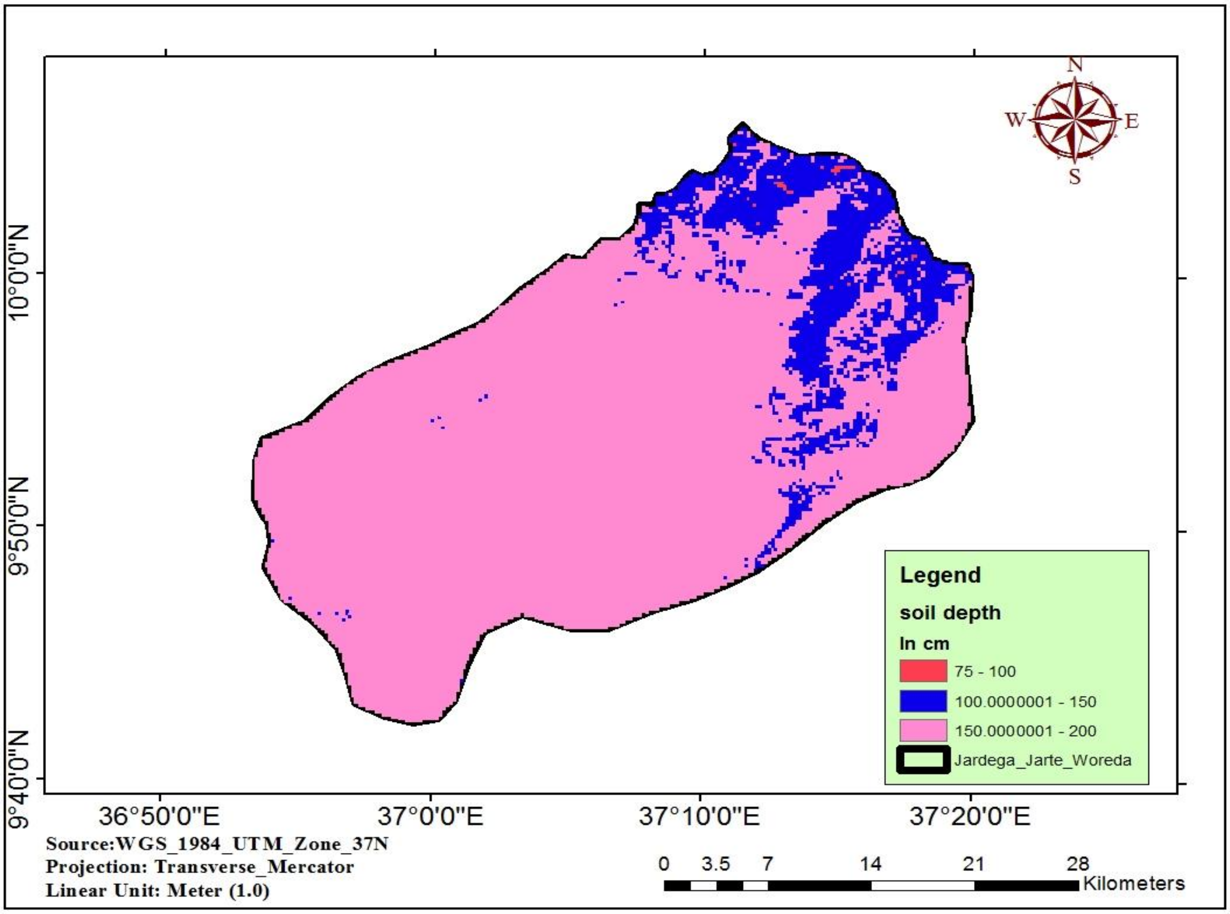


Figure 4. 9 : Soil depth map of the study area

4.1.3.1. Soil Depth Suitability Evaluation

Based on soil depth requirement of Coffee Arabica, soil depth of the study area was reclassified in to three suitability classes according to land suitability analysis classification of (FAO, 1984). Its suitability classes range from highly suitable to marginally suitable classes. The result in the (Figure 4.14 and Table 4.7) reveals that soil depth greater than 150 cm (86.34%) was classified as highly suitable for coffee Arabica. Soil depth that ranges between 100 and 150 cm (13%), 150 and 200 cm (0.14%) were classified as moderately and marginally suitable respectively for coffee Arabica production.

Table 4.14: Soil depth suitability class of the study area

Soil Depth Class	Depth in cm	Soil depth suitability class	Area(hectare)	Area%
Very Deep	>150	S1	99851	86.34%
Deep	100-150	S2	15616	13%
Moderately Deep	75-100	S3	170.82	0.14%

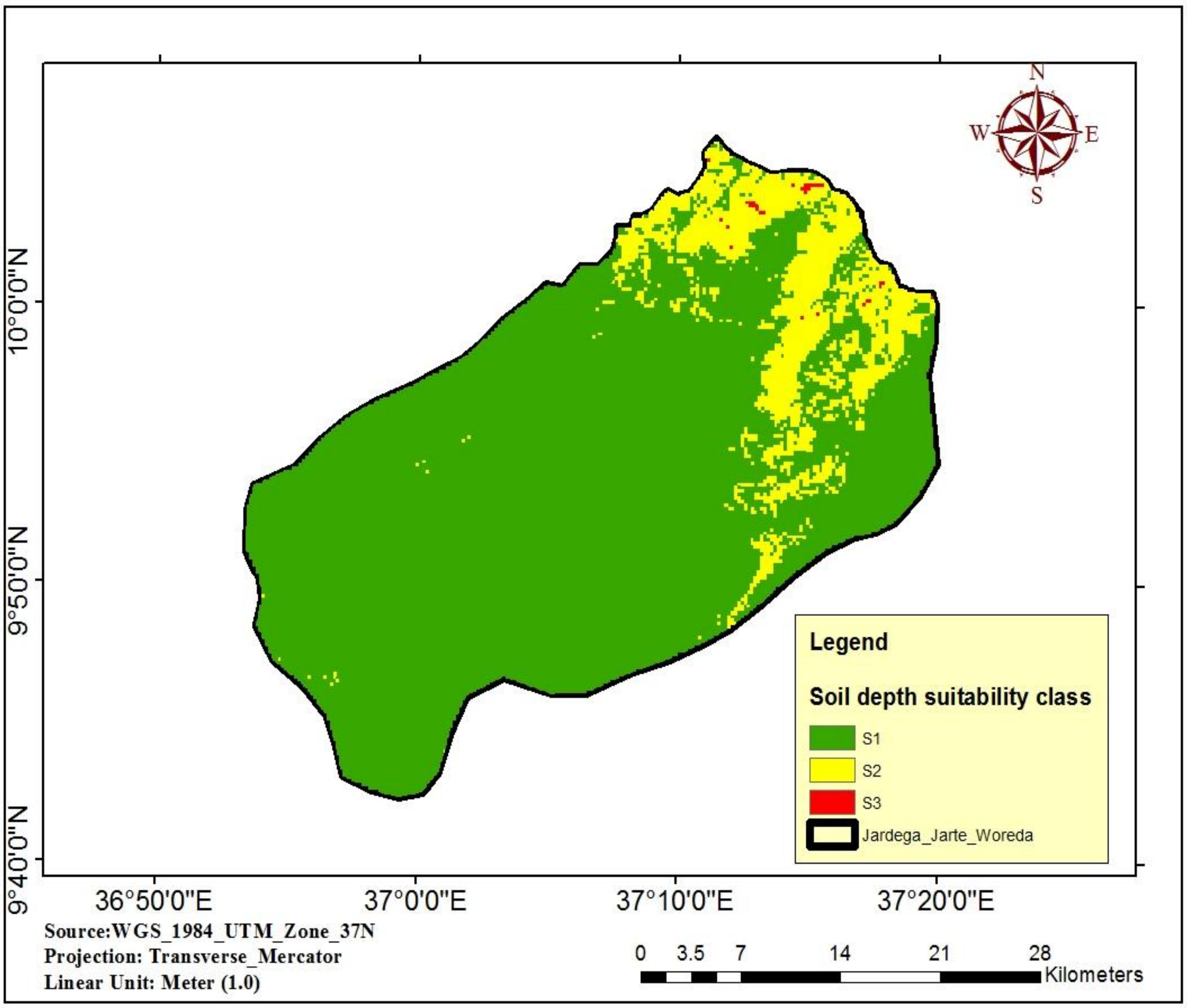


Figure 4. 10 : Soil depth suitability class map of the study area

4.2.4. Soil Texture

Soil texture describes the porosity of a soil .This is determined by the relative share of each of the primary soil particles and the organic matter content. Primary soil particles are sand, silt and clay (Kuit *et al.*, 2004).Some of earlier studies suggested that soil texture is the other factor that influence land suitability of coffee Arabica production (Ochoa *et al.*, 2017). The soil texture of the study area was evaluated and classified in to clay, clay loam and loam. The dominant soil texture types of the study area are clay loam, loam and followed by clay. Loamy is most appropriate for agricultural crop. Soil texture of the study area was as shown in (table 4.8 and figure 4.11)

Table 4.15: Soil texture class

Textural group	**Textural class**
Medium	Loam (L)
Fine	Clay Loam (CL)
	Clay (C)

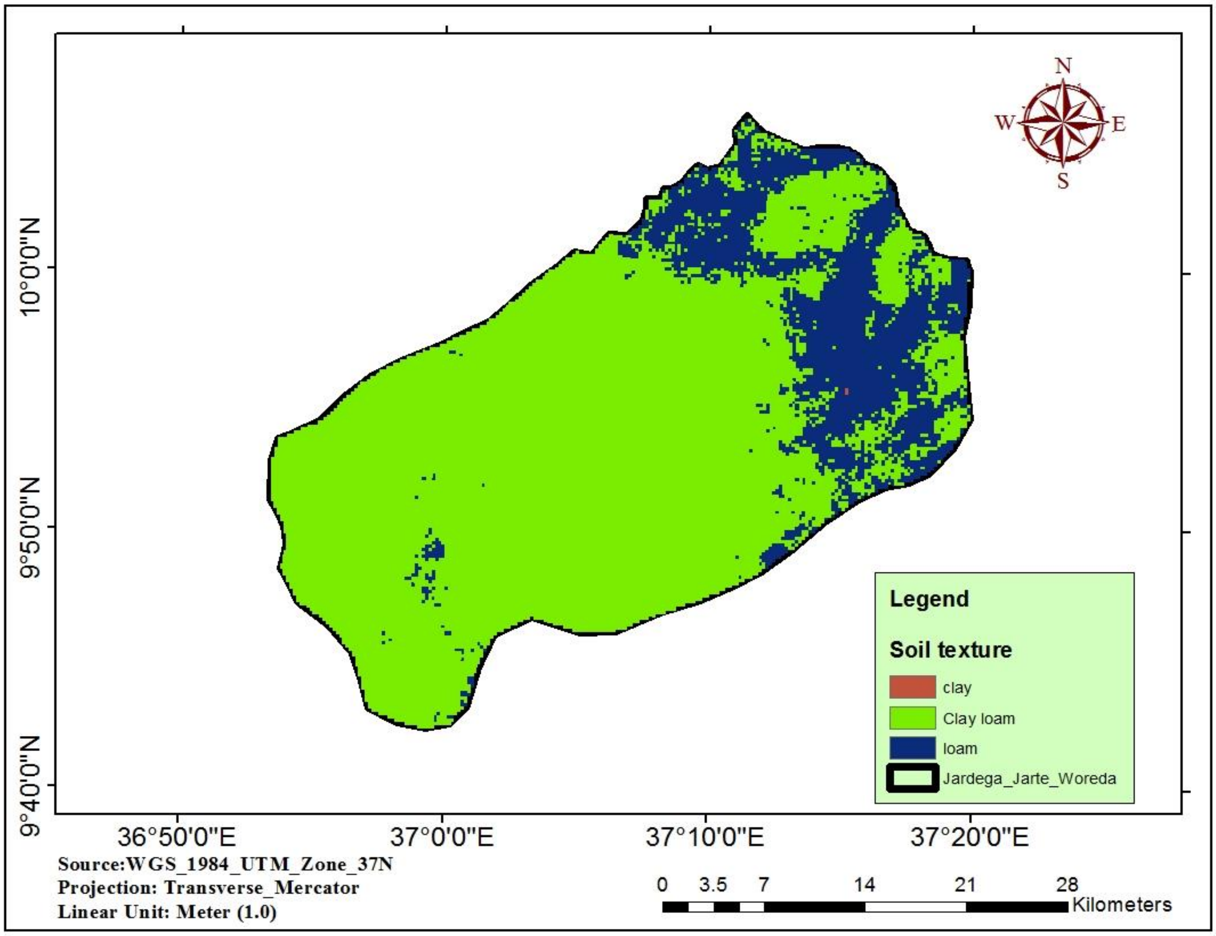


Figure 4.11: Soil texture map of the study area

4.1.4.1. Soil Texture Suitability Evaluation

The suitability of soil texture for coffee Arabica cultivation was evaluated through its suitability potential for coffee Arabica production. Soil texture has been considered as one of the evaluation parameters in land suitability analysis for coffee Arabica production. Based on soil texture requirement of Coffee Arabica production, soil texture of the study area was re classified in to three suitability classes according to land suitability analysis classification of (FAO, 1984) . Its suitability class range from high suitable to marginal suitable. Loamy, clay loam and clay soil were re classified as highly, moderately, and marginally suitable for coffee Arabica Production. The result in (Table 4.9 and Figure 4.12) revealed that 59.1 % of total area of the study area soil texture is dominated by clay loam and moderately suitable for coffee Arabica production. From the total area 39% of the area is loam and highly suitable for coffee Arabica cultivation, whereas, 0.11% the study area is clay and marginally suitable for coffee Arabica cultivation.

Table 4.16 : Soil texture suitability class of the study area.

Soil texture	Soil texture suitability class	Area(hectare)	Area%
loam	S1	22443	39%
Clay loam	S2	93185	59.1%
clay	S3	9.45	0.11%

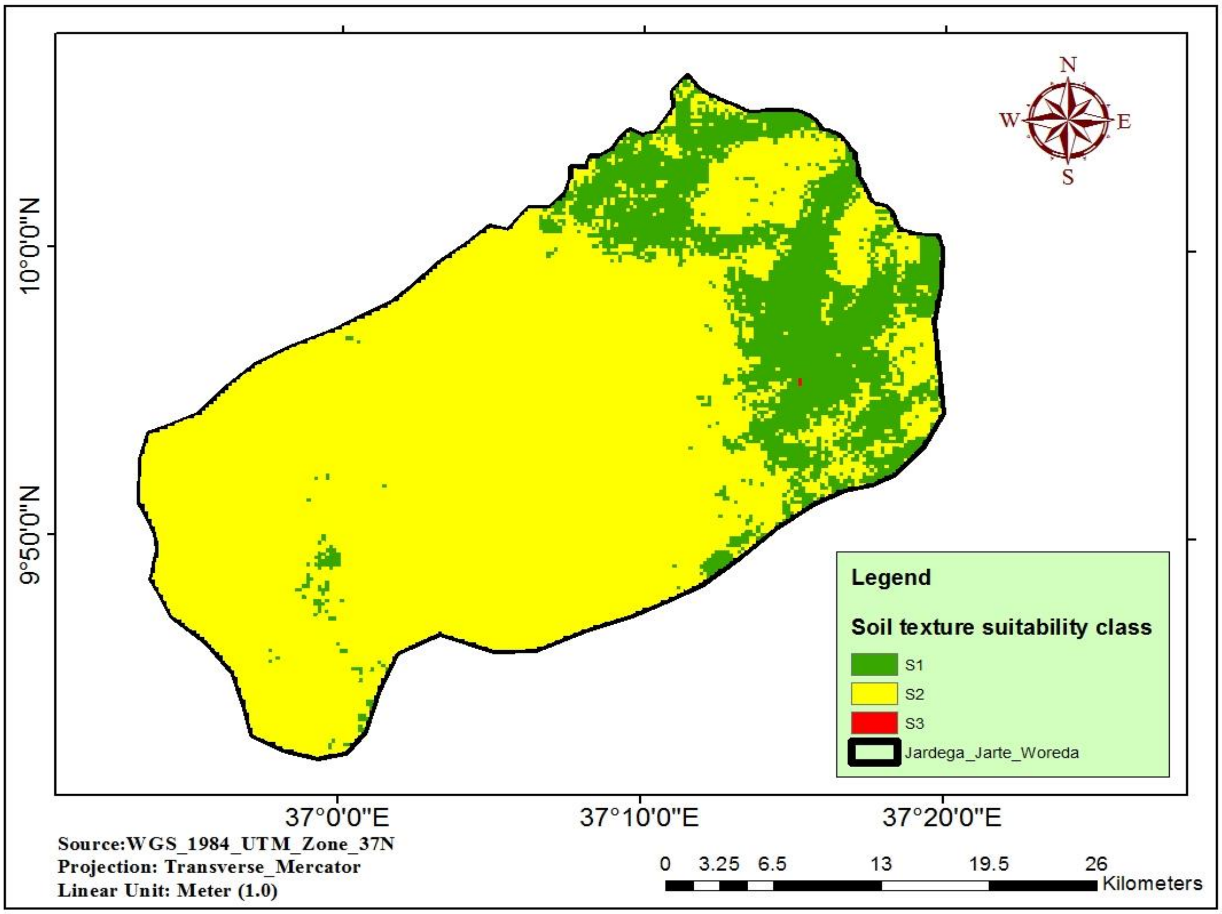


Figure 4.12: Soil texture suitability class map of the study area

4.1.5. Soil Drainage

Evaluation of the soil drainage requirement is a critical element in selecting land for crop production, because it permits normal plant growth (MULUGETA, 2010). Adequate soil drainage is essential to ensure sustained productivity and to allow efficiency in farming operations. Soil permeability properties of the study area which obtained from ISRIC data were classified as well drained, moderately drained, poorly drained, and very poorly drained. The result is as shown figure 4.13

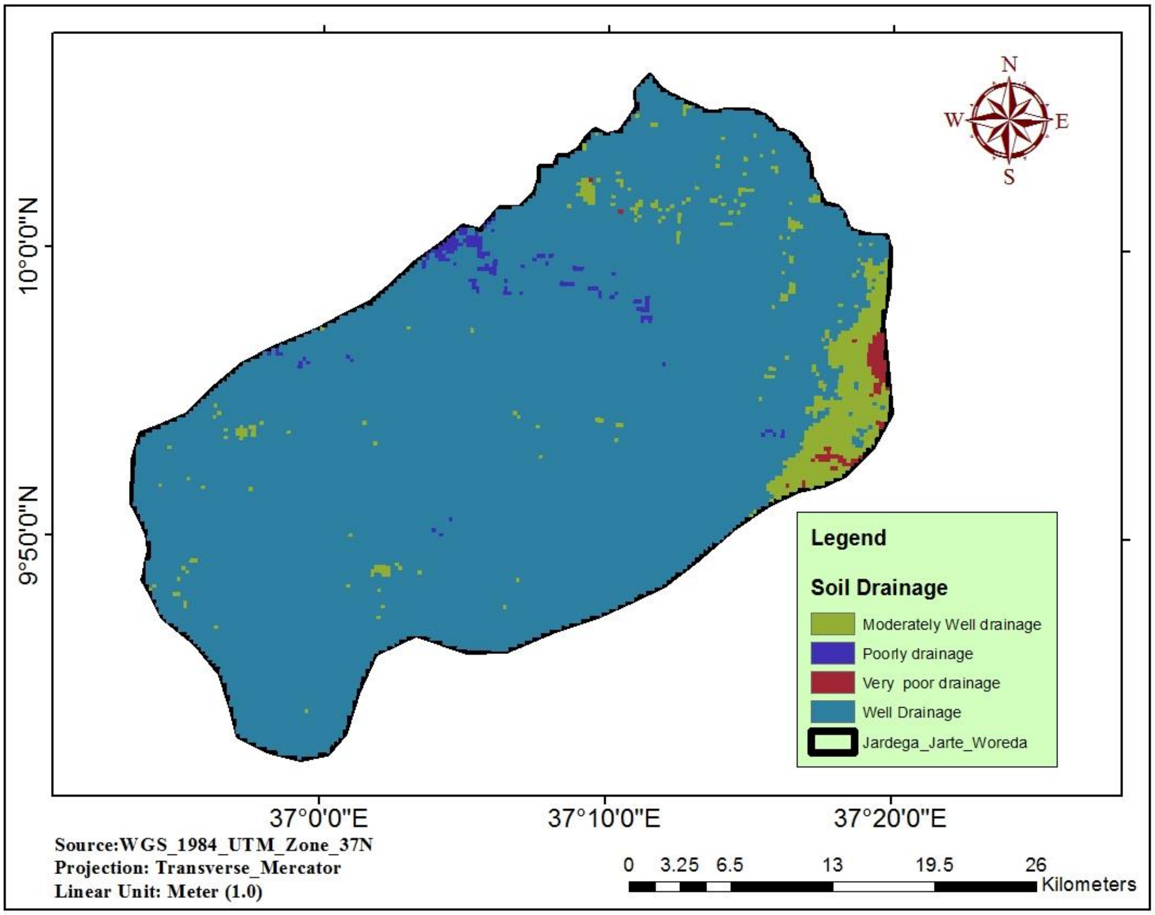


Figure 4.13:Soil drainage map of the study area

4.1.5.1. Soil drainage suitability evaluation

Soil drainage map was reclassified based on coffee Arabica requirements according to land suitability analysis classification of (FAO, 1984) . As a result suitability map of soil drainage within the study area was developed. The suitability classes were four i.e. very suitable, moderately suitable, marginally suitable and not suitable. The result in the table 4.10 and figure 4.9 revealed that well drained soil was reclassified as highly suitable for coffee Arabica production. Moderately well drained soil was reclassified as moderately suitable for coffee Arabica cultivation. Poor drained and Very Poor drained soil drainage were reclassified as marginally and not suitable for coffee Arabica cultivation respectively. From the total area of the woreda 99% is in the range of highly suitable to marginally suitable for coffee Arabica production with respect to soil drainage, whereas the remaining 0.46% of the total area (532.62 ha) is not currently suitable for coffee Arabica cultivation.

Table 4.17 : Soil drainage suitability class of the study area

Soil Drainage	**Soil Drainage suitability class**	**Area(hectare)**	**Area%**
Well Drained	S1	108863	94.1%
Moderately well Drained	S2	5376.51	4.6%
Poor drained	S3	811.71	0.7%
Very Poor drained	N1	532.62	0.46%

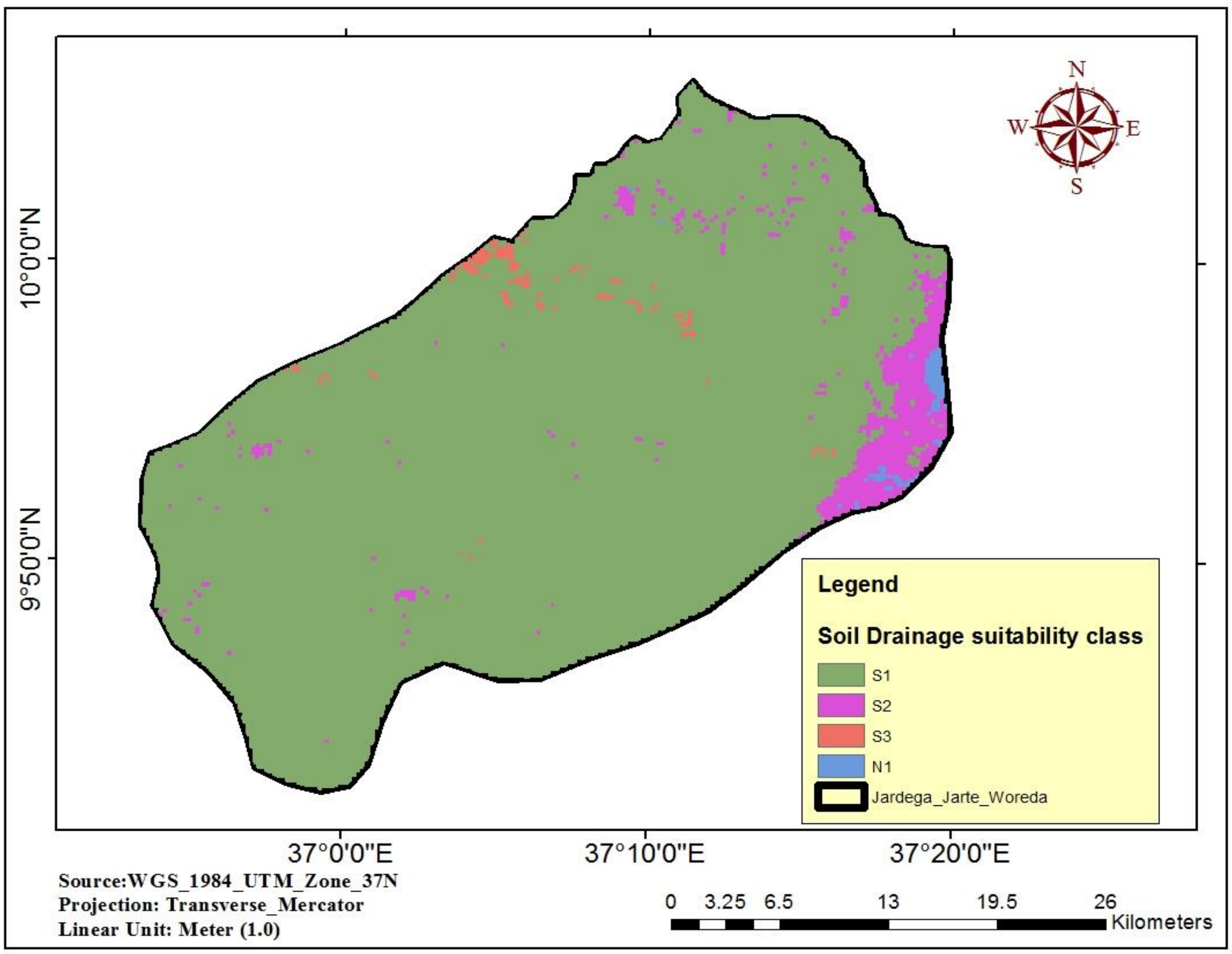


Figure 4:14: Soil drainage suitability map of the study area

4.1.6. Soil pH

Some of earlier studies suggested that soil pH is the other factor that influence land suitability of coffee Arabica production (Rono *et al.*, 2018). Soil pH of the study area which was obtained from ISRIC data hub was extracted by using study area boundary and resampled to 30 m resolution. The available soil pH in the study area was ranges between minimum values of 3.7 to the maximum value of 7.3. The result was represented in a map as shown in figure 4.15

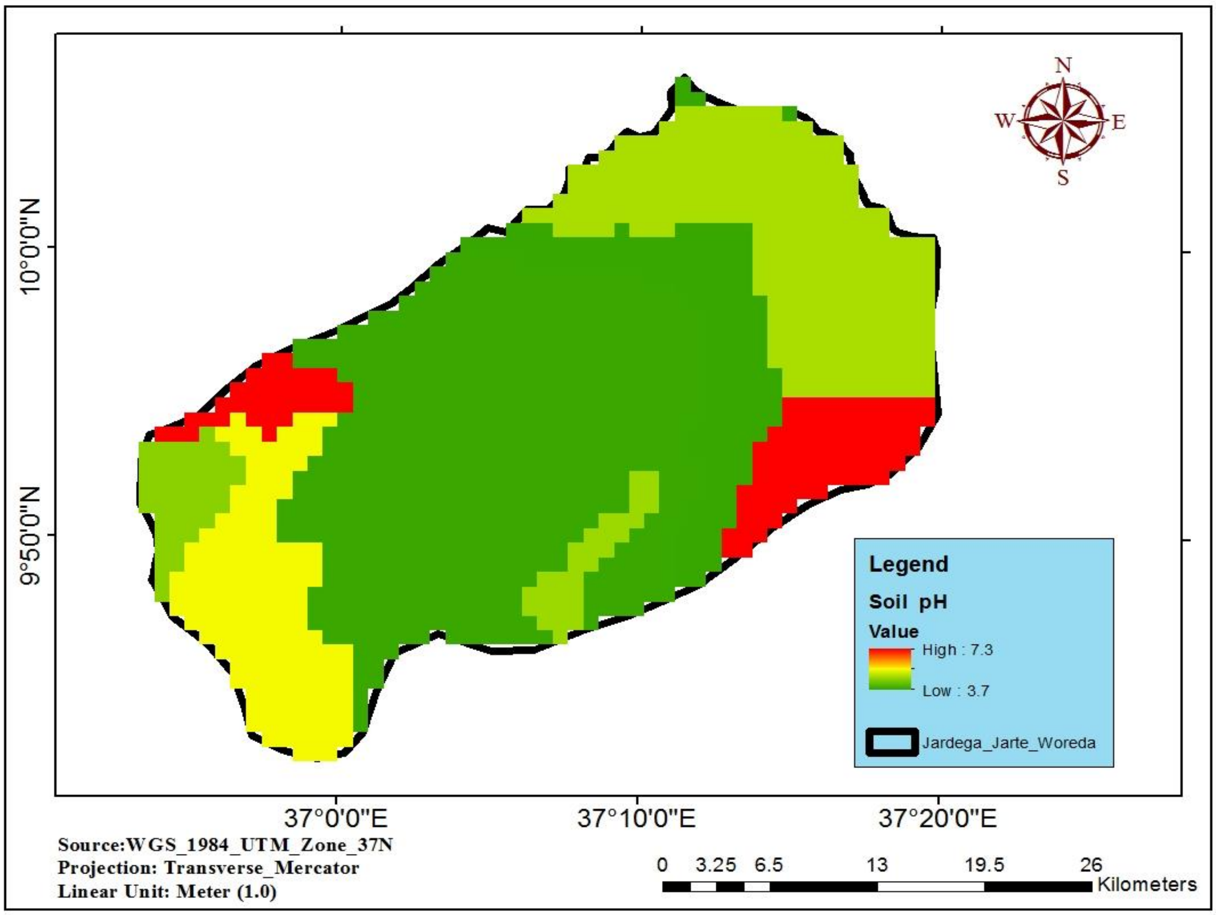


Figure 4.15: Soil pH map of the study area

4.1.6.1. Soil pH Suitability Evaluation

The Soil pH of the study area was reclassified in to four classes based on coffee Arabica requirements according to land suitability analysis classification of (FAO, 1984). The classes range from very high suitable (S1) to not suitable (N1). The result in the table 4.11 revealed that soil pH ranges between 5 and 5.5 classified as highly suitable for coffee Arabica cultivation. Soil pH range between 4.5 and 5 classified as moderately suitable for coffee Arabica. Soil pH that range between 5.5 and 6.7 was classified as marginally suitable for coffee Arabica production. Soil pH ranges less than 4.5 and greater than 6.7 were classified as not suitable for coffee Arabica cultivation. From the total area of the woreda (327760 hac) (25%) was highly suitable for coffee Arabica cultivation with respect to soil PH. 44% of the total area of woreda (561156 hac) was moderately suitable for coffee Arabica cultivation. 11% of the total area of woreda (148623 hac) was marginally suitable for coffee Arabica cultivation with respect to soil PH, whereas 18% of the total area of the study area (233648 hac) of the woreda was not suitable for coffee Arabica production.

Table 4.18: Soil pH suitability class of the study area for coffee cultivation.

Range of soil pH	**Soil pH suitability class**	**Area(hectare)**	**Area%**
5-5.5	**S1**	**29498**	25%
4.5-5	**S2**	**50504.04**	44%
5.5-6.7	**S3**	**13376.07**	11%
< 4.5 and > 6.7	**N1**	**21028.32**	18%

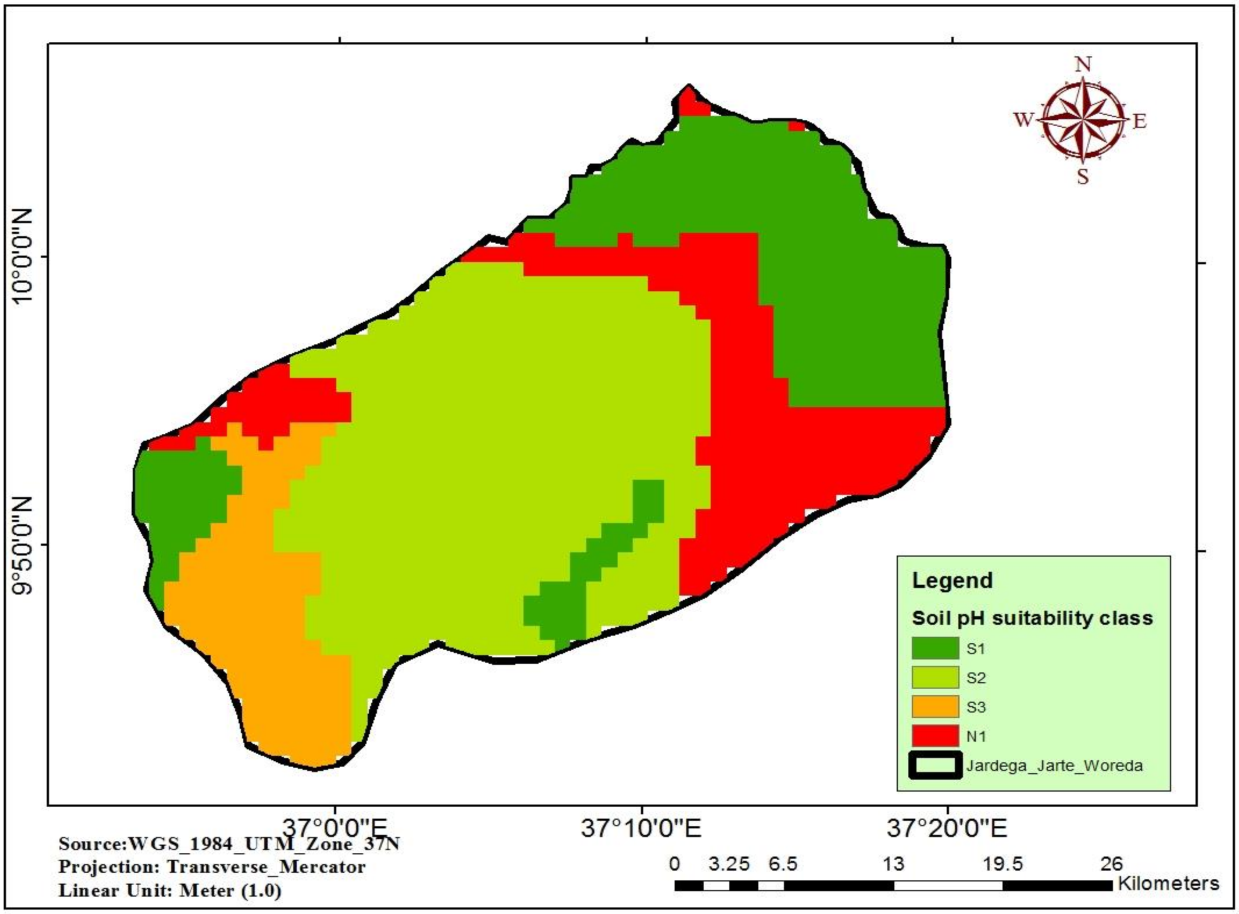


Figure 4. 16: Soil pH suitability class map of the study area

4.1.7. Current LU/LC Classification of Study Area

The Landsat 8 (OLI) of 2020 satellite image was used to classify the land use or cover of the study area. The satellite image was classified by the supervised image classification technique. The area was classified in to five main classes. These classes are Agricultural land, forest land, Grass land, water body and settlement. The results revealed that Agricultural land is dominant as compared to the other land cover or use types in the study area. It covers 71909.46 hac (65.3 %) of the total area of the woreda. Forest area is the second dominant land cover in the study area .It covers 33.7 % of total area of the woreda. From the total land 715.14 hectare (0.64%) was covered by Grass land. 212.04 hectare (0.19%) was covered by settlement. 76.23 hectare (0.068%) was covered by water body. Table 4.13 shows that LULC classes of the study area.

Table 4.19: LU/LC classes and area coverage of Jarte Jardega Woreda

Class Name	Area(hectare)	Area%
Water Body	76.23	0.069%
Settlement	212.04	0.19%
Grass Land	715.14	0.649%
Forest Area	29182	33.77
Agricultural land	71909.5	65.31
Total	102094.9	100

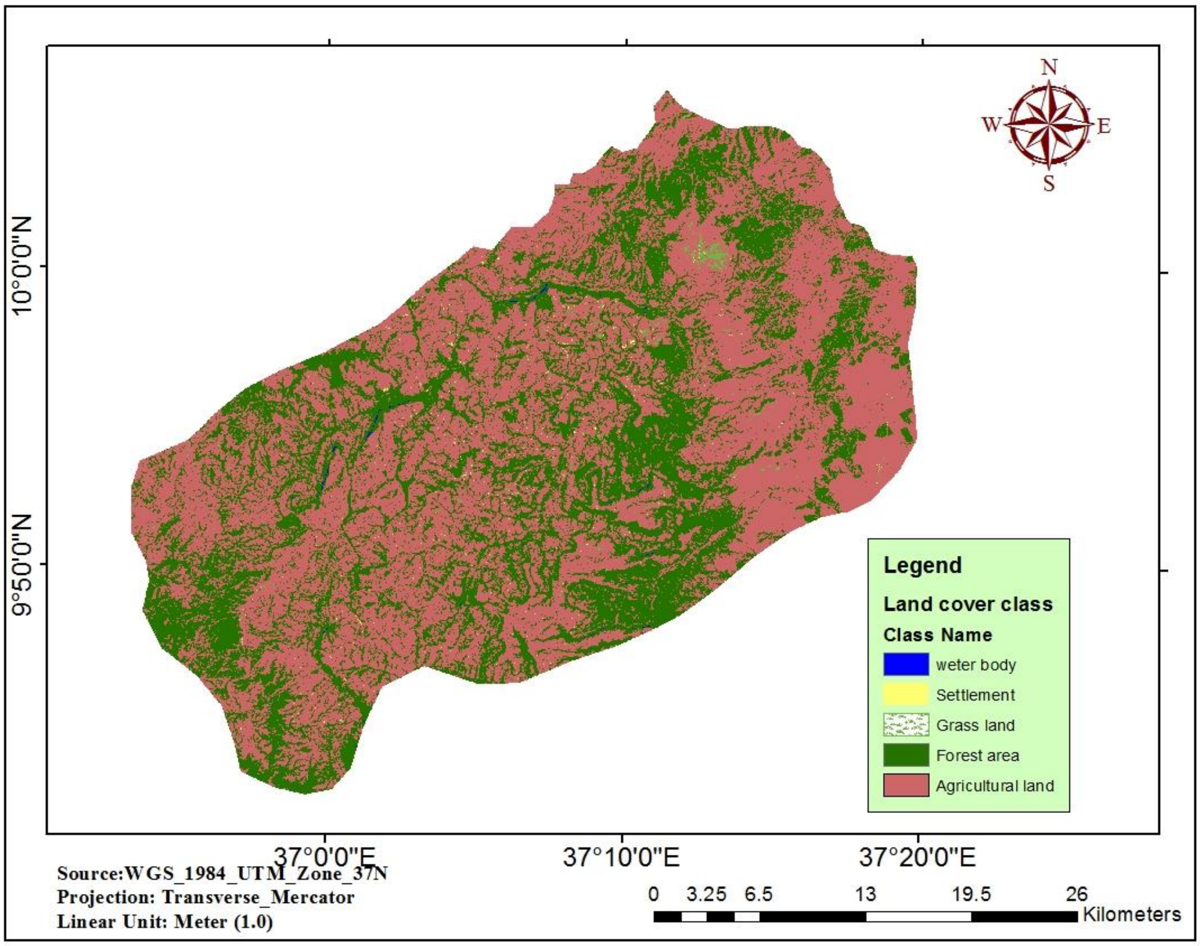


Figure 4.17: Current land use land cover map of the study area.

4.1.7.2. Accuracy Assessment Result

In order to determine classification accuracy, it is necessary to determine if the output map meets, exceeds, or does not meet certain predetermined classification accuracy criteria. One of the most common methods used to assess classification accuracy is the use of an error matrix (sometimes called a confusion matrix).

Therefore, in this study, the overall, user's and producer's accuracies, and the Kappa coefficient were calculated (Table 4.12). All land covers/uses were classified with high accuracy. Of all land cover classification, water body was classified with hundred percent (100%) accuracy level. The land cover or use of the study area was classified with overall accuracy of 91.17% and kappa coefficient of 0.882.The kappa coefficient of 0.882 of land use or cover classification in the study area represents a strong agreement according to Adam et.al (2013).

Table 4.20:Confusion matrix of Landsat 8 (OLI) 2020 land use/cover classification

Land cover Classes	**Reference data**							
	Crop land	Forest area	Grass land	Water body	Settlement	Total	User's accuracy	Kappa coefficient
Crop land	**31**	1	1	0	1	34	91.17%	0.882
Forest area	1	**28**	1	0	0	30	93.3%	
Grass land	2	1	**15**	0	0	18	83.3%	
Water body	0	0	0	**12**	0	12	100%	
Settlement	1	0	0	0	**7**	8	87.5%	
Total	35	30	17	12	8	**102**		
Producer's Accuracy	88.6%	93.3%	88.23%	100%	87.5%	**0verall accuracy 91.17%**		

4.1.7.2. Land Use / Cover Suitability Evaluation

The first stage in multi-criteria evaluation is preparing a land use land cover data to classify the land use and land cover according to their importance. Reclassification of land use land cover types was done based upon the relevance to the study area, expert's knowledge and literature reviews. Accordingly, from the land cover or use classes of the study area Agricultural land and forest area were classified as highly and moderately suitable for coffee Arabica production respectively. Forest was classified as moderately suitable because of coffee require shade trees. Grass land was classified as marginally suitable. Settlement and Water body were classified as not suitable for coffee Arabica cultivation.

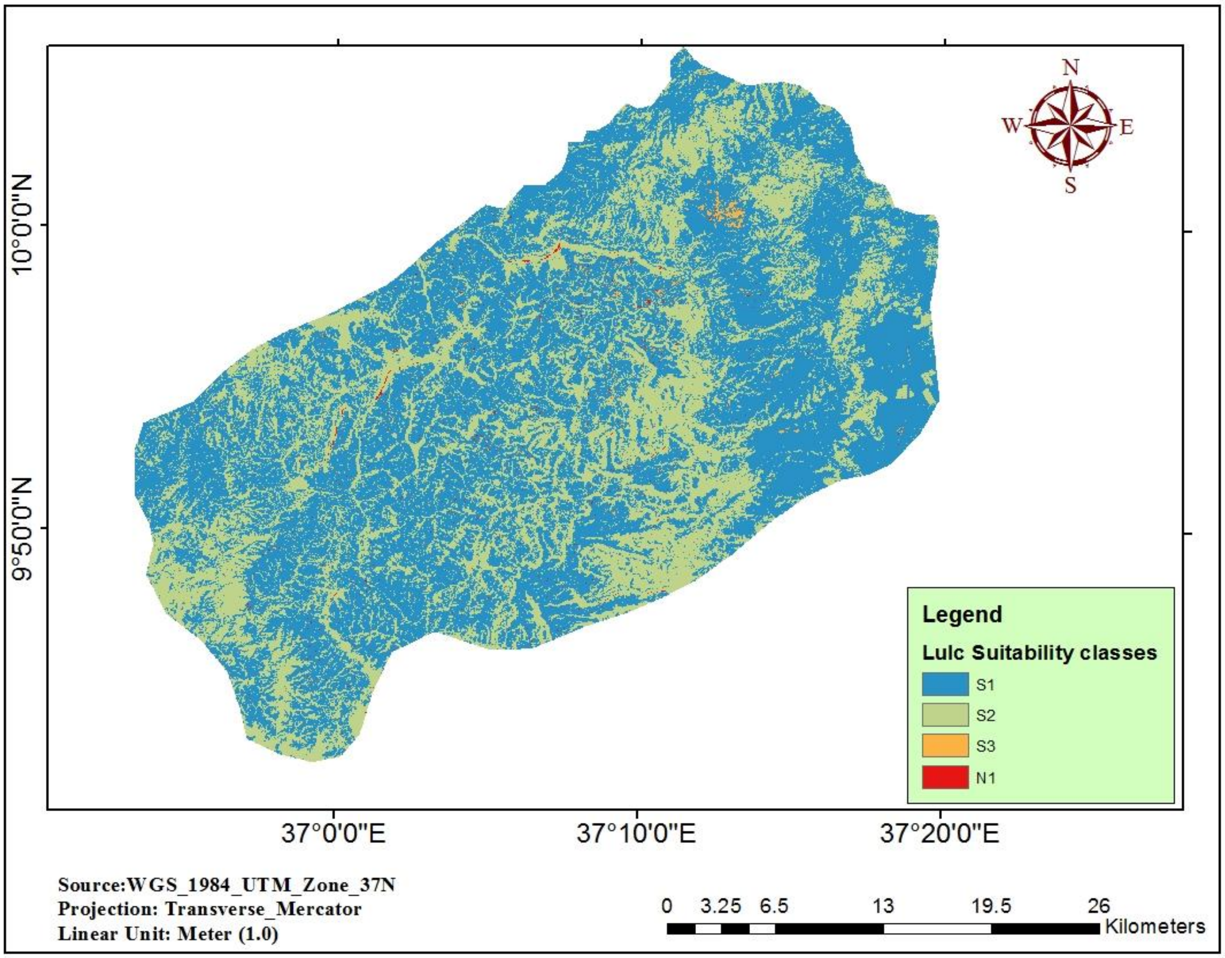


Figure 4.18: LU/LC suitability class map of the study area

Table 4.21:LU/LC suitability class of the study area

LU/LC Classis	**LU/LC suitability class**	**Are a%**
Agricultural land	S1	65%
Forest land	S2	33%
Grass land	S3	0.6%

Settlement	N1	0.2 %
Water body	Restrict	

The result in the above table revealed that Agricultural land was reclassified as highly suitable, Forest land was moderately suitable, Grass land is marginally suitable and settlement and water body is not suitable for coffee Arabica production. 98% of the total area of the *woreda* is in the range of highly suitable to marginally suitable for coffee Arabica production with respect to LULC, whereas, the remaining 0.2% of the total area is not currently suitable for coffee Arabica cultivation with respect to LULC.

4.2. Land Suitability Class Specification

According to FAO (1993) standards, which are widely used to classify land suitability for specified objectives of land utilization types, a land can be divided in to five classes. These include very suitable (S1), suitable (S2), marginally suitable (S3), not suitable (N1) and permanently not suitable (N2). Class-determining factors are those factors, which affect the performance of the land utilization types on the land units under the study. These factors include slope, elevation, soil drainage, soil depth, soil texture, and soil pH, temperature, and rainfall and land use of the study area (Figure 4.19).

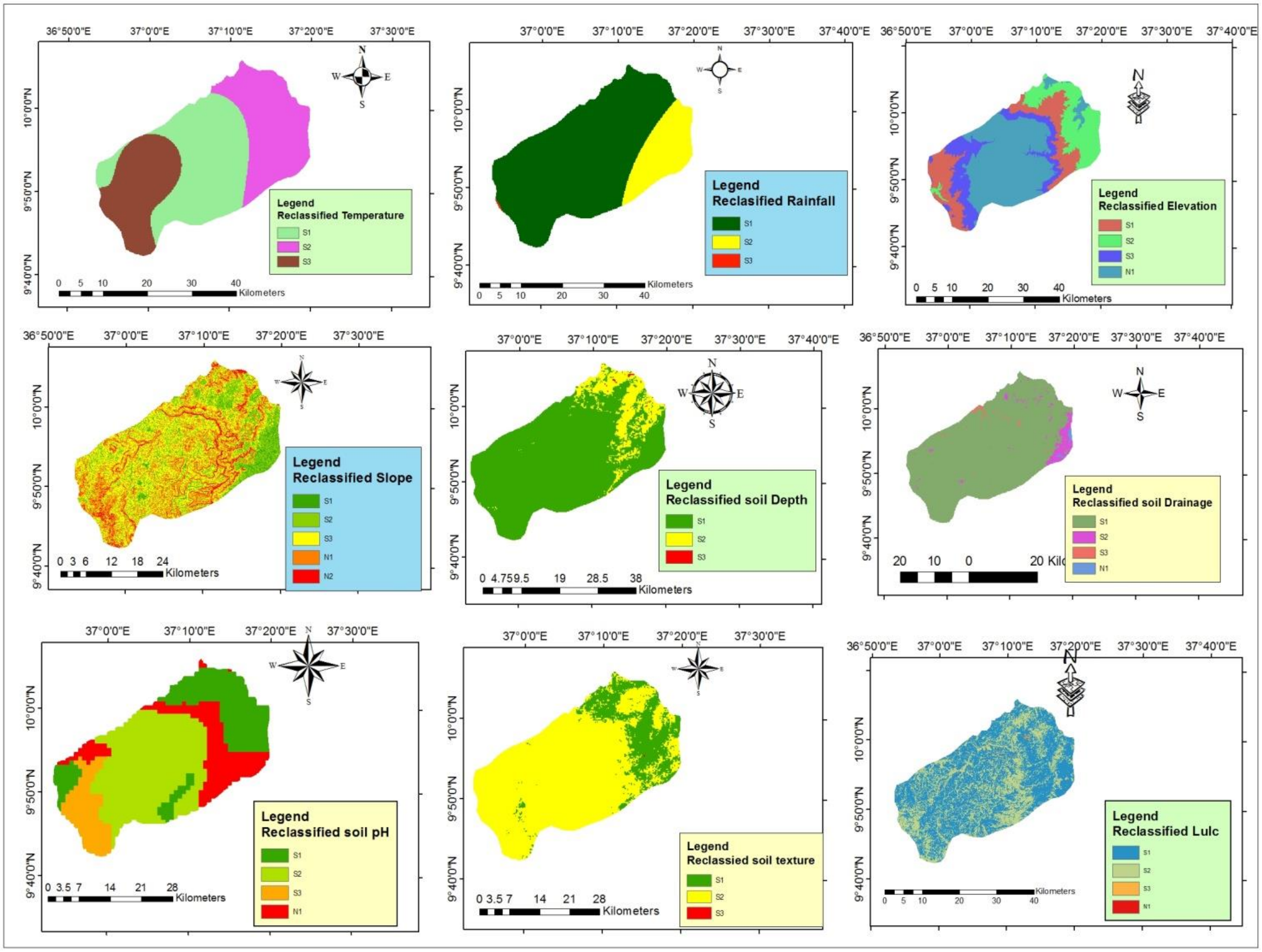


Figure 4.19: Overall reclassified parameters maps

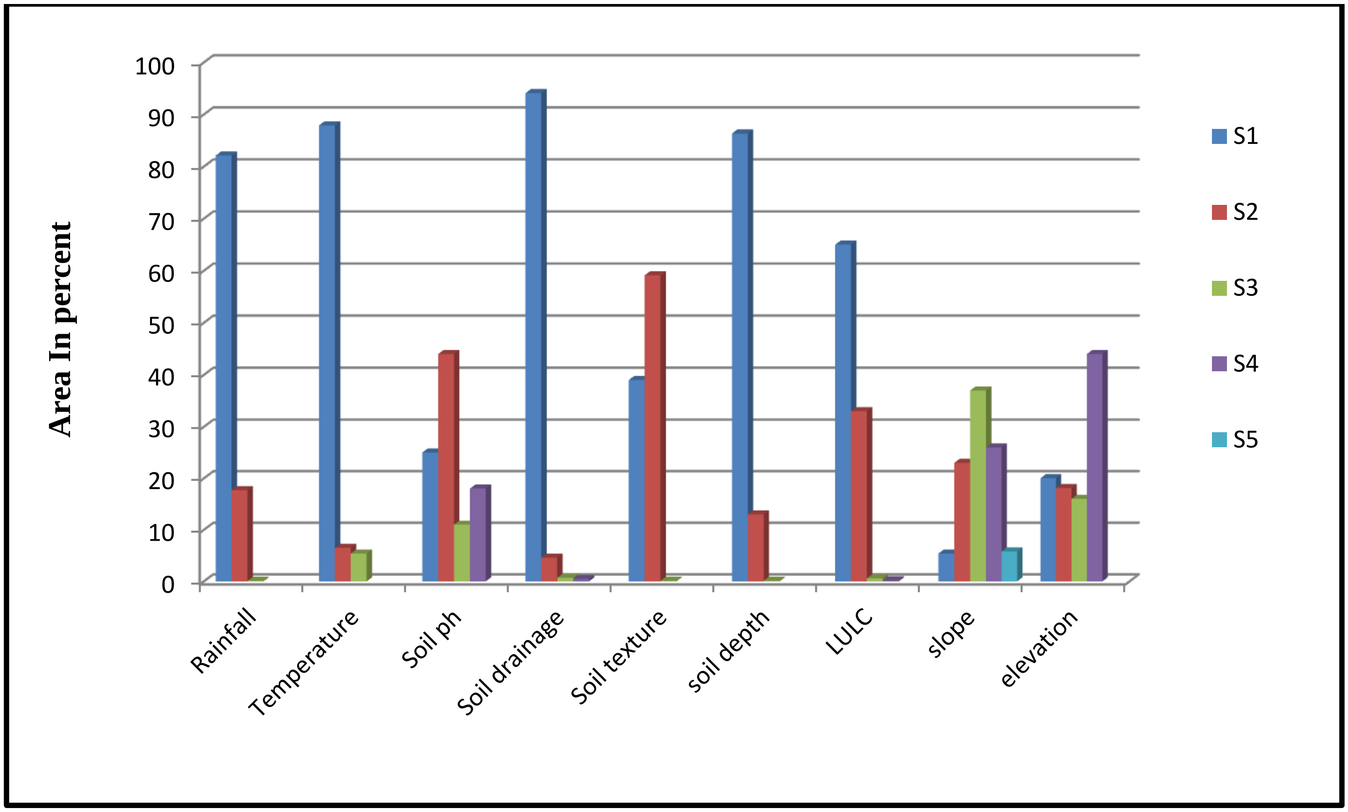
After reclassifying all parameters which were used for coffee Arabica production the following table 4.15 provides a comparative analysis of these parameters based on their suitability criteria.

Table 4.22:Overall Land Suitability class for coffee Arabica production based on 9 parameters (% Area)

	The area of Suitability class in %				
Criteria	**S1 %**	**S2 %**	**S3%**	**N1 %**	**N2 %**
Rainfall	82.12	17.7	0.1		
Temperature	87.9	6.5	5.4		

Soil pH	25	44	11	18	
Soil drainage	94.1	4.6	0.7	0.46	
Soil texture	39	59.1	0.11		
soil depth	86.34	13	0.14		
LULC	65	33	0.6	0.2	
slope	5.4	23	37	26	5.8
Elevation	20	18.1	16	44	

From the table above large area was categorized under highly suitable and moderately suitable for coffee Arabica production with respect to all factors. From the total area 82% is high suitable for coffee production with respect to rainfall. From the total area of the study area 17.7% and 0.1% is moderately and marginally suitable for coffee cultivation respectively with respect to rainfall. From the total area 87.9%, 6.5%and 5.4% were highly, moderately and marginally suitable for coffee production respectively with respect to temperature. With respect to soil pH, 25%, 44%, 11% and 18% of the total area is highly, moderately, marginally and not suitable for coffee Arabica production. From the total area of the study area, 65%, 33%, 0.6%, 0.2% is highly, moderately, marginally and not suitable for coffee Arabica production with respect to LULC respectively. From the total area of the study area 5.4%,23%,37%,26% and 5.8% were highly, moderately, marginally, not suitable and permanently not suitable for coffee Arabica production with respect to slope respectively. From the total area of the study area, 20%, 18%, 16% and 44% were highly, moderately, marginally and not suitable respectively for coffee Arabica Production with respect to Elevation .For better understanding it can be expressed in Graph 4.1.



Graph 4.1: Overall Land Suitability for coffee Arabica cultivation based on 9 factors (area %)

4.3. Determining Criterion Weights

All the nine factors, which were selected for the evaluation of Land suitability for coffee Arabica production in the study area, were weighted using pair wise comparison method. This comparison matrix was filled decided with the expert participation of natural resource in Jardega Jarte district, coffee expert and depending on (Frankline *et al.*, 2018). After the Pairwise comparison matrices were filled, the weight module was used to identify consistency ratio and develop the best fit weights. The consistency ratio (CR) computed and the result is 0.08, which was accepted able for weighting the factors to assess the land suitability of coffee Arabica in the study area. The Pairwise weight matrix compression result was as shown in table 4.16.

Table 4.23: Pairwise weight matrix for nine factors used in the study area

Factor	Temperature	Rainfall	LULC	Elevation	Slope	Soil depth	Soil Drainage	Soil pH	Soil texture
Temperature	**1**	2	3	3	5	3	3	5	5
Rainfall	1/2	**1**	2	3	5	3	3	3	5
LULC	1/3	1/2	**1**	3	3	3	2	2	3
Elevation	1/3	1/3	1/3	**1**	2	3	3	3	2
Slope	1/5	1/5	1/3	1/2	**1**	3	3	2	2
Soil depth	1/3	1/3	1/3	1/3	1/3	**1**	2	2	3
Soil Drainage	1/3	1/3	1/2	1/3	1/3	1/2	**1**	2	2
Soil pH	1/5	1/3	1/2	1/3	1/2	1/2	1/2	**1**	2
Soil texture	1/5	1/5	1/3	1/2	1/2	1/3	1/2	1/2	**1**
Total	**3.42**	**5.22**	**8.26**	**11.96**	**17.66**	**17.33**	**18**	**20.5**	**25**

To determine the weight of each factor map, normalization process is needed. To normalize the above pairwise matrix value (Table 4.16), each cell value is divided by its column total. To get the weight of each class, the mean value of the row calculated.

Table 4.17: Normalization result

Factors	Temperature	Rainfall	LULC	Elevation	slope	Soil Depth	Soil Drainage	Soil pH	Soil texture	Weights (%)
Temperature	0.29	0.38	0.24	0.2	0.17	0.166	0.28	0.25	0.36	26
Rainfall	0.146	0.19	0.14	0.2	0.17	0.166	0.28	0.25	0.24	20
LULC	0.096	0.095	0.097	0.12	0.17	0.11	0.169	0.25	0.12	14
Elevation	0.096	0.063	0.14	0.08	0.17	0.16	0.11	0.083	0.036	10
Slope	0.058	0.038	0.097	0.08	0.17	0.166	0.056	0.0418	0.036	8
Soil depth	0.096	0.063	0.097	0.12	0.057	0.11	0.018	0.041	0.039	7
Soil Drainage	0.096	0.063	0.097	0.08	0.028	0.055	0.01	0.025	0.06	6
Soil pH	0.058	0.063	0.048	0.08	0.028	0.027	0.028	0.027	0.06	5
Soil texture	0.058	0.038	0.024	0.04	0.019	0.027	0.028	0.041	0.039	4

Maximum eigenvector = 9.962695, n= 9, CI= 0.1203, CR= 0.082 which is less than 0.1 (acceptable).

The percentage influence of temperature was asigned as 26% of the total layers of the study area maps. The highest weight was given to temperature. This is the same with research done by Rono *et al.* (2018) who give highest weight to temperature. This is because of temperature is the most limiting factor in the identification of land suitability analysis for coffee cultivation. Rainfall was assigned the percentage influence of 20%. It was the second most limiting factor in identification of land suitability analysis for coffee Arabica cultivation .The Land use/cover map assigned 14%. Elevation and slope were assigned 10% and 8% percentage influence respectively. Soil depth ,Soil drainage, pH and texture were assigned the percentage influence of 7%, 6%, 5% and 4% respectivily. Table 4.17 shows the weight given for each cerateria.

4.3.1. Suitability Model Used

Using a model builder from ArcGIS toolbox, a suitability analysis model was designed and used in processing the suitability map. The model which generated the preliminary suitability map was as shown in Figure 4.20

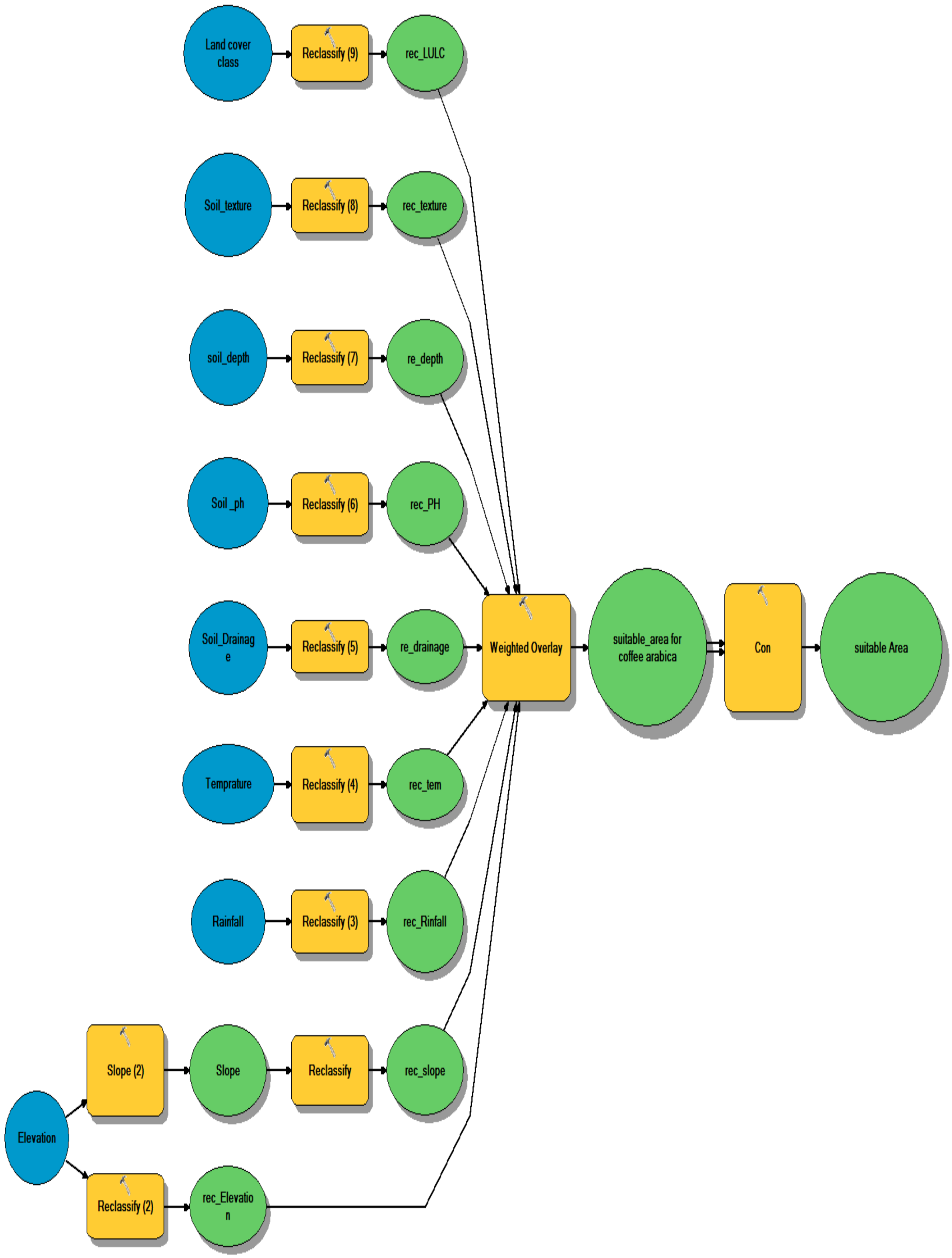


Figure 4.20: Suitability analysis model used

4.4. Weighted Overlay Analysis

After reclassifying each factor to common scale or suitable class and Assigning criterion weights each factor were added to weighted overlay tool. The added criteria (factors) were rated from 1 to 5 (most suitable to least suitable) to its suitability class range in ranking method. The area covered by water body was restricted from the use of suitability for coffee Arabica production. The final land suitability map coffee Arabica in the study area was developed. The final output of weighted overlay tool was named as map coffee Arabica production .The map of land suitable for coffee Arabica was further analyzed and queried.

The values which were obtained from the result were classified in to three suitability classes. These were very suitable, moderately suitable and marginally suitable .The final map of the study area was revealed that the woreda has land that is suitable for coffee Arabica production. From the suitability range of highly suitable to marginally suitable, the total land of the study area 8979.47 hac (8.4%) was very suitable, 97347.98ha (90.5%) moderately suitable and 1193.39 hac (1.1%) marginally suitable for coffee Arabica cultivation. Table 4.18 shows that land suitability of the study area for coffee Arabica production.

Table 4.24:Land suitability of the study area for coffee Arabica production

No.	Suitability class	Area (hectare)	Area in %
1	Highly suitable	8979.47	8.4
2	Moderately suitable	97347.98	90.5
3	Marginally suitable	1193.39	1.1
	Total area	107520.84	100

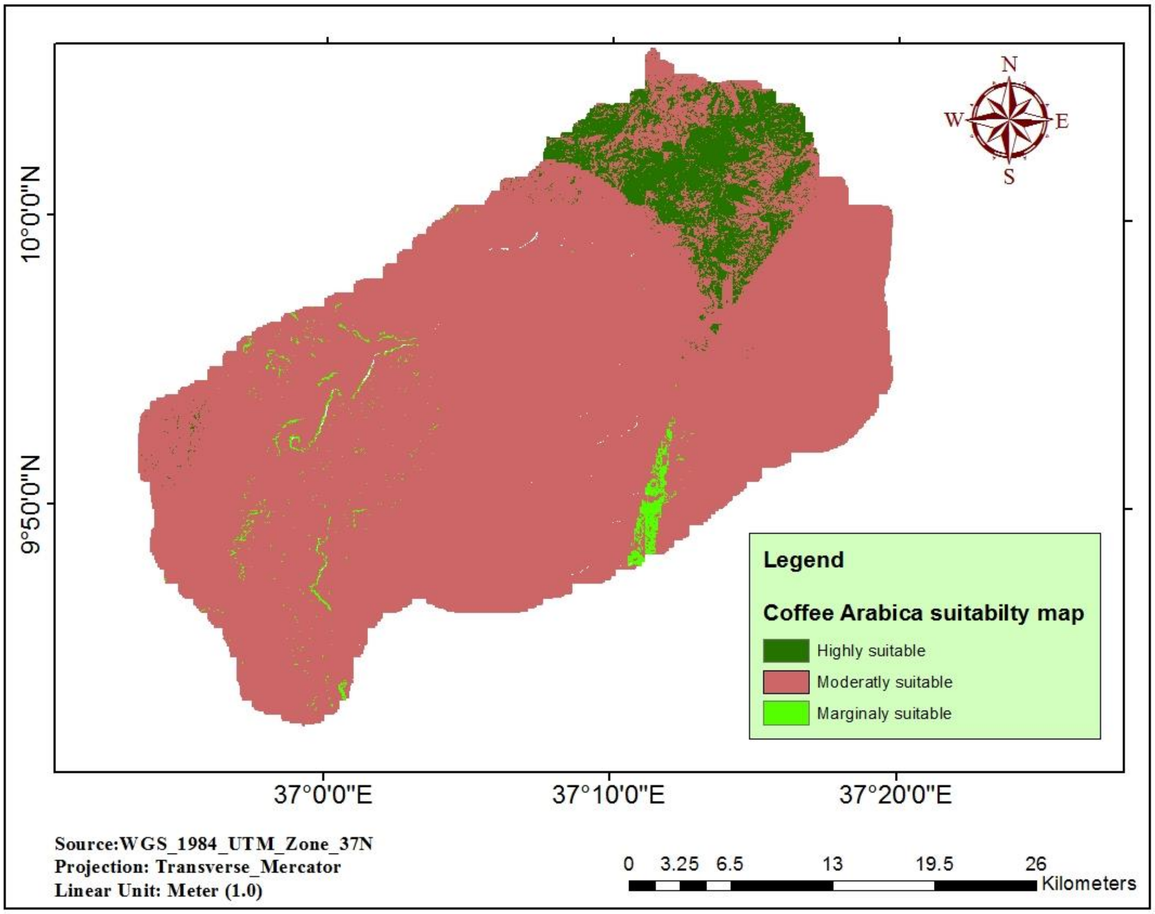


Figure 4.21: Coffee Arabica suitability map of the study area

From the Graph above 90.5% from the total area is moderately suitable for coffee Arabica production. 8.4% and 1.1% of the total area is highly and marginally suitable respectively for coffee Arabica Production.

The raster format map was converted to polygon in conversion tool of raster to polygon. The vector format potential coffee Arabica area map was used to select and query the results of map in the *kebeles* context with the use of spatial Analysis Tool. Figure 4.22 shows that the converted raster map to polygon vector of coffee suitability in the district.

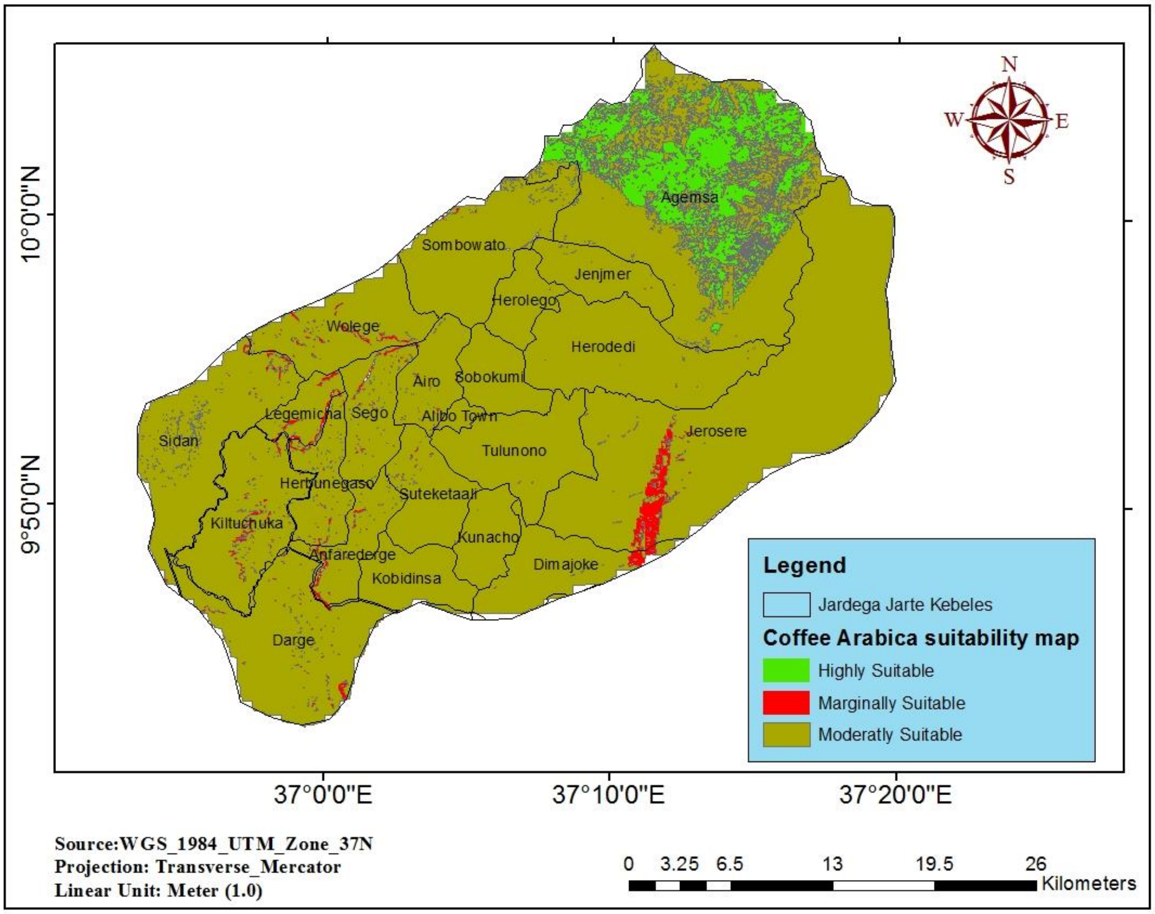


Figure 4.22:Coffee Arabica suitability map in Jardega Jarte Kebeles

From the result of coffee Arabica suitability map in the study area, 8979.47 hac (8.4 %) was highly suitable. From highly suitable area, 98.99% is found in Agemsa kebele. The other highly suitable area is found in Sidan, Jero Sire, Sombo Wato, Haro Dadi *kebeles.* Table 4 shows highly suitable kebeles for coffee Arabica production in Jardega Jarte district.

Table 4.25:Highly suitable area coverage of coffee Arabica in the study area

No	Kebele Name	Area(hectare)	Area in %	Geographically located
1	Agemsa	8812.063	98.99	Northern
2	Sidan	33.6552	0.38	western
3	Jero Sire	9.44	0.11	South eastern
4	Sombo Wato	34.93	0.39	North western
5	Haro Dadi	6.44	0.072	Around central

6	Janjimar	5.07	0.056	Northern
	Grand total	8901.5982	**100**	

From the result of land suitability analysis map of coffee Arabica production, 97347.98 hectare (90.5 %) was moderately suitable for coffee Arabica cultivation. The largest moderately suitable area (21.9%) was found in Jaro Sire kebele. The other moderately suitable kebeles were largely located in Agemsa, Sire, Haro Dedi, Tulu Nono, Darge, Sute Ketali, Sombo Wato, Lega Micha *kebeles*. Table 4.20 shows moderately suitable kebeles for coffee Arabica production in Jardega Jarte District.

Table 4.26:Moderately suitable area coverage of coffee Arabica in the study area

No	Kebele Name	Area(hectare)	Area in %	Geographically located
1	Anfare Derge	2878.82	3.03	Southern
2	Airo	2900	3.05	Central
3	Hero Lego	1758.55	1.8	North Western
4	Agemsa	12998.3244	13.6	North Western
5	Kiltu Cheka	5986.92	6.3	Southern Western
6	Kobidinsa	2912.54	3.06	Southern
7	Kunacho	2800.89	2.95	Southern
8	Sombo Kumi	2767.64	2.91	Central
9	Haro Dedi	7069.15	7.4	Central
10	Jaro Sire	20857.3	21.9	Eastern
11	Tulu Nono	4723.49	4.97	Central
12	Sombo Wato	4755.65	5	North Western
13	Sute Ketali	3803.35	4	Central
14	Sego	3088	3.3	Central
15	Herbu Nagaso	2859.79	3	central
16	Darge	4686.216	5	Southern
17	Dima Joke	3799.08	4	South Eastern
18	Lega Micha	1888.6	1.98	South western
19	Jenjimar	2411.11	2.5	Northern

Grand total	94945.4204

From the result of land suitability analysis map of coffee Arabica production, 1193.39 hac (1.1 %) was marginally suitable for coffee Arabica cultivation in the study area. From marginally suitable area, 53% was located in Jero Sire kebele. The other marginally suitable kebeles were located in Dima Joke, Kiltu Cheka, Lega Micha, Sego kebeles. Table 4.21 shows marginally suitable kebeles for coffee Arabica production in Jardega Jarte district.

Table 4.27:Marginally suitable area coverage of coffee Arabica in the study area

No	Kebele Name	Area(hectare)	Area in %	Geographically located
1	Kiltu Cheka	82.491	7.302166	South Western
2	Lega Micha	85.92	7.605704	South Western
3	Dima Joke	105.568	9.34496	South Eastern
4	Darge	38.19	3.380608	Southern
5	Herbu Negaso	43.17	3.821441	Central
6	Sego	49.392	4.372217	Central
7	Sute Katali	6.74	0.59663	Central
8	Sombo Wato	0.123	0.010888	North Western
9	Jero Sire	601.16	53.21514	Eastern
10	Anfare Derge	68.472	6.061194	Southern
11	Sidan	39.347	3.483026	South Western
12	Airo	8.1825	0.724321	Central
13	Jenjimar	0.923	0.081705	Northern
Grand total		1129.679	100	

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

This study was primarily focused on the identification of the suitable site for coffee Arabica production in the Jardega Jarte district. The parameters used for land suitability analysis were topography (elevation, slope), climate (temperature and rainfall), soil (texture, drainage, depth and Soil pH) and LULC. Geographical Information System (GIS), Remote Sensing application and Multi-Criteria Decision making methods have been used to interrogate and verify the conditions which favor growing of coffee in Jardega Jarte District.

Land suitability analyses performed by using the AHP method through assigning different weights to all parameters. The parameters were placed in well-defined hierarchy after passing through hit and trial method and also incorporated with expert knowledge from various discipline and literature review. On the basis of all these factors suitability maps were generated base on FAO guideline. In this model all required parameters work together and according to their suitability ratios, highly, moderately and marginally suitable areas were identified for coffee Arabica production. This finding indicates that the study area has a potential for coffee Arabica cultivation.

The results revealed that, 8.4%, 90.5%, 1.1% of the total land area is highly, moderately and marginally suitable for coffee Arabica production. Hence, the suitability of land classification analysis assured that more area of land is available which is suitable for coffee Arabica cultivation. The higher potential area is located in northern part of the study area and small amount western part of study area *kebeles* of Jarte Jardega woreda. This is because most of the physical land resources accessibility was suitable for coffee Arabica cultivation. The north-eastern part, central part, south eastern; north western part of the study area is moderately suitable for coffee Arabica cultivation. Along the southern, eastern and along western part of the study area the land is marginally suitable for coffee Arabica production.

5.2. Recommendation

- Land suitability analysis should be considered as a necessity in any agricultural venture. Hence, Ethiopia Agricultural research institute in collaboration with other agricultural research institute should encourage this scientific approach to avoid loss generating agricultural activities. This is because farmers avoid unnecessary losses before they engage in any farming activity.
- According to the finding of this research work, potential areas of coffee Arabica production were fairly distributed across the woreda. So that, it should be encouraged in the study area to product coffee Arabica production so that farmers may get better income.
- This study report can be used as an initial for developing and implementing an optimum physical land use planning for proper allocation of the land for the major cash crops in the study area. Hence, land use planning office of the study area should have to consider coffee Arabica and give priority to it because, it is important crop in the national economy of Ethiopia .
- The final land suitability for coffee Arabica map of Jardega Jarte is good if it is used by the *woreda* Agricultural Office to give awareness to rural farmers to produce coffee Arabica in the study area.
- Land suitability for coffee Arabica was assessed by using criteria such as soil, topography, climate, and LULC data. In the future, further studies should be conducted by considering socio-economic criteria factors to get sound and reliable result.

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APPENDIX

The Ground Control Points for LULC classification

Jardega Jarte Woreda major LULC Location GPS Point Data's.

FID	Easting	Northing	Remark
1	289418	1098830	Forest
2	289449	1098778	Forest
3	289979	1098707	Forest
4	289909	1099006	Forest
5	289716	1105102	Forest
6	288500	1099957	Forest
7	287810	1099400	Forest
8	287212	1098438	Forest
9	286576	1098058	Forest
10	286450	1097022	Forest
11	286676	1097049	Forest
12	286764	1097149	Forest
13	286842	1097105	Forest
14	286974	1097260	Forest
15	286889	1097260	Forest
16	287157	1097510	Forest
17	287333	1097549	Forest
18	287478	1097602	Forest
19	302446	1101681	Forest
20	302378	1101844	Forest
21	302353	1101924	Forest
22	302348	1102018	Forest
23	302319	1102190	Forest
24	302179	1102240	Forest
25	302002	1102328	Forest
26	301940	1102389	Forest

27	301884	1102291	Forest
28	301879	1102239	Forest
29	301919	1102095	Forest
30	301787	1101907	Forest
31	301741	1101844	Agricultural land
32	301683	1101822	Agricultural land
33	301717	1101777	Agricultural land
34	301728	1101756	Agricultural land
35	301758	1101747	Agricultural land
36	290679	1102418	Agricultural land
37	300954	1103844	Agricultural land
38	299971	1104238	Agricultural land
39	297857	1102664	Agricultural land
40	297316	1104434	Agricultural land
41	297808	1102713	Agricultural land
42	289646	1104680	Agricultural land
43	289499	1104877	Agricultural land
44	302626	1085555	Agricultural land
45	303560	1088544	Agricultural land
46	299676	1093264	Agricultural land
47	297070	1090019	Agricultural land
48	296333	1082497	Agricultural land
49	290531	1080186	Agricultural land
50	294022	1086135	Agricultural land
51	294661	1085053	Agricultural land
52	293973	1083972	Agricultural land
53	284828	1083873	Agricultural land
54	284828	1085004	Agricultural land
55	290138	1089331	Agricultural land
56	289548	1090363	Agricultural land
57	288958	1092133	Agricultural land

58	288565	1092871	Agricultural land
59	288024	1095378	Agricultural land
60	283648	1093510	Agricultural land
61	293116	1102121	Agricultural land
62	299687	1091021	Agricultural land
63	284695	1091053	Agricultural land
64	301664	1105120	Agricultural land
65	283004	1080663	Agricultural land
66	304203	1106887	Grass land
67	305097	1106185	Grass land
68	307617	1111991	Grass land
69	308574	1114447	Grass land
70	300312	1113617	Grass land
71	306660	1101050	Grass land
72	315336	1100660	Grass land
73	304363	1095142	Grass land
74	289345	1107965	Grass land
75	297511	1088549	Grass land
76	287419	1090718	Grass land
77	270021	1089825	Grass land
78	277326	1093812	Grass land
79	279846	1097735	Grass land
80	297537	1088612	Grass land
81	301747	1118153	Grass land
82	307553	1112029	Grass land
83	298781	1105637	Water body
84	296197	1105700	Water body
85	294022	1104584	Water body
86	294723	1096896	Water body
87	300497	1092517	Water body
88	292905	1085359	Water body

89	294819	1097991	Water body
90	283616	1096316	Water body
91	292548	1100335	Water body
92	298066	1099410	Water body
93	297014	1093158	Water body
94	298577	1091659	Water body
95	289422	1093238	Settlement
96	293862	1101802	Settlement
97	294213	1096986	Settlement
98	290449	1098070	Settlement
99	295712	1094242	Settlement
100	297148	1102335	Settlement
101	289384	1093445	Settlement
102	295699	1103971	Settlement