ADDIS ABABA UNIVERSITY

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Application of GIS and Remote Sensing for coffee growing Land Suitability Analysis: the Case of Guraferda District, South west Ethiopia

A Thesis Submitted to the School of Graduate Studies in Partial Fulfillment of the Requirements for the Award of Masters of Art Degree in GIS, Remote Sensing and Digital Cartography.

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DECLARATION

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This is to certify that the thesis prepared by Amare Melku entitled as "Application of GIS and Remote Sensing for coffee growing Land Suitability Analysis: The Case of Guraferda District, South West Ethiopia" is submitted in partial fulfillment of the requirements for the Degree of Master of Art in GIS, Remote Sensing and Digital Cartography compiles with the regulations of the university and meets the accepted standards with respect to originality and quality.

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List of Acronyms

AHP	Analytic Hierarchy Process
AIM	Aspiration-level Interactive Method
BCEC	Brazil Coffee Exporters Council
CBK	Coffee Board of Kenya
CRF	Coffee Research Foundation
CSA	Central Statistical Agency
DEM	Digital Elevation Model
EATA	Ethiopian Agricultural Transformation Agency
ECFF	Environment and Coffee Forest Forum
ECTDA	Ethiopian Coffee and Tea Development Authority
GII	Geospatial Information Institute
ERDAS	Earth Resource Data Analysis
ESRI	Environmental Systems Research Institute
FAO	Food and Agriculture Organization of the United Nations
FNC	Federation of Coffee Growers
GAIN	Global Agricultural Information Network
GCS	Geographic Coordinate system
GDP	Gross Domestic Product
GIS	Geographic Information Systems
GPS	Global Positioning System
IT	Information Technology
LSA	Land Suitability Analysis
LULC	Land Use Land Cover

LUTs	Land Utilization Types
M.A.S.L	Mean Average Sea Level
MADM	Multiple Attribute Decision Making
MCA	Multi-Criteria Analysis
MCDM	Multi Criteria Decision Making
MCDMA	Multi-Criteria Decision Making Analysis
MCE	Multi-Criteria Evaluation
MDS	Multi-Dimensional Scaling
MODM	Multiple Objective Decision Making
RS	Remote Sensing
SNNPR	South Nation, Nationalities and Peoples Region
UET	Ultimate Environmental Threshold
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
VCRA	Vietnams Coffee Report Association
WGS	World Geodetic System
WOA	Weighted Overlay Analysis

Abstract

Land suitability analysis is a prerequisite to achieve optimum utilization of the available land resources for sustainable agricultural production. One of the most important and urgent problems in the study area were to identify the best place of coffee growing area. In Guraferda district, coffee is the most important cash crop but the production is very low due to misuse of land resources. The aim of this study was to develop a suitability map for coffee growing areas based on physical and climatic factors of production using geospatial Technique. This study is intended to determine suitable land for coffee cultivation in Guraferda District, South west Ethiopia region, using multi-criteria decision schemes through GIS and Remotely Sensed imagery processing. It covers a total area of about 2565.42 km^2. Relevant biophysical variables of land use land cover, soil, climatic, and topography were considered for suitability analysis. All data were stored in ArcGIS 10.7 environment and the factor maps were generated. For Multi Criteria Evaluation (MCE), Pair wise Comparison Matrix known as Analytical Hierarchy Process (AHP) was applied and the suitable areas for coffee growing land were identified. To generate present land use/cover map, landsat 2020 satellite image was classified using ERDAS Imagine 2015 by means of supervised classification. The satellite image and DEM data were obtained from Ethiopian geospatial institute. In addition to these; the meteorological data such as annual rainfall and temperature also obtained from the Ethiopian Meteorological Agency. Next to this, the soil data that incorporated the soil type, texture, PH and drainage were acquired from Ethiopian Agricultural Transformation Agency. Reclassification and Weight overlay analysis was applied to classify the study area into five coffee suitable zone classes. Accordingly the result indicated that 57.19% the study area is determined as Highly Suitable (HS), 39.51% of the study area also determined as moderately Suitable (MS) and the remaining 3.3 % of the district analyzed as low suitable for coffee cultivation. This research provided information at local level that could be used by coffee farmers, investors and coffee unions to select coffee farming land, growing patterns and suitability and governments give attention best sites for coffee growing areas to maximize the exporting earning dollars.

Keywords: *Suitability Analysis, coffee cultivation, AHP, Weighted overlay analysis, Multi-Criteria Decision Making Approach.*

CHAPTER ONE

1. INTRODUCTION

1.1. GENERAL BACKGROUND

The word coffee drives from Kaffa, the name of a place where coffee was first found in the high-lands of south-western Ethiopia, Ethiopia is the birthplace of Arabica coffee and produces mostly Arabica coffee. It has a wide range of coffee and a number of roots. Due to the geographical (altitude, soil, temperature, precipitation, topography, ecology), genotypical and cultural variety in the region, Ethiopian coffee is rich with original flavor and aroma. Coffee has been rising in southwestern forests in Ethiopia for thousands of years (Melkamu, 2015).

Ethiopia has huge potential to increase coffee production as it is endowed with suitable elevation, temperature, and soil fertility, indigenous quality planting materials, and sufficient rainfall in coffee growing belts of the country. Coffee is a shade loving tree that grows well under the large indigenous trees such as the *Cordia Abyssinica* and the Acacia species. Coffee is mainly grown in two regions of the country namely Oromia and Southern Nations, Nationalities and People Regions (Global Agricultural Information Network report, 2013).

Coffee is the main export of cash crop commodity to the Ethiopian economy; it generates billion dollars every year. The need to increase coffee production countrywide has forced the Central Government to find out ways and means of expanding the areas where the cash crop can be planted and empowerment of coffee farmers: To increase the exchange and the world market value. But investors and small holder Farmers have embraced the practice and hence resorting to clearing coffee bushes to have space for other crops like maize and Inset. In some areas this does not means that coffee is major source of income. Since coffee is being produced in some areas, this land suitability analysis have two major aims 1) to give geographical information clue where coffee suitable farming areas, 2) to help in finding out areas where coffee growing can be done Using GIS, Remote Sensing and Multi-Criteria Evaluation (MCE) methods could done accurately locate areas where coffee can grow well.

1.2. Statement of the Problem

Ethiopia is one of the countries with a large population and food insecurity in developing Africa. Agriculture is the pillar and cornerstone of the country's economy, with the largest proportion of its population employed. The country has got immense potential for agricultural crop production due to its vast arable land, water resource and wide range of climate that can support varieties of crops. Besides this, the problem of selecting the correct land for cultivation of a certain agricultural product is a long standing and mainly empirical issue. The classification of land into different capability classes is useful in some soil, climate, topographic and other attributes of land that can be suitable for specific crops and unsuitable for others; therefore, precision of land utilization types is necessary.

Although the issue of agricultural productivity and food security is widely studied in various parts of the world, the impact of unwise land use and the absence of land use according to potential suitability is still a serious problem, especially in developing countries. Ethiopia currently face various problems resulted from unwise use of land resource while the degree of the problem is not clearly identified. As a result, still there is lack of information on the status and classification of land use suitability.

Coffee has economical, environmental as well as social significance to the country (Global Agricultural Information Network report, 2013) Nevertheless, the suitability has not been studied. This is the main reason for identifying coffee growing potential areas. Therefore, in order to ensure the optimum production of coffee cash crops one has to grow the crops, where they suit best and for which first and the foremost requirement is to carry out land suitability analysis. Land suitability analysis is more than just a Geographical Information System (GIS) based procedure; it also can be used to locate the most suitable location for a project (Birch 2009). So, Suitability is a measure of how well a land unit's characteristics meet the criteria of a specific type of land use. Land suitability analysis has to be carried out in such a way that local needs and conditions are reflected well in the final decisions. Hence, this study aimed to study the suitability of the study areas for coffee growing with a view to determining physical land suitability for coffee cultivation using a multi-criteria decision with Analytical Hierarchical Process (AHP) and GIS approach and compare the results of the study area. The best favorable farming areas were determined within the integration of geographic information system (GIS), weighted over lay analysis (WOA) analysis, and remote sensing techniques. Several parameters were collected from various sources in vector and raster GIS formats, and then, used within the GIS-based WOA analysis to select suitable area.

The research was carried out in Guraferda district, South West Ethiopia. Land suitability analysis is needed for various purposes in Guraferda District. There were three main reasons for selection Guraferda district, 1) coffee and honey are the major source of income but the production is very low. 2) Majority of the study area is covered by dense forest and very depth fertile soil, so farmers and investors deforest the dense forest to cultivate cereals like maze, rice and sorghum this have negative impact to the environment. 3) Even if the coffee land suitability was not studied, coffee cultivation have positive impact to the environment, it needs forest. So, the researcher had done the land suitability of coffee growing area in the district.

1.3. Objectives

1.3.1. General objectives

The general objective of this research was to analyze land suitability of coffee farming area of the study with the help of Geospatial Techniques.

1.3.2.Specific objectives

The specific objectives were to:

- Identify the required evaluation criteria to assess the coffee growing- land suitability model?
- Analyze the suitability of coffee growing areas in Guraferda district using Geospatial Techniques.
- Produce thematic maps of coffee farming suitable areas in the study area.

1.4. Research questions

Present study aims at answering the following Questions framed in order to achieve the above mentioned objectives:

1) What are the required evaluation criteria to assess the coffee growing- land suitability model?
2) How do multi-criteria evaluations techniques and weighted over lay analysis helps to evaluate coffee suitability land?
3) Produce maps showing suitable land for coffee farms in the study area?

1.5. Scope of the study

This study is limited to Guraferda district in SNNPR, South West Region of Ethiopia. It covers a total area of about 2562.42 km^2 with two municipalities and 27 rural *kebele's*. The study is only concentrated on the identification of suitable land for coffee cultivation by using multi-criteria decision approaches through GIS and remotely sensed imagery processing techniques. Moreover, this research also employed only on the following Land and climatic factors (parameter) such as; climate, topography and soil characteristics were used in the study to carry out analysis with a view of designing a land suitability model which can be used to evaluate land suitability level of the study area for coffee cultivation.

1.6. Significance of the study

The research study was expected to produce a potential coffee growing area map. The result detail map of the area can be one input for understanding the potential area, and used as data for further research work. The most important thing in this research is using multi criteria evaluation method with integrate GIS remote sensing showing the favorable areas and the government was focused on these areas in order to maximize the productions of coffee.

1.7. Limitations of the study

This study has attempted to identify potential coffee growing areas in Guraferda district, has successfully achieved its objectives. Nevertheless, security cause and the global pandemic corona virus (covid-19) with respect to national state of emergency had its impact on to move one place to the other place freely and to discuss in groups.

1.8. Thesis Structure

This research work is explained in six chapters. Chapter one dealt with general back ground, statement of the problem, research objective, research question, justifications of the study, scope of the study, and limitations of the study and thesis structure. Chapter two dealt with the theoretical and historical development of coffee cultivation, the empirical literature, land suitability theory and model, the role of GIS and remote sensing, multi criteria decision making and the physical and climatic parameters of coffee. Chapter three shows back ground of the study area, materials and methodologies, suitability frame work. Chapter four dealt spatial data processing, analysis and result were obtained. In the end, Chapter five dealt with conclusion on the present study and recommendations for the future work.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Historical Development in Coffee Cultivation

2.1.1.Origin and Distribution

All species of commercial coffee come from Africa and belong to the Coffee family. The high quality Coffee Arabica species originates from the rainforests in the southwestern highlands of Ethiopia. One hypothesis suggests that when they invaded the country in AD 500, the Ethiopians brought it to Yemen. Another hypothesis says that it was initially brought to Yemen and the Arabian Peninsula by Arab merchants, where it was cultivated and contributed to the prosperity of the Mocca seaport. This explains why Arabica coffee is associated with the name Mocca, although the prime centre of origin and diversity is on African content (Mugwe, 2014).

2.2. Coffee Cultivation Potentials and Constraints in Ethiopia

2.2.1. Coffee Growing in Ethiopia

In its wild state, Arabica coffee (*Coffea Arabica*) is a forest plant restricted to the highlands of Ethiopia and a small area in neighboring South Sudan. Coffee has been used in Ethiopia as a food and beverage for many hundreds, if not thousands, of years. Ethiopia can be seen as or considered as the biological and cultural home or habit of coffee. Its early use was no doubt restricted to gathering fruits from the wild forests, with semi-domestication possibly coming soon afterwards (ECFF, 2017).

Today, an estimated 525,000 hectares (5,250 km2) of coffee are planted in Ethiopia, although the actual area is probably in excess of 20,000 km2. Coffee makes the most important agricultural product or commodity available or provide to Ethiopia, contributing about one quarter of its total export earnings. In 2014/15 Ethiopia exported around 180,000 metric tons of coffee at a value estimated to be in excess of 800 million USD (ECFF, 2017)..

Ethiopia is Africa’s largest coffee producer and the world’s fifth largest exporter of Arabica coffee, even though yields (kg/hectare) are low compared to other producing countries. Coffee farming alone provides occupations or livelihood income for around 15 million Ethiopians (16 percent of the population), based on four million smallholder farms. For many of these farmers, coffee is their single most important source of income (ECFF, 2017).

Figure 1, Coffee cultivation in Ethiopia (Bebeka)

Ethiopia is the main storehouse of genetic diversity for Arabica coffee, and this has several key implications. For the coffee sector and consumers, the most notable of these is the broad diversity of flavor profiles exhibited by Ethiopian coffees. These profiles are associated with geographical location (which is often referred to as 'origin', in a similar way as 'terroir' is used in the wine industry) and factors associated with harvesting and processing. Included among these origins are the well-known coffees of Sidamo, Yirgacheffe, Harar, Nekemte and Limu, but there are numerous lesser-known coffee regions that have equally distinct flavor profiles. The range of flavor profiles adds a unique element to Ethiopian coffee, and makes it especially well-suited to development within the specialty coffee market (ECFF, 2017). As we'll see below, Ethiopian coffee production provides protection for biodiversity and other environmental benefits.

Figure 2, Coffee Plantation in south west Ethiopia, Keffa (Bahaland)

2.2.2. Coffee Farming Systems in Ethiopia

Ethiopian coffee is mainly grown under the shade of trees (shade or forest coffee), either within forest or forest-like environments, or in farming systems that incorporate specific shade plants – usually indigenous (native) trees, or sometimes fruit trees and other crop plants. There two main coffee production systems in Ethiopia, those are Forest (shade) coffee and sun coffee can be considered. In some areas of Ethiopia, coffee is grown with little or no shade (sun coffee). Irrigation is confined to few locations and mostly where water is easily available and can be diverted to the farm using simple means (e.g. diversion from rivers using trenches). Irrigation is mainly practiced in Amhara and Benishangul-Gumuz Regions, and the north east part of Oromia Region in the Harar coffee zone. The use of chemical inputs, such as pesticides, fungicides and artificial fertilizers is rarely practiced, and although certification is not common, Ethiopian coffee can often be considered as organic by default, and may indeed exceed the standards set for organic authorization or certification (ECFF, 2017).

Forest (shade) coffee: into two broad categories: It is possible to separate forest (shade) coffee into two major categories: forest coffee and semi-forest coffee. The forest coffee system utilizes wild coffee stands, which occur naturally throughout the forest, and the farmer undertakes minimal management and intervention. Semi-forest coffee is more intensive with increased farming management and interventions (e.g. thinning of trees, understory clearance and weed cutting, and planting of coffee seedlings).

Sun coffee farming systems are typically small and mostly fall into the coffee gardens group, which are planted at high density in a regular-sized plot. Sun coffee is typically found at higher altitudes (1700-2100 m), mostly near dwellings, and in the Harar coffee zone it is characteristic of coffee farming.

Coffee gardens are mostly planted near dwellings and vary from a few plants to around 100 plants on a plot. Usually, coffee gardens are part of a mixed cropping system and provide coffee for household, local or wider market consumption.

Agro forestry systems are typically family run, of between a quarter and one hectare, and comprise a wide variety of crops in association with indigenous (native) forest cover. Coffee is typically or mainly grown under the shade of indigenous trees, on the margins or in more open areas with other crops. Coffee is almost exclusively grown in the Sidamo region (including Yirgacheffe) within an intensively controlled agro-forestry system (ECFF, 2017).

Coffee farms/plots are dedicated to coffee growing for profit, and are typically around one to two hectares, sometimes less (a quarter hectare) or more (five hectares). The area is mostly dedicated to coffee growing or cultivation, with few other crops, or may be intercropped, as in agro forestry systems. Most coffee farms use shade, provided by tree cover, but some are situated in partial to full sun light (ECFF, 2017).

Coffee plantations are large and intensively-managed systems, mostly or mainly planted within forest (shade). There is no definitive size limit for a plantation but generally or usually they are more than ten hectares. Large commercial plantations (e.g. over 500 hectares) are uncommon and contribute less than 5% of exportable production (ECFF, 2017).

Figure 3; Harvested coffee around Bebeka, Ethiopia

2.2.3. Coffee Producing Regions and Areas in Ethiopia

Within Ethiopia, coffee is produced or cultivated within specific or particular agro-ecological zones over numerous political divisions. Most coffee is grown or cultivated in areas of humid (moist) evergreen forest. This type of rainforest grows at 650-2600 m above sea level, with coffee primarily or mainly confined to 1200-2100 m altitudes. These forests are cool-tropical, distinctly seasonal, and mostly comprise evergreen trees and shrubs, with a high diversity of other plants and associated fauna. In some highland areas, mostly or commonly at the higher range for Arabica coffee (1900–2100 m), coffee farming is undertaken in a drier type of vegetation, dominated by evergreen trees or shrubs, and common native coniferous species, particularly in the Harar coffee zone (ECFF, 2017).

The main coffee growing or cultivation areas are found within Oromia Region and Southern Nations, Nationalities, and Peoples' Region (SNNPR), with modest production in Amhara Region and minor or limited output in Benishangul-Gumuz Region (ECTDA report, 2018).

Table 1: Main coffee growing areas of Ethiopia:

Position in Ethiopia	Main coffee growing areas	Coffee area	Region (administrative
West of Rift Valley	North	Amhara	Amhara
		Benishangul-Gumuz	Benishangul-Gumuz
	South West	Wellega	Oromia
		Illubabor	Oromia
		Jimma-Limu	Oromia
		Tepi	SNNPR and Gambela
		Kaffa	SNNPR
		Bench-Maji	SNNPR
Rift Valley	Rift	Rift North	SNNPR and Oromia
		Rift South	SNNPR
East of Rift Valley	South East	Sidamo (including Yirgacheffe)	SNNPR and Oromia
		Bale	Oromia
		Central Eastern Highlands	Oromia
	Harar	Arsi	Oromia
		West Hararge	Oromia
		East Hararge	Oromia

2.2.4. Coffee Consumption in Ethiopia

Ethiopia is unique or usual among the world's coffee producing countries in that around 50% of the coffee it produces stays within the domestic market, for consumption by Ethiopians. Drinking is not only part of daily life; it is also profoundly or deeply rooted in the history or culture of Ethiopia. Apart from the well-known Ethiopian coffee ceremony, coffee is used at major events such as marriage and birth, regionally-specific celebrations, and as a medium to build and sustain relationships between family, friends and community (ECFF, 2017).

The advent or development of small roadside stalls selling coffee to passers-by customers is an important new development in Ethiopian major cities regarding coffee consumption. In a traditional way or manner, the small roadside stalls serve coffee. In the major cities of Ethiopia, they have emerged and flourished, increasing very popular coffee consumers.

Figure 4: Coffee ceremony in Ethiopia.

Factors Causing Low Coffee Production in Ethiopia

1. Khat (Cata edulis), especially in the eastern part of the country in the Hararge area, is increasingly competing with coffee for farmland. A fresh leaf has been chewed as a stimulant in many towns in Ethiopia and neighboring nations. Khat is growing in demand in major Ethiopian cities and countries such as Somalia, Kenya and Yemen; Khat is imported from Ethiopia by these countries. Khat is a relatively highly resistant crop to drought, illness, and pests.
2. It is harvested three or four times a year and provides farmers with better revenue than other cash crops, including coffee. Several small-scale farmers have moved in the Hararge region from coffee production to Khat production. The fact that coffee farms have been transformed into Khat farms has offset newly planted coffee farms in other regions, leading to a very marginal increase in the overall size of the coffee field. In Ethiopian farm management systems, agronomical methods are traditional. In addition, extension services provided to smallholder farmers are inadequate or insufficient.
3. Government organization does not have a specialized institution or organizations that provide extension support for coffee production. (Alemseged, 2013).

2.3. Requirements for Coffee Growing Environment in Ethiopia

Agricultural land suitability requirements are conditions of a given land necessary or desirable for a successful and sustained practice of a defined land use type (FAO, 1996). Evaluation of agricultural requirements is a useful tool in assessing adaptability and suitability in a given area. Bio-physical requirements refer to the need for favorable climatic and soil attributes. The climatic requirement is concerned with attributes such as temperature, rainfall, length of growing period, frost hazard, drought hazard, etc. The soil requirements refers to conditions of rooting, wetness, fertility, excess salt, ease of cultivation, mechanization potential, etc. Management conditions may, however, change the relative impact of these attributes. In practice, it is very difficult if not impossible to include in any evaluation all the environmental requirements that affect the agricultural land suitability performance.

So, the potential of coffee production in Ethiopia is very high as a result of altitude, ample rainfall, optimum temperature, suitable planting material as well as fertile soil. Furthermore, the country is of particular value to the world as it is the home or the origin of coffee Arabica with best inherent quality and production potential. The total area covered by coffee is approximately 400,000 hectares, producing a total of production of roughly 250,000 tons per annum and 25 million people depend on it.

The production of coffee is greatly influenced by precipitation, temperature, topography, soil, soil texture, soil ph, soil depth, altitude or elevation, and slope.

Altitude

In Ethiopia, coffee is grown at various altitudes ranging from 550-2750 meters above sea level. However, the bulk of Coffee Arabica is produced in the Eastern, Southern and Western parts of the country with altitudes ranging between l300-1800 meters (Ministry of Agriculture, 2011).

Rainfall

The annual rainfall in the coffee growing regions of the country varies between 1500 and 2500 mm. However in the Eastern part of the country, the rainfall decreases to 1000 mm per annum where it is supplemented with irrigation. It is not only the rainfall amount which contributes to higher production, but also its distribution over eight months. Rainfall distribution in the Southern and Eastern part of the country is bimodal and the Western part is mono modal. This distribution pattern assists or allows the country to harvest coffee at different times of the year, making it possible to supply fresh coffee throughout the year (Ministry of Agriculture, 2011).

Temperature

Temperature is a key or crucial factor in coffee production, and the strongest or the greatest influences on temperature are latitude and elevation. Coffee is grown or cultivated around the world at latitudes from 24ºN to 25ºS and elevations ranging from sea level to as high as or greater than 7000 ft. Coffee Arabica grows or cultivates best in a temperate, shady environment in the forests of the Ethiopian highlands. The ideal or optimal temperature for coffee Arabica is considered to be l5c-25c. These temperatures prevail or succeed in most coffee growing areas of Ethiopia (Ministry of Agriculture, 2011).

Relative Humidity

Humidity is primarily related to rainfall and temperature in Ethiopia's coffee regions. There is a major difference in moisture between day (low percent of RH) and night (high RH percent). The amount of sun (sunshine hours) is linked to seasonality, with greater cloud cover and less sunshine in the wet season(s), and less cloud and more sun in the dry season (Ministry of Agriculture, 2011).

Soil

Coffee grows best on dense or deep, porous, well drained soils, especially those of volcanic origin. The soil is volcanic origin in the southern and western parts of the coffee growing areas of Ethiopia, with a high nutrient retention or holding capacity for clay minerals. All coffee growing regions have fertile, friable loamy soil with a depth of more than 1.5 m. The top soil is predominantly dark brownish in color with a slightly sour pH. One ironic thing about the soil is that its fertility is maintained by organic recycling. Enough organic material is added to the soil through litter fall, pruning and root residue from the perennial coffee trees (Ministry of Agriculture, 2011).

Furthermore, the small coffee farmers, who are the major producers, use organic fertilizers to supplement the natural fertility of the soil. Moreover, as close to 50% of the natural production is consumed locally, representing the highest national consumption in any producing country, local consumers insist on top quality and would never accept the use of chemical inputs. Most buyers know that the bulk of coffee produced in Ethiopian qualifies itself as organic (Ministry of Agriculture, 2011).

Slope

The coffee growing areas have undulating landscape with hill slopes and gentle slopes. This has ensured well drained and aerated soils with good Capacity which dictates the soil fertility (Ministry of Agriculture, 2011).

2.4. Land Suitability Analysis for Coffee Cultivation

2.4.1. LAND SUITABILITY ANALYSIS

Land suitability analysis is the separation of the essence or condition of the land into its component parts, based on the ability of the land to serve a specific use or purpose. High land suitability implies that the land has relatively high numbers of component parts that it requires to serve a specific use or purpose, whereas low land suitability analysis implies that the land has relatively small numbers of component parts that it needs to serve a specific use or purpose (Joseph, 2006).
Each part of the Earth's landscape has a different set of characteristics that make it more suitable for certain uses than others. The concept of land suitability for particular uses is successfully developed by the late Ian McHarg, former professor of urban design and landscape architecture at the University of Pennsylvania. The definition of land suitability can also be discussed in a more specific way through McHarg's discussion of using the land for suitability evaluation (Joseph, 2006).

The management of natural resource is a cross boundary issue that should be emphasized in all planning processes within multi-sectoral approach (administrative and geographical). Land suitability is part of land use planning and describes potential alternatives for future land use and helps to define these relationships (policies, agencies and data management) (Ignas, 2004). Land suitability is the fitness of a given type of land for a defined use (FAO, 1976). The classification and grouping of particular areas of land in terms of their suitability for specified uses is the process of land suitability assessment (FAO, 1976; 2007).

The way the people use the land is based on the available skills, knowledge, culture and experiences. The land suitability evaluation is similar to the selection of a suitable site, except that the aim is not to isolate the best alternatives, but to map the suitability index for the entire study area. Senes and Toccolini (1998) combine UET (Ultimate Environmental Threshold) method with map overlays to evaluate land suitability for development. Hall et al. (1992) cited in Malczewski (2006) also use map overlays to define a homogeneous zones, but then they apply classification techniques to assess the agricultural land suitability level of each zone. Combining GIS and MCDA is also a powerful approach to land suitability assessments (Florent et al., 2001). FAO (1985) Land suitability was analyzed based mainly on the quality of the land. The quality of land is a complex feature of land that directly affects land use (FAO, 1993). These attributes are, soil texture, soil drainage, soil PH, topography and climatic factors. Most land qualities are determined by interaction of several land characteristics, which are measurable attributes of the land. The importance of land quality is the role of evaluating and grouping land types in the sense of their fitness into orders and groups. Land suitability is generally categorized as suitable (S) and not suitable (N). Whereas S has lands that are ideal for use with good advantages, N denotes land qualities that do not allow the form of use considered or are not suitable for appropriate results (FAO, 1985). The suitability of land is essentially the future biological productivity of land (FAO, 1985). Land productivity can be determined by environmental components such as temperature, local topography (roughness, steepness, and exposure), soil type and existing vegetation. Land suitability classification is developed by considering different factors of land characteristics. The classification of the suitability of the land is calculated by taking into account different factors relating to the characteristics of the land. Based on the suitability of each land use, a weighted value ranging from 5 (inappropriate) to 1 (most suitable) is given. The weighted value of each factors were reclassified for each land use. Each parameter is given a value depending on its suitability for each land use category. The weighted value of each land characteristics factors is added and the average value of them is taken to determine the suitability of land for each land use type. The average value of them is categorized in to five suitable classes to get the final suitability for each land uses.

Table2. Suitability classes according to FAO, 1996 frame work or guide line).

Order	Class	Description
Suitable (S)	Highly Suitable (S1)	Land without significant limitations. Include the best 20%-30% of suitable land as S1.this land is not perfect but that can be hoped for.
	Moderately Suitable (S2)	Land that is clearly suitable but which has limitations that either reduces productivity or increase the inputs need to sustain productivity compared with those needed for S1 land.
	Marginally Suitable (S3)	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.
Not suitable (N)	Currently not Suitable (N1)	Land with limitations to sustained use that cannot be overcome at a current acceptable cost.
	Permanently not Suitable (N2)	Land with limitations to sustained use that cannot be overcome.

Land suitability analysis using a scientific procedure is essential to assess the potential and constraints of a given land parcel for agricultural purposes (Rossiter, 1996). In the recent years, the negative effects of land use on the climate and the environmental sustainability of agricultural production systems have become a matter of concern. The problems of declining soil fertility, stagnant yield level and unfettered soil erosion are associated with intensive agriculture in industrialized countries, while over-exploitation of natural resources and lack of inputs such as chemical fertilizers are associated with intensive farming in developing areas (Martin and Saha, 2009).

Land evaluation and crop suitability analysis using GIS and remote sensing would resolve these issues while providing better land-use options to the farmers. Therefore, it is vital to evaluate crop suitability under different systems that could be grown in a given region. GIS is an important help for decision-making in space (Carver, 1991; Pereira and Duckesstien, 1993). Developments in GIS have led to significant improvements in its capability for decision making processes in land allocation and environmental management (Jiang and Eastman, 2000). For decision-making processes based on GIS, MCE is one of the most important procedures (Malczewski, 2000).

Site /Land suitability assessment is inherently a multi-criteria problem (Mendoza, 2004).That is, study of land suitability is an issue of evaluation/decision involving many factors. According to Mendoza (2004), A site/land suitability generic model can be defined as: S = f (x1, x2... xn); where S = measure of suitability; x1, x2... xn = are the factors influencing site/land suitability. The central issue of suitability assessment is calculating the individual and cumulative effects of the different variables; x1... xn. In other words, suitability analysis usually requires an acceptable approach to be determined in order to combine these criteria.

Suitability analysis is a methodology or a set of analytical processes that use their geographic feature spatial relationships to simulate real-world conditions within a GIS to classify geographic areas that are optimally suitable for a specific land use. In order to identify geographical areas that are optimally suitable for a specific land use, the creation of criteria is essential. There can be two types of criteria: factors and constraints. Constraints are Boolean parameters that restrict the analysis to a specific geographical area (i.e. limit). Factors, on the other hand, are criteria that determine a certain level of suitability for all geographical regions (Eastman, 2006). The composite effect of physical parameters describes the degree of suitability and also helps to further categorize the land into various development classes. Moreover, the process of suitability assessment is very much dependent upon the prevalent conditions, such as pressure on land.

2.4.2. Land Suitability Analysis and Sustainable Development

From a land use planning perspective, to ensure long-term productivity and sustained land use, land use systems should be well suited to the inherent characteristics of the land. Land suitability assessment (LSA) plays an important role in this regard (Imhof et al, 2000).

Land includes the physical environment to the degree that it affects the capacity for land use, including climate, relief, soils, hydrology, and vegetation. This involves the effects of past and current human activity, e.g. sea reclamation, clearing of forest, and even negative results, e.g. soil salinity, (FAO, 1996).

Evaluation and grouping of particular areas of land in terms of their suitability for a given use is the process of classification of land capacity. The key objective of the land assessment is to estimate the intrinsic capacity of a land unit to sustain, for a long period without depreciation, the specific use of land in order to reduce socio-economic and environmental costs (FAO, 2003).

The broadly specified study of land suitability aims to determine the most suitable spatial pattern for future land use according to particular requirements, expectations or predictors of certain activities (Hopkins, 1977 and Collins et al., 2001). Land-suitability has been studied in terms of topography, soil, ground cover, and interrelationships between landform, soil, and vegetation. Land-use suitability methods enable land-use managers and planners to analyze the interactions among three types of factors: location, development action, and environmental elements (Malczewski, 2004).

The production of land suitability maps also provides an opportunity to analyze their points of view and coordinate their policies for all governmental agencies involved in land management. Furthermore, subject to the agreement of the decision makers, all the interested stakeholders (e.g. the public, construction enterprises, environmental NGOs) could also be involved in the procedure. In such a situation, land suitability maps could be universally acknowledged and decisions based on these maps would be more readily endorsed by the population at large (Florent et al., 2001).

2.4.3. Suitability model and model builder

A suitability model is generally answered by the question "Where is the best location?" whether it involves deciding the best location for a new road or pipeline, a new housing scheme, or a retail store. Sometimes, a Multi Criteria Evaluation approach is needed to address this query. Multi-criteria evaluation is the process by which a set of known project criteria are explored, ranked and/or weighted, in order to find the best outcome. For example, a commercial developer building a new retail store may take into consideration distance to major highways and any competitors' stores then combine the results with land use, population density, and consumer spending data. This information would be ranked based on its importance to the store's success. Some of the parameters may be absolutely important, and others may not be so important, but they are definitely helpful. Based on these rankings, this information could then be weighted, enabling the critical criteria to be met first. The developer would then come up with a group of locations that meet all, most, some, or none of the criteria, allowing them to choose the best location for the store.

A land suitability model was developed using GIS capabilities and modeling functions. The GIS Model Builder was used to coordinate and integrate spatial procedures to model the property's suitability. The spatial geo-environmental factors (e.g. soil, climate and topography) were integrated into the GIS environment as information layers and overlaid to produce overall land suitability assessment for a particular land utilization type. The suitability analysis for geo-environmental factors is calculated by linking the two tables in the GIS Model Builder, considering matching in ID, visual basic and integrated. All parameters or factors are reclassified into five classes to produce suitability input layers. The system is designed to achieve the suitability result directly with one click. It operates specific analysis through different steps.

The next steps classify the weighted overlaid raster into five classes based on suitability values, and then convert the classified raster into polygon feature layers. There is a grid code for of polygon that is equivalent to a suitability value. The suitability value refers to one of the five alternatives, 1, 2, 3, 4, and 5, where the value 1 is the most suitable and 5 is the least suitable.

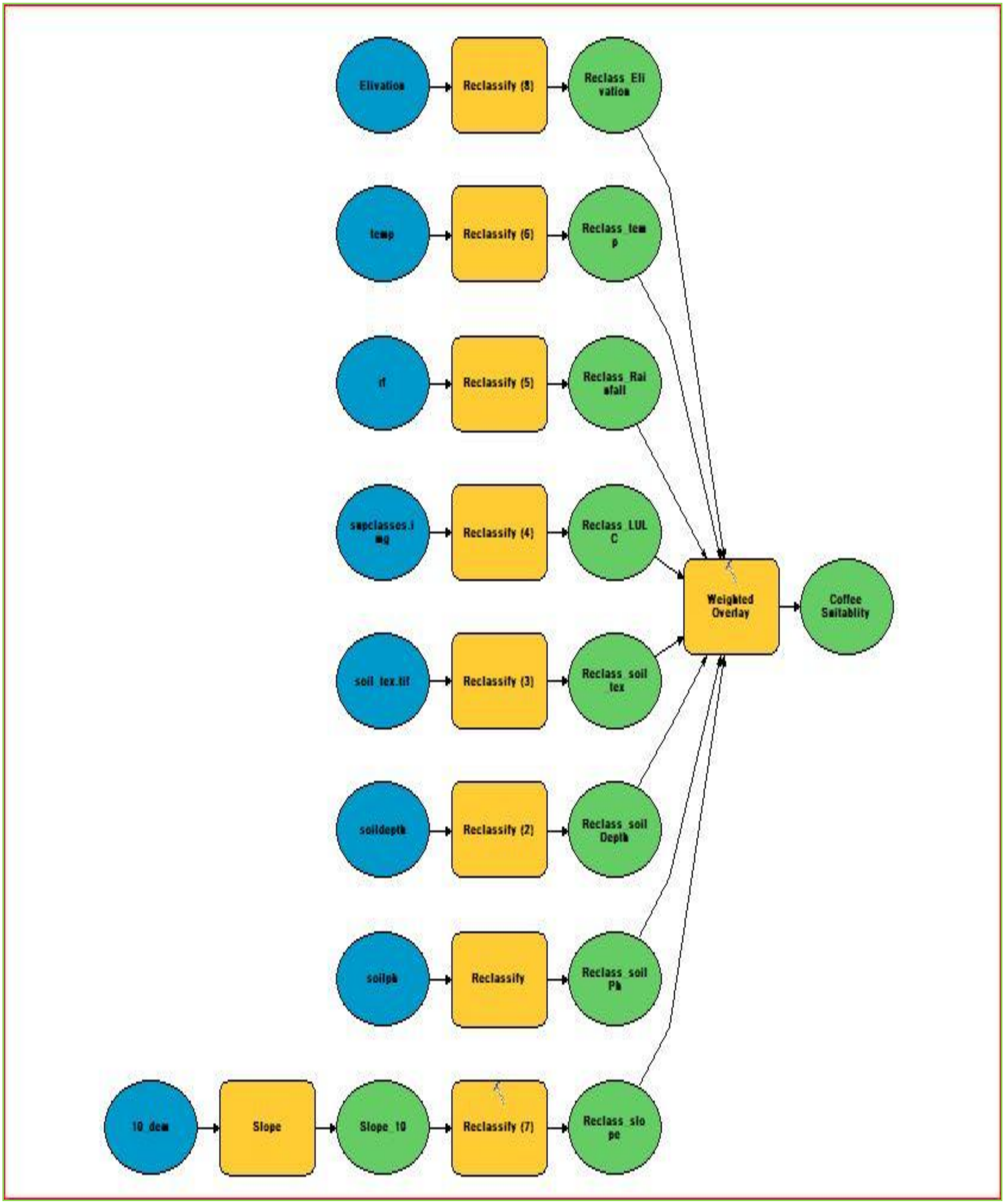


Figure5: Coffee suitability model builder.

2.5. The Role of Geospatial Techniques in Land Suitability Analysis

2.5.1. Role of GIS for Land Suitability Analysis

The distinctive feature of Geographic Information System (GIS) is its capability to perform an integrated analysis of spatial and attributes data. GIS can not only be used to produce maps automatically, but is unique in its ability to interpret and spatially analyze multi-source datasets such as land use data, population, topography, hydrology, climate, vegetation, transport network, public infrastructure, etc. . The data are manipulated and analyzed to gain information useful for a particular application such as land-use suitability analysis (Malczewski, 2003).

According to Foote and Lynch (1996) cited in Prakash (2003), the ultimate goal of GIS is to provide or support for the way of making spatial decisions. Many data layers need to be treated in multi-criteria evaluation in order to arrive at the suitability that can be easily accomplished using GIS. GIS allows the consumer to assess which locations are most/least fit for particular purposes in the sense of land suitability assessment. The findings of GIS analysis also may provide help for decision-making in this context. It also enables to create and modify any land suitability analysis that makes the best use of available data.

2.5.2. Role of Remote Sensing for Land Suitability Analysis

Remote sensing helps to provide the information about the various spatial criteria/factors under consideration. Remote sensing can provide us with data such as land use/cover, drainage density and topography. It is also possible to infer many of the non-spatial parameters by looking at various spatial parameters. In combination with GIS, remote sensing would be a powerful tool for the most accurate and transparent integration and analysis of real world situations. In order to save time and yielding good data quality, integrated GIS and remote sensing technologies have the ability to identify possible new cropland sites (Leingsakul et al. 1993).

According to Lillisand et al. (2004), remote sensing is a technique used to derive information about physical, chemical and biological properties of objects without direct physical contact. Remote Sensing techniques are more effective and useful for understanding and studying those areas in the out-of-the-way mountains and remote deserts (LO and Young, 2005). Hence it offers an efficient and effective means of collecting the information required in order to map land suitability.

Remote sensing has been recognized that land suitability is assessed as part of a 'rational' cropping system (FAO, 1996) and optimizing the use of a piece of land for a specified work should be based upon its attributes. In addition, land can be considered either in its current condition or after specific improvements have been made. Although the parameters which differ, they are typically based on climate, soil, topography and the availability of water, which are the most critical categories of environmental information needed to determine the suitability of the land. Assessing the suitability of an area for agricultural production requires considerable efforts in terms of information that presents both opportunities and limitations to decision-makers.

Remote sensing data are used for estimating biophysical parameters and indices besides cropping systems analysis, and land use and land cover estimations during different seasons (Martin and Saha, 2009). However, remote sensing data alone cannot mean crop suitability for a region unless the data is combined with location-relevant soil and climate data. Remote sensing data can be used to delineate different physiographic units compared to ancillary data on site characteristics such as slope, direction, and function of the study area. Land use /land cover mapping from satellite imageries of remotely sensed data are one of the advantages of remote sensing.

Knowledge of land use and land cover is important for many planning and management activities and is considered an essential element for modeling and understanding the earth as a system. Land cover maps are presently being developed from local to national to global scales (Lillesand et al., 2004). The objective of land cover mapping is to mimic the earth surface as much as possible by delineating the different features as they exist in nature. Remote sensing have continued to play a key role in providing information from satellite images and/or aerial photographs for characterizing spatial variation in land cover and monitoring temporal changes in land resources at various scales through classification procedures (Gholz et al., 1996; cited in Owusu,2007). Multispectral image classification is the procedure used to automatically categorize all pixels in an image in to land cover classes or themes based on the spectral patterns in the image data (Lillesand et al., 2004).

The unique purpose of image classification is to translate image data to thematic data. The resulting classified image consists of a mosaic of pixels, each of which belongs to a particular theme, and is ultimately the original image's thematic map. In the application context, one is reasonably interested in thematic characteristics of an area rather than in the reflection values. Thematic characteristics such as land use / land cover can be used for further analysis and input into GIS based models. In addition, image classification can also be considered as data reduction: then multispectral bands result in a single band raster file. As far as classification of image is considered, there are two common classification types: unsupervised and supervised classifications

(Lillesand et al., 2004). However, the current study used the supervised classification technique to categorize the image in to different land use / land cover categories.

Multi Criteria Decision Making (MCDM) for land suitability analysis

Multi criteria Decision-making (MCDM) is a concept that encompasses multiple attribute decision-making (MADM) and multiple objective decision-making (MODM). MADM is functional when a choice out of a set of discrete actions is to be made. It is presumed in MODM that the best solution can be found anywhere in the space of feasible alternatives, and is therefore viewed as a problem of continuous decision. MADM is often referred as multi criteria analysis (MCA) or multi criteria evaluation (MCE. Instead, MODM is similar to Pareto's optimal search using mathematical programming techniques (Jankowski 1995, Malczewski 1999). Here, the term multi criteria decision making is used in reference to multiple attribute decision-making and the other expressions are used as equivalents. The primary aim of the MCDM is "to assist the decision-maker in selecting the 'best' alternative from the number of possible alternatives of choice in the presence of multiple criteria and priorities of various criteria." Each MCDM method has common procedural measures, referred to as a general model, (after Jankowski 1995). This procedure includes the following actions;

1) Obtaining a set of alternatives
2) Obtaining a set of criteria
3) Estimating the impact of each alternative on each criterion in order to obtain criterion scores
4) Formulation of a decision table using discrete options, parameters and ratings for the criteria.
5) Defining priorities of decision-makers (DM) in the form of criterion weights.
6) Aggregating the data from the table of decisions in order to identify the alternatives (simple and multiple aggregation functions).
7) Perform sensitivity analysis to deal with imprecision, uncertainty, and inaccuracy of the data.
8) Make a final recommendation in the form of either a single alternative, a reduced number of 'strong alternatives' or a ranking of the best to the worst alternatives.

All the MCDM techniques are based on the general model presented above. However, division can be made for compensatory and non-compensatory methods. It is possible to further subdivide the compensatory methods into additive and ideal point techniques, where the first one includes e.g. weighted summation, concordance analysis and Analytical Hierarchy Process and the latter, Technique for Order Preference by Similarity to Ideal Point (TOPSIS), Aspiration-level Interactive

Method (AIM) and Multi-Dimensional Scaling (MDS). Non-compensatory techniques, for example, are dominance, conjunctive, disjunctive, and lexicographic techniques.

It is useful to believe, multi-criteria decision-making as a process that integrates and translates a number of geographical data inputs into a resulting decision output. In the form of decision-making problems of a geographical nature, a wide variety of feasible options and several overlapping and inappropriate evaluation criteria must be considered. As a result, many real-world spatial problems lead to multi-criteria decision-making (MCDM) based on the geographic information system (GIS). In MCDM, each and every criterion is given a weight to represent its genuine importance in the phenomenon. These are dependent on the nature of the alternatives under consideration, the criteria used to compare alternatives, and the weights derived for criteria. MCDM involves input data, the decision maker's preference and manipulation of both information using specified decision rules. In this spatial, multi-criteria decision making strategy, the input data is geographical data. In this study topography, physical and chemical properties of soil and climate will selected for suitability analysis of suitable coffee farming areas. Then, the causal factors, including elevation, slope, soil depth, soil PH, soil texture, temperature and rainfall was selected based on expert's knowledge and consideration of literature inputs and data availability.

GIS has good spatial problem management capabilities and can, as such, be used to assist spatial decision-making. Without spatial analytical and visualization software, solving a complex multiple criteria problem would be computationally difficult, if not impossible, Jones (1997). Multi criteria decision making techniques, as standalone tools, have been computerized and nowadays there is much software to use. However, it is not common that such software is capable to handle spatial problem in the form of maps. There are two strategies: The loose coupling depends on a file sharing mechanism that enables the communication of the two types of software. Different operations are conducted in each of the services. GIS is used to perform land suitability analysis, select a set of parameters and their rankings in order to export the decision table into MCDM program. The MCDM module is used for executing multi criteria evaluation and the result is transferred again into the GIS for display. Rather, the close coupling strategy is realized by a standard interface and generic database for GIS and MCDM. This in fact means that the multi criteria evaluation functions are embedded into the GIS software. The benefit is that all necessary functions are on place and troublesome data exchange is avoided. Conversely, not every proprietary GIS have developed such a facility in its basic version. There is example of IDRISI, which employs pair wise comparison and Analytic Hierarchy Process to evaluate weight scores (Clark Labs). Another Spans platform by Tydac Technologies has built-in weighted overlay functions similar to the Carver weighted summation MCE technique (1991). The ESRI software, which is capable of handling similar decision problems, supports a cartographic modeling method called Model Builder, thus requiring some initial job input. Generally speaking, multi criteria evaluation with use of GIS can be done in two stages, (i) survey and (ii) preliminary site identification. In the first step, the area is screened using deterministic decision criteria for feasible alternatives. Here, all the locations that simultaneously meets all the exclusion requirements (constraints) are listed and omitted from the study. This process is often referred to as an analysis of suitability, historically carried out by manual map overlay, further revolutionized by digital GIS maps.

The second stage, called preliminary site identification, is operational zed by MCE techniques. First, secondary sitting factors are elaborated and then weighted according to their importance. The second stage helps Carver (1991) to handle some objective questions; Jankowski (1995). In order to ensure the social and economic viability of the project, McHarg (1969) introduced several overlay specifications which suggested defining physical, economic and environmental criteria. Whether the overlay form of binary or multiple values is used is determined by the complexity of the decision problem. In geographic analysis, most commonly used operations are AND and OR (Boolean), which correspond to spatial ‘intersection’ and ‘union’. If the decision variables have different degrees of importance, weighted overlay may be used. However, special scores aggregation technique is required to achieve realistic Jones Jones outcomes (1997).

2.5.3. Evaluation Criteria

An evaluation criterion is a term used to include both objectives and attributes of the multi-criteria decision issue Malczewski (1999). Other writers refer them as decision criteria or factors and scores respectively Voogd (1983); Carver (1991). The objectives describe the desirable state of a geographical space. In order to make the correct decision by "minimizing" or "maximizing" certain factors, they formulate the conditions that need to be satisfied. On the other hand, the attributes include indicators used by each alternative to determine the level of achievement of the criterion. In GIS, evaluation criteria are presented as thematic maps or layers of data. Decision characteristics must meet several requirements. Firstly, they need to be measurable, which implies that it should be easy to assign numerical values that correctly asses the references to or the level of achievement of the objective. Secondly, an attribute should clearly indicate to what degree the aim is accomplished, which is transparent and comprehensible for decision-making. This is called comprehensiveness of an attribute. In addition, a set of attributes should be operational. If the attribute is clear for the decision maker, he/she can correctly describe relation between the attribute and a level of achievement of the overall objective than it can be used significantly in the decision-making process. A list of attributes should also be complete, which means that it covers all aspects of a decision problem. The set of attributes should be minimal, forming the smallest possible set that defines the issue of the decision fully. No redundancy means that only one attribute is affected by the effects of the valuation of the decision. The coefficient of correlation test can be used to test for no redundancy for any pair of attributes. Finally, the attribute set is expected to be decomposable. It is true that it is possible to simplify the assessment of the attributes in the decision process into a few smaller decisions. A hierarchical structure is usually created by evaluation criteria (Malczewski, 1999). It is possible to choose a proper set of evaluation criteria by means of literature analysis, analytical studies or opinion surveys. Literature can be identified with some authors providing a particular spatial decision issue with a literature analysis of criteria evaluation. Governmental agencies and governmental publications can provide standards or guidelines for selection of evaluation criteria. Another strategy or method is to recognize objectives from governmental or other documents and review relevant literature to identify attributes associated with every objective. Analytical studies can be performed for example by system modeling. Opinions' survey is aimed at people affected by decision or a group of experts, where several formalized techniques exists (Malczewski, 1999).

2.6. Conceptual Framework of the Study

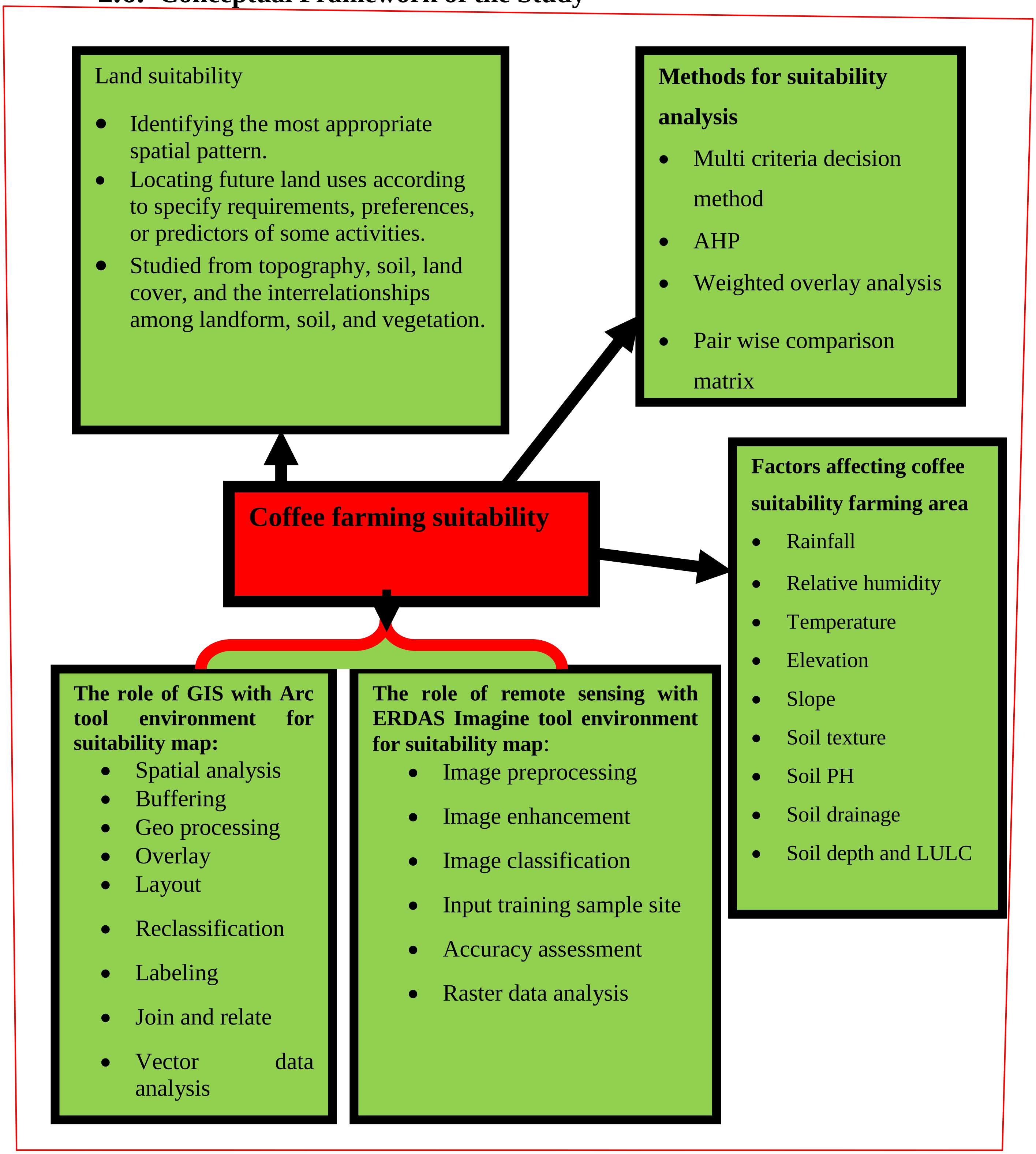


Figure 6: Conceptual frame work chart of the study.

CHAPTER THREE

MATERIALS AND METHODS

3.1. Description of the Study Area

3.1.1. Location

The Gura-Ferda administrative woreda is situated within the Bench Maji zone in the SNNPR (Southern Nations, Nationalities and Peoples) region. It is located in the southwest part of Bench-Maji Administrative Zone and the country as well. The woreda is located 602 Km southwest of Addis Ababa and 65 Km from *Mizan Teferi* (the principal town of the zone) in South Nation Nationalities and Peoples Region (SNNPR). Geographically, it is located between 34°55’59” to 35°26’13” E (Latitude) and 6°29’5” to 7°13’20” N (Longitude). It borders the Bero district to the south, the area of Gambela to the west and north, the district of Sheko to the northeast, the district of South Bench to the east, and the district of Menit Shasha to the southeast. The estimated area of the district of Guraferda is approximately 2565.42 km2. It is the fourth largest district of the zone. The district has two municipalities and 27 rural *kebele’s* (the smallest administrative division) with administrative town of Biftu. Some of these kebeles are recently emerged by splitting larger kebeles because of population increase or growth. The largest part of the district is not administered as a kebele, but is governmental territory (Guraferda Woreda Administration Office, 2018).

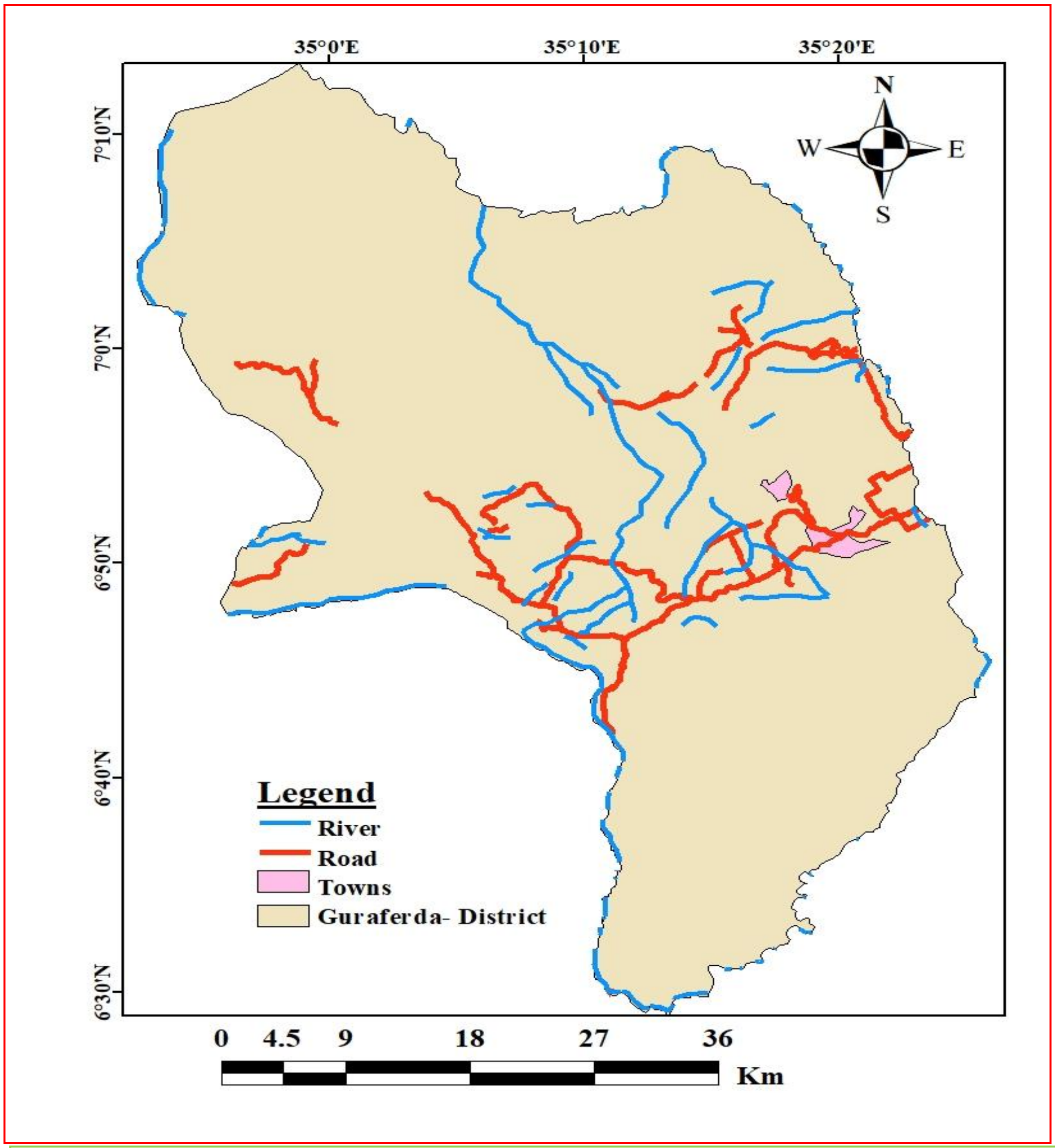


Figure 7: map of the study area.

3.1.2. Population

Before the Derg resettlement of the 1980s, the province consisted of only three ethnic groups, namely Mejengir, Sheko and Me'enit. After 1984, people from other parts of the country, mainly from North Shoa, Gondar, Gojam and Wollo have massively migrated in to the area seeking for farmlands as government organized and spontaneous resettlement program. In addition, starting from 2001/2002, government sponsored resettles mainly from northern and southern parts of the country have also entered into the district. Now, the district became the place of multiple ethnic and linguistic groups. Therefore, the Woreda is home for Amhara, Keffa, Sidama, Wolayta, Kambata, Guragie, Hadiya, Bench, Gedeo, Oromo and others. It is also the most diverse district in terms of language, culture and ethnic background (Guraferda Woreda Administration Office, 2018).

According to the 2007 census carried out by the Central Statistical Agency of Ethiopia (CSA), the total population of the district is estimated at 35,271, of which 19,410 were male and 15,861 were female.30280 or 85.85% of the populations are estimated to be rural inhabitants, while 4,991 or 14.15% of its population are urban dwellers. This makes the district is most rural. However, as the survey conducted by the Woreda Health office, the population reached 47,000.This is because of the steady influx of internal migrant population to the Woreda (Guraferda Woreda Health Office, 2015).

3.1.3. Religion

According to the Ethiopian Central Statistical Agency (2007 census), the majority of the inhabitants practiced Ethiopian Orthodox Christianity, Protestants, Muslim and traditional beliefs accounts 53.23%, 28.82% , 13.87% and 2.9% respectively.

3.1.4. Topography

The topography of Guraferda district is highly variable. A number of hills and mountains characterize the landform of the area. Among other things, the Susuka Mountain bordering the Gambela National Regional State and the Ambesa mountains to the north are popular. The district's elevation range is between 559 and 2389 meters above sea level.

3.1.5. Climate

Agro-climatic zones of *Gura-ferda* are mostly low land (Moist *kolla*) and medium (*Woynadaga*), which constitute 78.25% and 21.75% respectively. The annual precipitation ranges from 1601-2000 mm. The average is around 1332 mm. The mean annual minimum and maximum temperature of the area ranges between 20^{o}C and 29^{o}C, respectively. Fertile nitosols are mainly the soil of the region or the district (Guraferda woreda agricultural office, 2018).

3.1.6. Vegetation

The broad-leaved deciduous woodlands are found in the northwestern, western parts and the southwest along the Gambela region boundary between 500-1900m.a.s.l. The vegetation is characterized by Combretum spp., *Oxytenanthera abyssinica* (A.Rich.) Munro,*Boswellia papyrifera*, *Lannea schimperi*, *Anogeisus leiocarpus*, and *Stereospermim kunthianumcham*, where the under-storey vegetation is constituted of a combination of herbs and grasses (Guraferda woreda agricultural office, 2018).

3.1.7. Economic Activities

Agriculture is the main economic activity in the area of study, particularly for the rural population, where agriculture is the dominant means of earning a living. The main economic activity for urban residents is trading. There are huge large uncultivated lands in the area and low farming densities and as a result farm holding per head is high and reported to be 2-3 hectares per head. Like the economy of the Zone, *the district* is predominantly plough-based agriculture dominantly of cash crops, like coffee, sorghum and rice. The first four major products of the districts are coffee, rice, maize and sorghum. The type of named as *Gobi* which is being used for baking *Injera* (the traditional Ethiopian bread) is widely produced next to rice. Among the annual crops rice covers the bulk of production. Perennial cash crops; such as coffee and fruits were being intensified in the woreda. *It becomes* one of the surplus crop producers in the region. Besides crop production, the farmers of the woreda raise livestock for their farm and for their milk consumption. In addition to livestock rising there is also beekeeping due to this the district is well known by forest honey (Guraferda Woreda Agriculture Office, 2018).

3.1.8. Social Institutions

Social institutions play big role to preserve and maintain the continuity of generation. Schools, health centers, water, post service, transport, telecommunication can be mentioned examples of social institutions. Guraferda district has small number of social institutions compared to the total population size. Even though many of the population found in rural areas, they do not have much access to these institutions. This district consisted of 36 schools, of which 34 are primary schools (grade 1 to 8); 2 are high schools (grade 9 to 10). It also comprised of 16 health institutions, of which 2 are health stations; 4 are health clinics, and 10 are health extension centers. It has also one bank and one micro finance institution services. Another social well being for working diffrent activites, the resettlers and the local *Me'enit* people use *dabo* (festive work group) and *wanfal* (reciprocal work group) for sowing, weeding and harvesting. There are two main weekly markets on Sunday and Saturday in *Biftu* and *Kuja,* respectively. *Kuja* (Megen‟teya) is recently established town following the 2001/2 spontaneous resettlement. Being center for the farmers from different directions, it becomes the biggest market place in the woreda. For this reason, the town is piled with services like hotels, cafés, shops and bars. It became service center to the resettlers and people in the large-scale agricultural investment sites around the town. The woreda has unfit all-weather road which has never been repaired for years. The road was constructed by UNHCR to access the South Sudan refugees resettled in *Dima* refugee camp which is about 90 Km from *MizanTeferi*. The road connects the woreda capital, *Biftu*, with the zone capital-MizanTeferi, and now, it is under construction to make it all-weather road. In addition to this main road, there are dry-weather roads to the large-scale agricultural investment sites. Of these the one which runs from Biftu to Bibita from Berji junction to Bibita (the former capital of the woreda) passing through *Quttir Sost*, *Qu'ttir Amist* and reaches. The second track runs from Kuja to the west through *Komata*, *Kuki* and *Samartha* leads to Bibita again. These two roads hardly serve for tracks like ISUZU only during the dry season with the assistance of people. Regardless of the devastated infrastructure, the woreda become known for its booming economy not only because of the smallholders‟ farm but also being site for many large-scale agricultural investors planting different perennial and annual crops. It is also a path way to gold mining places in neighboring woredas and South Sudan (Guraferda Woreda Adiminstration offie report, 2018).

3.2. Materials and Research Methods

3.2.1. Materials

Computer based technology using GIS software was used to conduct the study. The following software and applications were used in the study. These are ArcGIS 10.7 (none_ licensed), ERDAS IMAGINE 2015, Google earth pro, IDRISI Andes and AHP calculator, and Global Mapper, (Table 3).

Table 3: Details of materials and soft ware's used in the current study.

S/N	Type	Description	source
1	Softwares	ArcGIS 10.7 (none_ licensed), ERDAS IMAGINE 2015, Google earth pro, IDRISI Andes and AHP calculator, and Global Mapper	From ESRI website
2	instruments	GPS (GARMIN_78)	CSA
		Digital Camera	

3.2.2. Research Methods

3.2.2.1. Data Collection

The success of any GIS application depends on the quality of the geographic data used (Lo and Yeung, 2002). Collecting high-quality geographic data for input to GIS, therefore, marks a critical stage. Data collection is one of the most time-consuming and expensive, yet important for GIS-based studies. GIS can contain a wide variety of geographic data types originating from many diverse sources (Longley et al., 2005). So, data collection and preparation using GIS Data preparation is the first fundamental step in land suitability analysis. Various spatial and non-spatial datasets were obtained from different organizations and processed using multiple GIS tools and remote sensing techniques for mapping and analysis purposes. For the study, both primary and secondary raster and vector data were used.

Table 4: Source of data

Dataset	Format of Data	Data Source	Resolution of Data
Climate (rainfall, temperature) and rainfall distribution)	MS Excel or tiff	from Ethiopian Metrology Agency	
DEM /elevation and slope/	raster	Ethiopian Geospatial information institute	
Soil(Depth, PH, Drainage, Texture)	Shapefile	Agricultural Transformation Agency	
Training sites or signature site	UTM coordinates	Handheld GPS	
Administrative Boundaries	Shapefile	Ethiopian Geospatial information institute	
Satellite Image (Landsat 8 Image	Tiff	Ethiopian Geospatial information institute or US Geological Survey (USGS) website	30m accuracy
Other non-spatial data	-	From Guraferda woreda administration office	updated
		Ethiopian coffee and tea development Agency	

3.3. Data Analysis

3.3.1. Satellite image processing

a. Data Pre-Processing

Before LULC classification, remotely sensed data pre-processing techniques were employed using ERDAS IMAGINE 2015 software. Image enhancement is concerned with the modification of images to optimize their appearance of the visual system. Various false color composite raster band combinations in Red-Green-Blue order, contrast enhancement, noise removal, haze reduction, histogram equalization, convolution, environmental correction, brightness adjustment and principal component analysis image enhancement techniques were employed.

b. Image classification

Satellite imageries were classified and analyzed using the basic photogrammetric elements (color, tone, texture, size, shape, structure, association, and shadow); the prior knowledge of the area and field observation. LULC map was produce by supervised classification using the maximum likelihood classifier of ERDAS IMAGINE 2015 software. In supervised classification, three activities was done such as collecting spectral signature, evaluating signature and classified images using maximum likelihood classification. LULC classification was employed from the prior knowledge of the study area and based on the U.S. Geological Survey Land Use/Cover System developed by Anderson et al. (1976). The images were interpreted or classified into seven LULC classes, namely settlement, water body, shrub, forestland, grassland, cultivated land and bare land.

Image classification has categorized all pixels in an image into LULC classes. Normally, multi-spectral data were used to perform the classification and the spectral pattern present within the data for each pixel is used as the numerical basis for categorization. Hence, different feature types manifest different combinations of digital numbers based on their inherent spectral reflectance properties. Spectral pattern recognition refers to the family of classification procedures that utilizes this pixel-by-pixel spectral information as the basis for computerized LULC classification.

c. Accuracy assessment

Accuracy assessment has been used to decide whether or not the output map meets the standard of acceptance. Error matrices are a common way of expressing the accuracy of classification and have been developed to compare category by category basis, reference data (ground truth) and corresponding classification outcomes (Lillesand et al., 2008). The study assessed the accuracy of the classification results for each classified image.

Later creating the error matrix for each classification, user accuracy, producer accuracy, overall accuracy and Kappa coefficient were computed Conferring to Lillesand *et al.* (2008). The producers accuracy is measured by dividing the number of correctly classified pixels in each category (on the main diagonal) by the number of training pixels used for that category (the column total). For the multi-variate statistical measure that can be used to assess the accuracy of the LULC classification, the Kappa coefficient of agreement was used. Here below figure shows the satellite image processing.

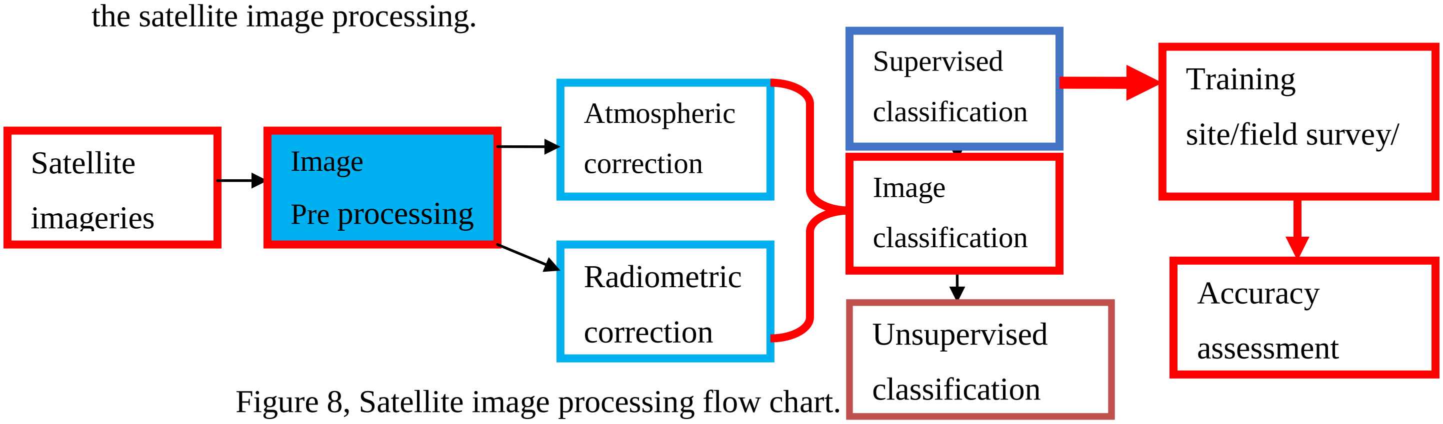


Figure 8, Satellite image processing flow chart.

3.3.2. Multi-Criteria Evaluation (MCE)

Land suitability for agriculture involves various social, technological, environmental and economic aspects. Geographic Information System-MCDA is a method that translates and integrates geographical data and value judgments (preferences of decision-makers) to obtain decision-making information (Malczewski, 2006). GIS-MCDA provides a unique method that can manage and fit together a wide variety of variables assessed in various ways and thus provide the decision-maker with valuable assistance in pointing at suitable locations (Taha & Daim, 2013).In order to select the best favorable coffee growing area in Guraferda district, six GIS-based MCA steps were followed (Figure 9).

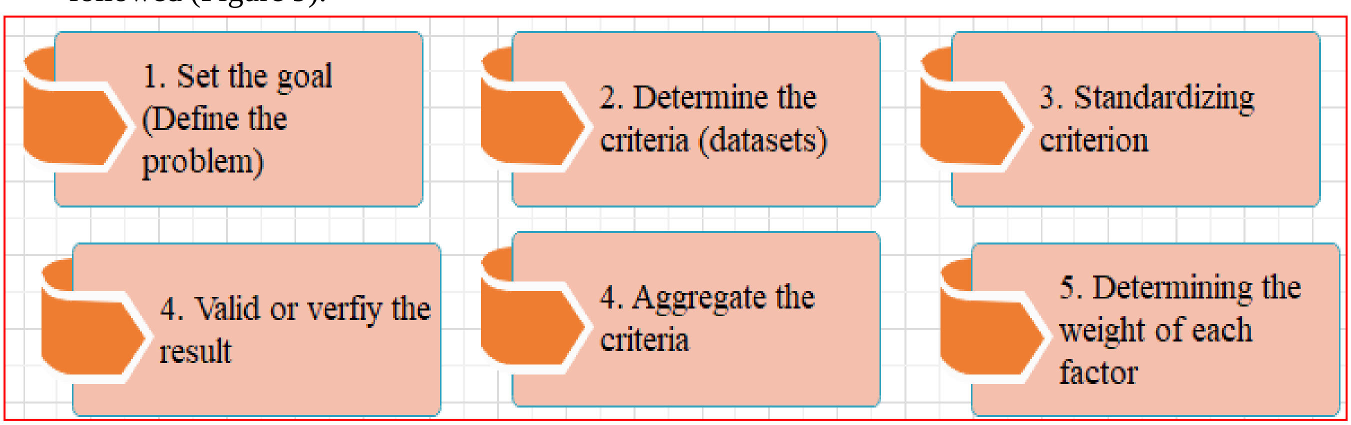


Figure 9: Methods of Multi-Criteria Evaluation Steps (modified after Eastman *et al*., 1995)

The first phase was to set the objective or to define the problem. In this study the aim of GIS based MCA is to produce a map showing suitable coffee growing area in the district. The second phase was determining factors/ criteria that are important for coffee cultivation or growing. The factors (parameters) used for selecting best suit were selected based on different literatures and prior knowledge that is Agricultural experts or standards guide line of that particular area. Based on ministry of agriculture and FAO guide line, Elevation, slope, LULC, temperature, rainfall, Relative humidity, soil texture, soil depth, and soil PH were important factors for selecting best suit of coffee cultivation in the area of interest.

The third phase was standardizing each factor/ criterion scores. It is necessary to set the suitability values of the factors to a common scale to make comparisons possible. Generally, all input datasets were changed into a raster at 30 meter resolution and to a common measurement scale using conversion. On the basis of the FAO land suitability classification, data sets were reclassified from highly suitable (S1) to permanently unsuitable (N2); where S1 is highly suitable, S2 is moderate, S3 is less suitable, N1 is not suitable and N2 represents permanently unsuitable conditions for favorable coffee growing conditions.

The fourth phase was defining weights for each criterion based on its importance for coffee cultivation. Several processes are available to determine the weight like Analytical Hierarchy Process (AHP), ranking and rating. In this study the Analytical Hierarchy Process (AHP) method was adopted to assign weight for each factor because, AHP uses a hierarchical structure; It helps decision-makers to identify high-level strategic priorities and basic indicators for a better evaluation of strategic alignment and can be used in any organization with any level of maturity since the inputs are structured when metrics are not accessible and the method gives itself to sensitivity analysis using either numerical data or subjective judgments (Saaty, 1980).

AHP and the Geographic Information System (GIS) are an integrated technique used to assess land suitability for favorable coffee growing area.

Figure 10 below indicates the general methodology flow chart followed throughout the work of this research.

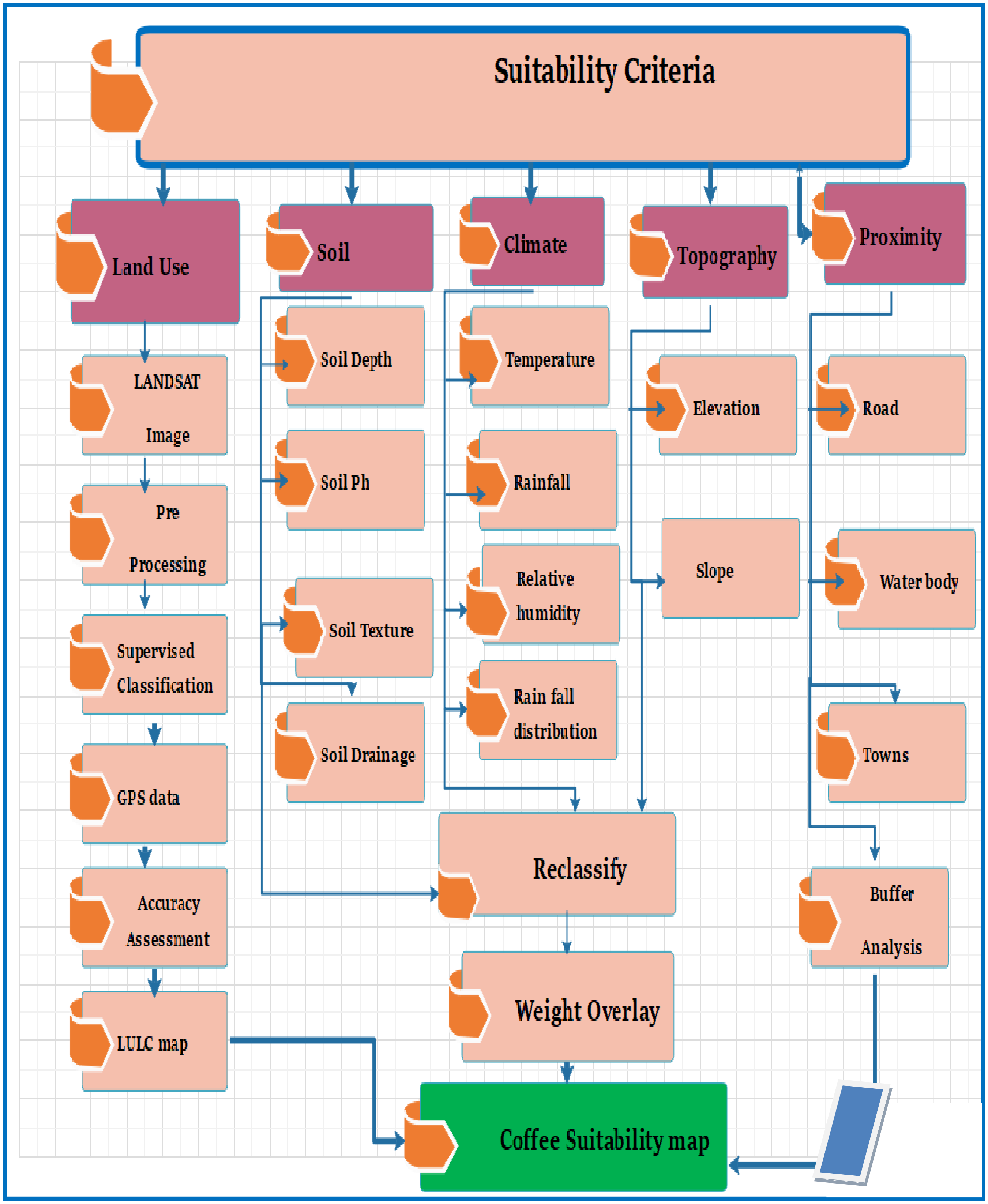


Figure 10: Schematic Flow Chart of the Research Methodology

CHAPTER FOUR

4. Spatial Data Processing, Analysis and Result

4.1. Coffee Cultivation Suitability Analysis

4.1.1. Factors of Coffee Farming Suitability Analysis

As discussed in chapter two (suitability analysis and multi-criteria decision making section), GIS is an important aid for spatial decision making (Carver, 1991; Pereira and Duckesstien, 1993). Developments in GIS have led to significant improvements in its capability for decision making processes in land allocation and environmental management (Jiang and Eastman, 2000). Multi-Criteria Evaluation (MCE) is one of the most important procedures for GIS-based decision making processes (Jankowski, 1995; Malczewski, 2000). Hence, in order to locate optimally suitable geographic areas for a specific land-Use (identifying coffee growing area, criteria development is crucial.

The current study illustrates the use of multi-criteria evaluation (MCE) methods in the context of land use suitability analysis for identifying the suitable areas for favorable coffee growing areas. It focuses on the application of the GIS-WOA method. To this end, the set of evaluation criteria for the current objective was identified from field survey, literature review and consulting decision makers. They include topography/elevation, slope, land cover types, moisture availability/rainfall/, temperature, soil texture, soil drainage, soil depth and soil PH. Every criterion map shows land suitability measured on an ordinal scale, namely, parcels of land were allocated values of very high, high, medium, low and very low suitability depending on land attributes. On the contrary, the study constrains or restricts water bodies, roads and towns from the analysis. These lands over classes were classed as restricted during the analysis to sustain the natural environment.

The criteria maps are the input data to the GIS-WOA based decision making procedure. Given these maps, the next phase is to combine the maps so that one can identify the suitable sites for coffee cultivation. The combination method follows the conventional scheme for GIS-based MCDA (Malckzewiski, 1999). It involves three main phases. First, the criterion maps were standardized/ reclassified using Spatial Analyst's Reclassify tool. This approach is important since the criterion maps include the ordinal values (high, medium, and low) indicating the degree of suitability of the land in relation to a particular criterion (see standardization/reclassification criteria section). Secondly, derivation of the weights of relative criterion importance using the pair wise comparison method (cf. assigning criterion weights-section). The criterion weights are automatically calculated once the pair wise comparison matrix is entered in the IDRISI-AHP weight derivation module. Third, the criterion weights and the standardized criterion maps were combined/ aggregated by means of the WOA operations.

1. Topography

Elevation and slope of a given area plays an important role for agricultural activities in general, and specifically for coffee cultivation. Workability of the area, erosion hazard and potential for mechanization, especially for coffee growing area, depends on slope or Elevation of the area in one or the other way. Hence, this particular study considers Elevation and slope are factors for the land suitability analysis for coffee cultivation. Slope and elevation of the study area were derived from the digital elevation model (DEM) which in turn was clipped from SRTM data of NASA satellite 30m resolution of Ethiopia by using a masking layer of the study area boundary.

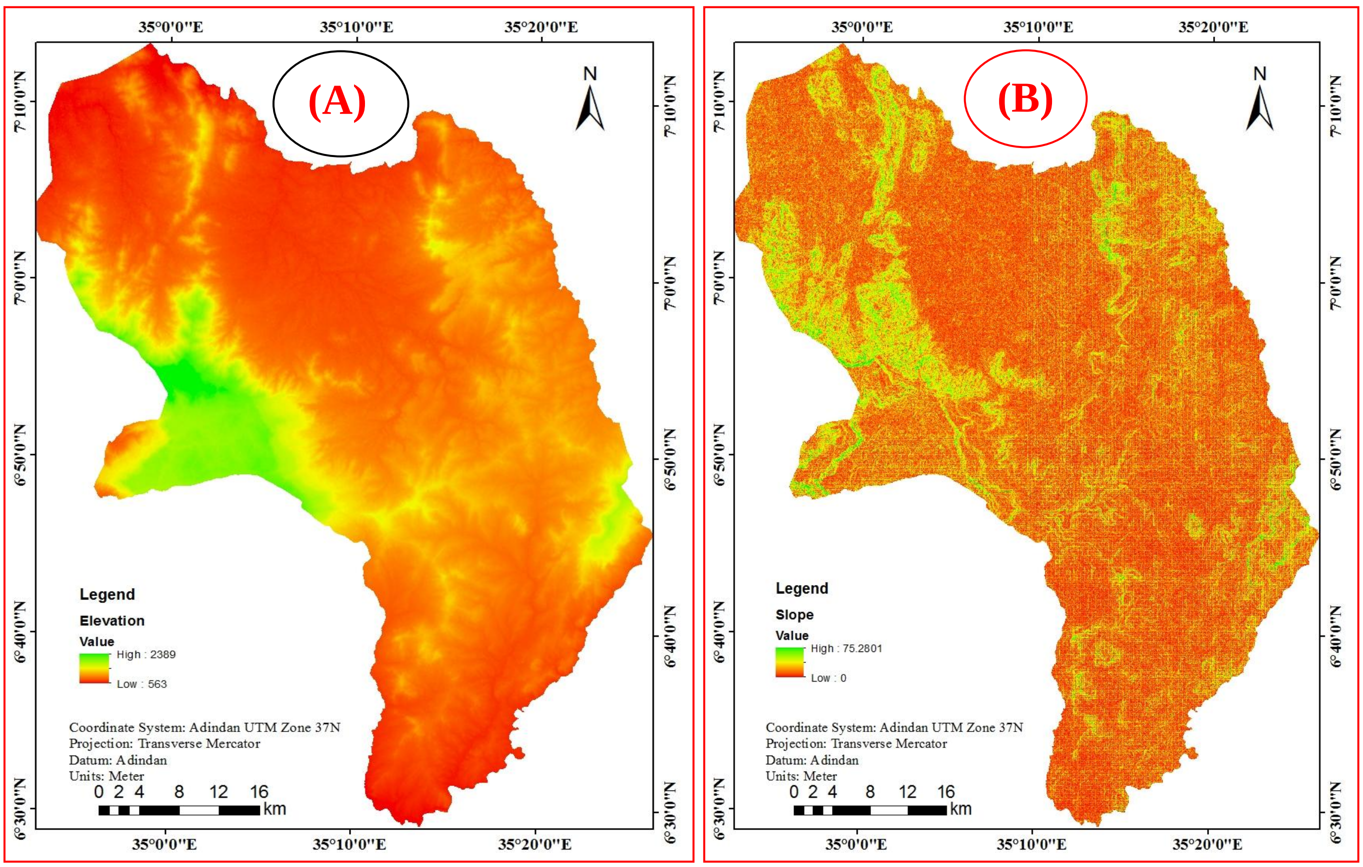


Figure 11: DEM maps of the study area (A=rainfall, B= slope)

2. Climate

Coffee growing potentials areas and land use patterns are closely related to the temporal and spatial patterns of climatic elements; and success of land use strongly depends on climatic situation of an area. Rainfall and temperature are the major climatic factors that influence agricultural processes in general, particularly for coffee cultivation. Climate influences the spatial and temporal variations of agricultural activities and land use pattern. Consequently, in the land suitability evaluation climatic variables should be considered as a diagnostic land qualities/ or land characteristics.

Since the source of water for rain-fed agriculture is rainfall, its distribution and dependability plays a significant role in optimizing agricultural production. Therefore, the mean rainfall distribution together with its variation in both frequency and extent entail its agronomic importance. Coffee cultivation is affected by moisture availability through the effect of moisture stress on growth, and the possible death of the crop through drought. This study considered mean monthly average rainfall to evaluate moisture availability for coffee cultivation in the study area.

Temperature regime influences the growing of coffee. The temperature regime can be measured in different ways. In this study, it is assessed in terms of mean monthly and mean annual temperature. The climate factors were collected from NMSA of Ethiopia in raster form.

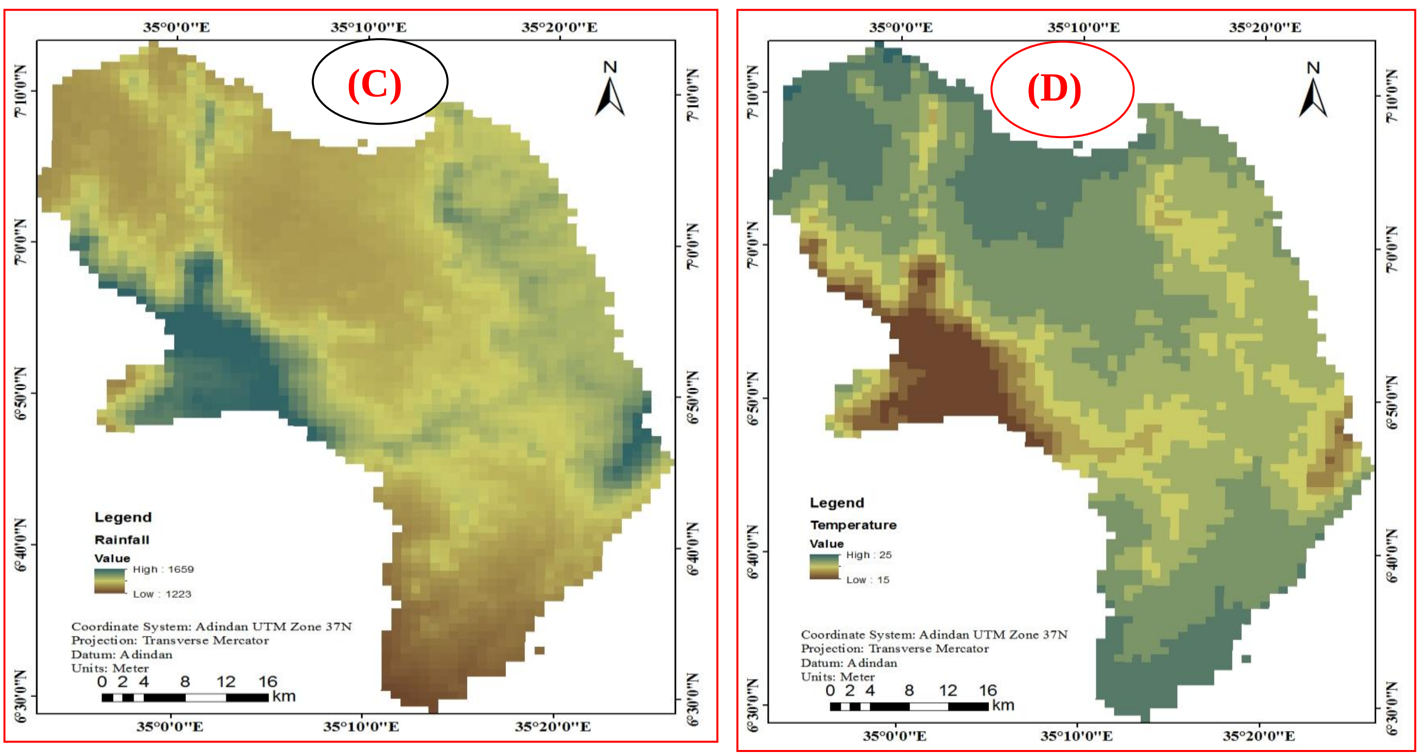


Figure 12: climate maps of the study (C=rainfall, D= temperature)

3. Soil

The major soil types in the study area include Dystric nitisols, Eutric Cambisols, Clacic xerosols, Dystric gleysols, Gypsic yermosols, Leptosols, Orthic acrisols and Ortic solonchaks. The soil texture, soil PH, soil depth and soil drainage of the study area were collected from EATA (Ethiopian Agricultural Transformation Agency) in raster form.

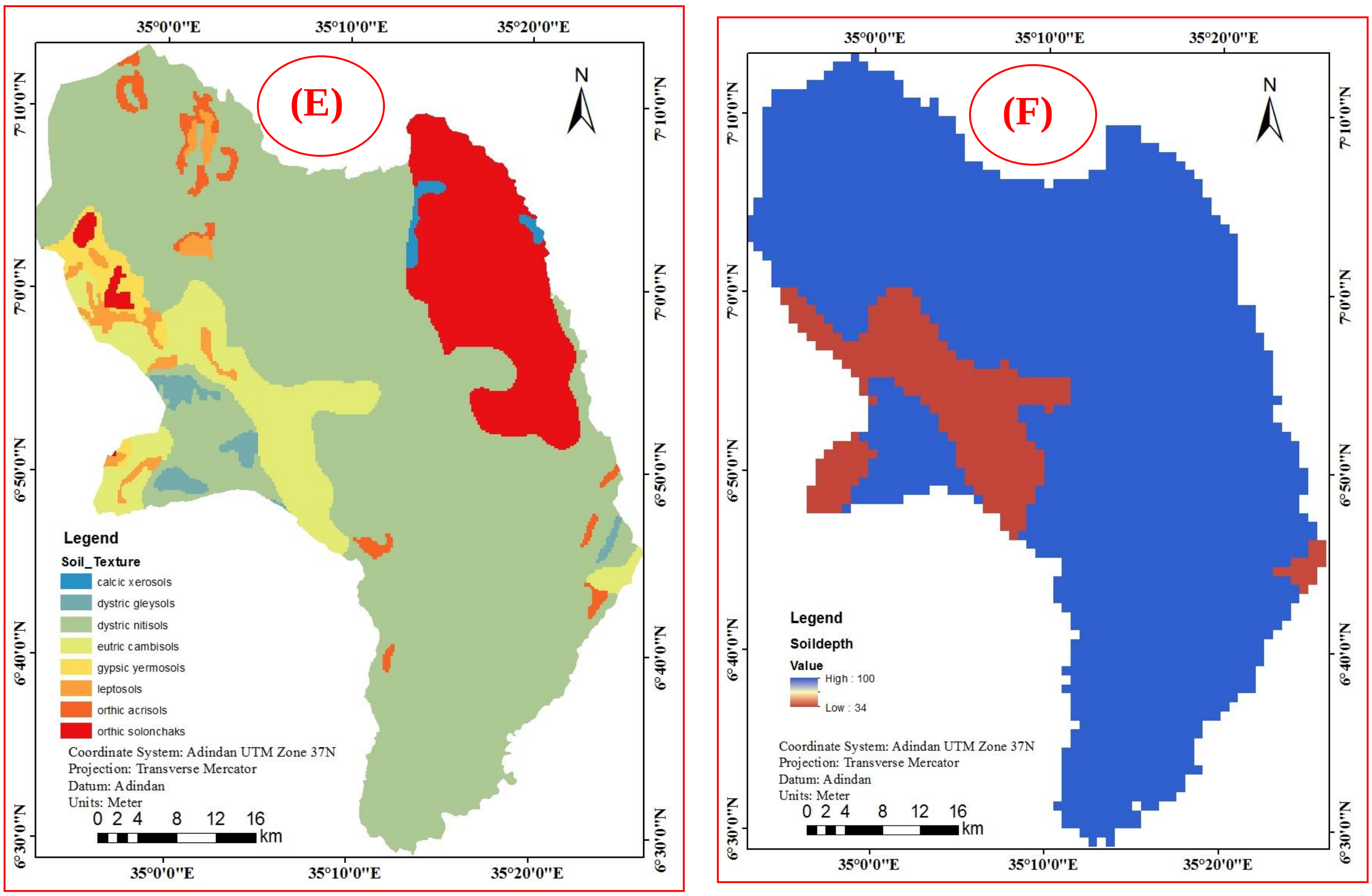


Fig.13. Maps of soil properties considered (E= soil texture & F= Soil depth) maps of the study area.

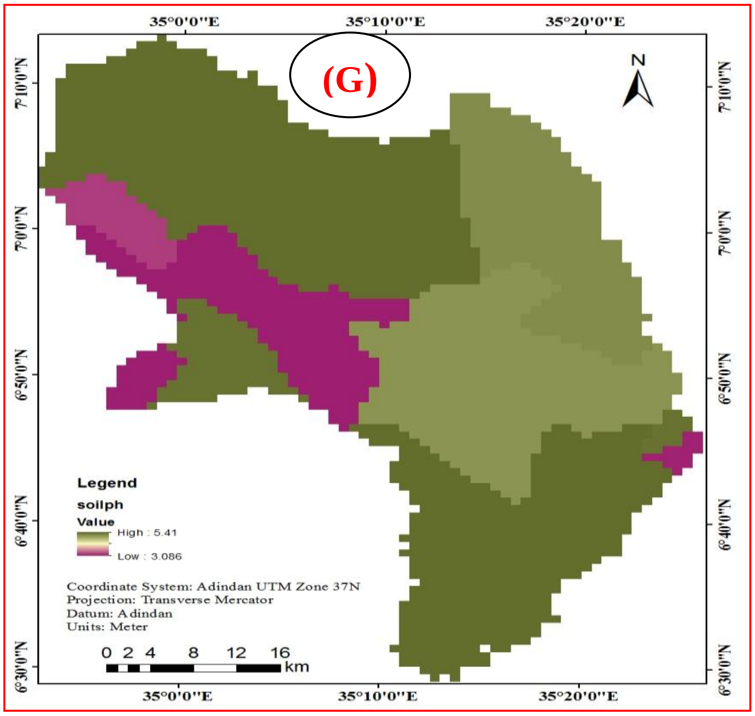


Fig.14. Maps of soil properties (G= soil pH) maps of the study area.

4. Land use land cover

Before doing the land use land cover map, 1st the landsat image data should be done in pre processing data operations (geometric correction, radiometric correction) (Lillesand et al., 2004).

The Landsat images obtained for this study had already been orthorectified by the image supplier (the Ethiopian Geospatial information institute). Accordingly, the current study used both of the classification types, i.e., the unsupervised classification before field visit and the supervised classification after field survey. So, representative points thought to represent the various land cover classes were marked using GARMIN GPS during the field visit. These points were used to sample representative signatures for the various types of land cover identified during the field visit. By taking those training signatures supervised land use/land cover classification has been carried out using ERDAS IMAGINE 2015 software. Since image classification without accuracy assessment is incomplete (Lillesand et al., 2004), the accuracy assessment for the images is done. Because of that, land cover maps derived from remote sensing imagery always contain some sort of errors due to several factors which range from classification technique to method of satellite data capture. Most assessments were carried out using the same data set as was used to train the classifier. The training and testing on the same data set result in overestimates of classification accuracy (Congalton, 1991). The present study, however, used a total of 220 randomly selected pixels for the 2020 land use / land cover map, which were checked with reference data (ground data) in the field to determine the accuracy of the classification.

Land use/land cover map is useful for resource assessment, land use planning, land evaluation, and land use/ land cover change detection. For the present study, LU/LC is one of the major factors that are considered for coffee suitability analysis. It was developed from the landsat 8, satellite image down loaded in 2020 (Fig. 14).

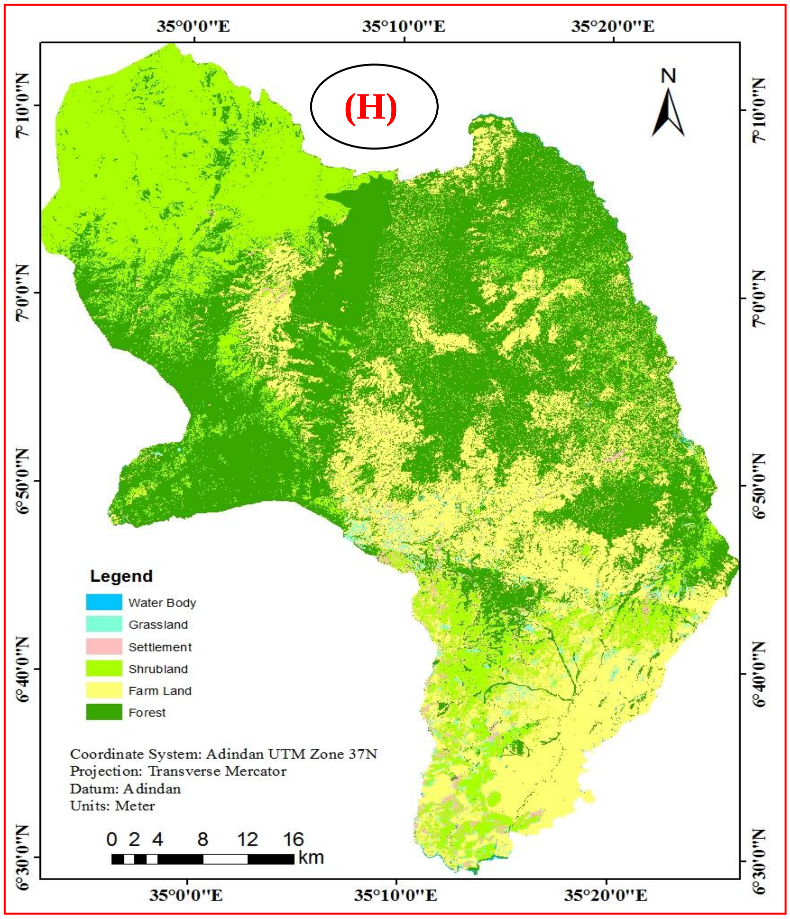


Figure 15: map of land use land cover of the study area (H)

Table 5: Summary of areas of land use/ land

LULC Classes	Area (Ha)	Percentage (%)
Settlement	5741.1	2.24
Forest	114081	44.53
Shrub	63321.6	24.71
Grassland	2497.14	1.0
Farmland	69973.4	27.31
Water Body	555.57	0.21
Total	**256169.81**	**100**

4.1.2. Factor (criteria ratings)

Coffee growing or potential area needs suitable land use land cover, slope, sufficient moisture availability, and fertile soil for growth. These are the most important requirements common for all agricultural crops in general and coffee cultivation in specific.

Thus, as a first step, compilations of the coffee growing potential area requirements that will be considered in the evaluation were made. In the present study, requirements for land use land cover, slope, rainfall/moisture availability, and soil were assessed for the selected cash crop according to the environment of the study area. Then, the second stage is to decide on the factor ratings for each parameter. Factor ratings are sets of values showing how well each factor/criterion is satisfied by specific conditions of the corresponding land quality. In general, Factor ratings are usually made in terms of five classes: Highly suitable (S1), moderately suitable (S2), marginally suitable (S3), currently not suitable (N1), and Permanently not suitable (N2) (FAO, 1985; 1993).

In establishing the factor rating table (table 6) reference were made to: national manuals, guidelines, research station publications, and relevant literature. In addition, local agricultural experts experience and opinion were considered in arriving at a factor rating of a given land use that can be used in the matching processes.

Table 6: Rating of factors (criteria for coffee growing area)

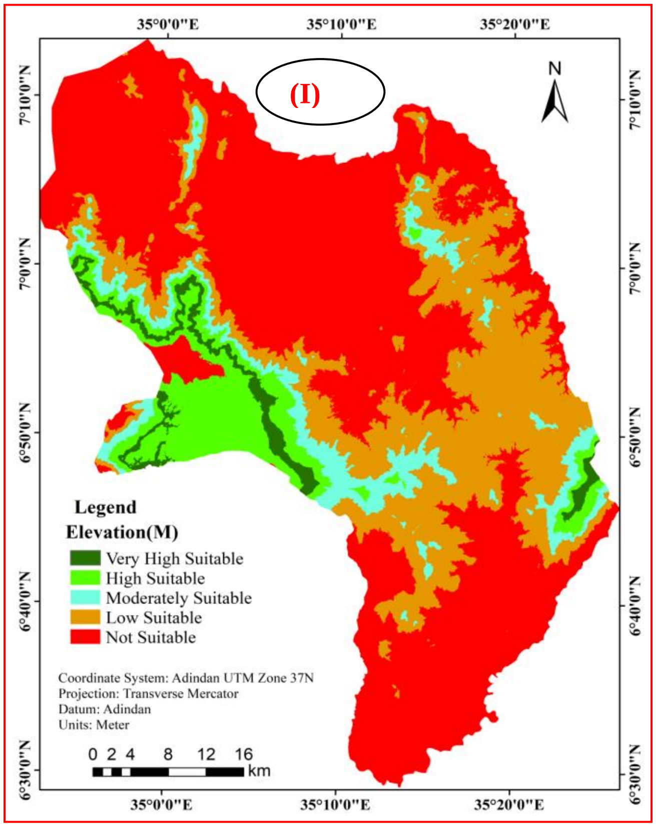
Type of crop	Factor (Criteria)for selecting coffee potential area	Range of suitability				
		Very high suitable (s1)	high Suitable (S2)	Moderately Suitable (S3)	Low suitable (s4)	Very low suitable (s5)
Coffee	Elevation (m)	1600-1800	1400-1600 & 1800-2100	1200-1400	1000-1200	<1000 >2100
	Slope (%)	0-4%	4-12%	12-25%	25-50%	>50%
	Rain fall (mm)	1400-1600	1200-1400& 1600-1800	1000-1200& 1800-2000	800-100& >2000	<800
	Rain fall distribution (m/y)	9-10 month/year	8-9 month/year	7-6 month/year	4-5 month/year	<4 month/year
	Relative humidity (%)	>75	70-75	60-70	50-60	<50
	Temperature (°c)	18-21	16-18	15-16& 21-25	14-15&25-26	<14 & >26
	Soil texture	vertisols	nitosols & andosols	cambisols & luvisols	lithosols	Yermosols & xerosols
	Soil ph	5.3-6.5	5.3-4.9& 6.5-6.8	4.9-4.4.4& >6.8	4.4-4.00	<4.00
	Soil depth (cm)	>150	100-150	<100-75	<75-50	<50
	Soil drainage	Excessive drained soil	Well-drained soil	Moderately drained	Marginally drained	Poor drained
	Land use land cover	forest	Shrub& settlement	grass land	Farm land	Water body

4.2. Standardization and reclassification Criteria

The coffee land suitability analysis evaluation criteria discussed above are typically non commensurate (i.e. not measured using compatible units). To make them comparable a standardization of each factor is required (Malczewki, 1996). There are a number of methods that can be used to make the attribute map layers comparable. The present study used the module named Re-class (in ArcGIS environment) for standardization/reclassification of the factors.

- Reclassifying Elevation and slope

Reclassification means assigning higher or lower values to more suitable locations, or cell values. In this study, the suitable elevation and slope values are represented. Thus, it is reclassified in to five suitability classes in accordance with the FAO (1993) suitability class. Since the range of the new reclassified value is 1-5, the value of 1 takes the most suitable values where as 5 takes the least suitable.



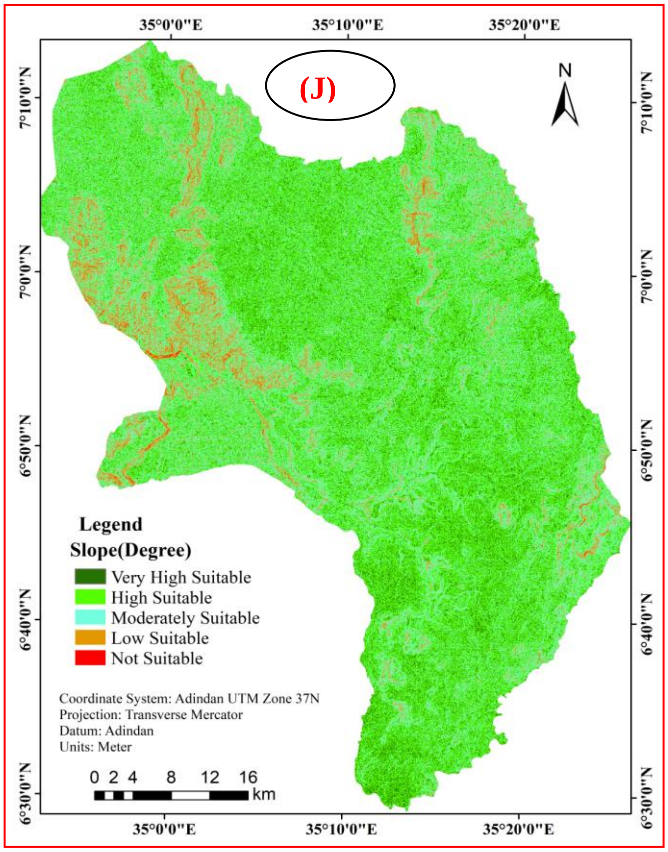


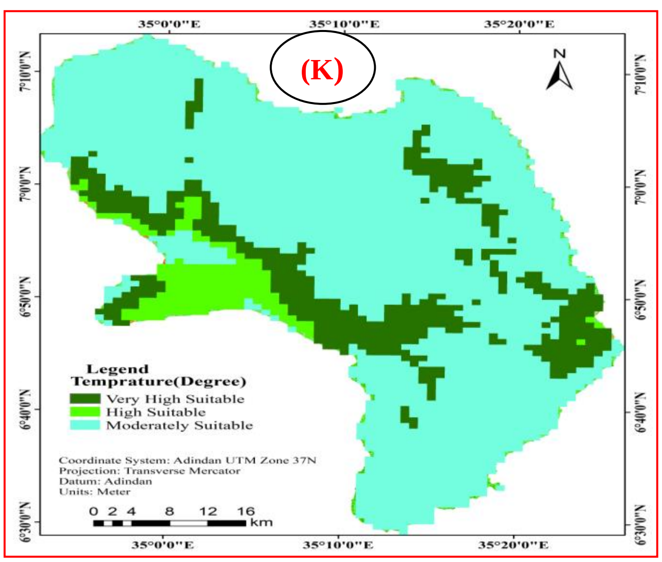
Figure 16: Standardized factor maps for coffee suitability analysis (I=Elevation, J= slope)

Table 7, Suitability classes versus area for elevation and slope.

Elevation					
OBJECTID *	Shape *	Grid code	Suitability Rank	Area (Ha)	Percentage (%)
2	Polygon	1	Very High Suitable	6108.09	2.38
3	Polygon	2	High Suitable	20929.85	8.17
4	Polygon	3	Moderately Suitable	17199.69	6.71
5	Polygon	4	Low Suitable	64268.89	25.1
6	Polygon	5	Not Suitable	147663.29	57.64
				256169.81	100
Slope					
OBJECTID *	Shape *	Grid code	Suitability Rank	Area (Ha)	Percentage (%)
1	Polygon	1	Very High Suitable	28218.2	11.01
2	Polygon	2	High Suitable	129256.25	50.45
3	Polygon	3	Moderately Suitable	77435.86	30.24
4	Polygon	4	Low Suitable	20759.75	8.1
5	Polygon	5	Not Suitable	499.75	0.2
				256169.81	100

- Reclassified Rainfall, Relative humidity and Temperature

Temperature, relative humidity and rainfall surface were reclassified in to common scale with the assumption that the higher the rainfall amount the more suitable the area will be. Like other suitability factors, rainfall, relative humidity and temperature maps were reclassified in to five suitability classes ranging from 1 to 5 where 1 indicates the most suitable and 5 the least suitable areas.



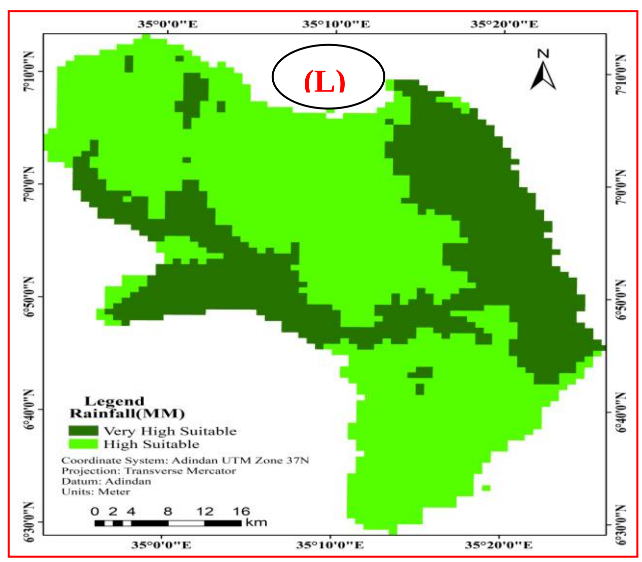


Figure 17: Standardized factor maps for coffee suitability analysis (K= temperature, L= rainfall) maps of the study area.

Table 8: Suitability classes with area coverage for (rainfall and temperature).

Temperature					
OBJECTID *	Shape *	Grid code	Suitability Rank	Area (Ha)	Percentage (%)
1	Polygon	1	Very High Suitable	43881.12	17.12
2	Polygon	2	High Suitable	14646.88	5.73
3	Polygon	3	Moderately Suitable	197641.81	77.15
	Total			256169.81	100
Rainfall					
OBJECTID *	Shape *	Grid code	Suitability Rank	Area (Ha)	
1	Polygon	1	Very High Suitable	93889.29	36.65
2	Polygon	2	High Suitable	162280.52	63.35
	Total			256169.81	100

- Reclassifying soil texture, soil Ph, soil depth and soil drainage

The major soil types are converted to raster format and then reclassified based on their suitability rate. In the new reclassified evaluation scale of 1 to 5, 1 represents the highest suitability and 5 the lowest suitability.

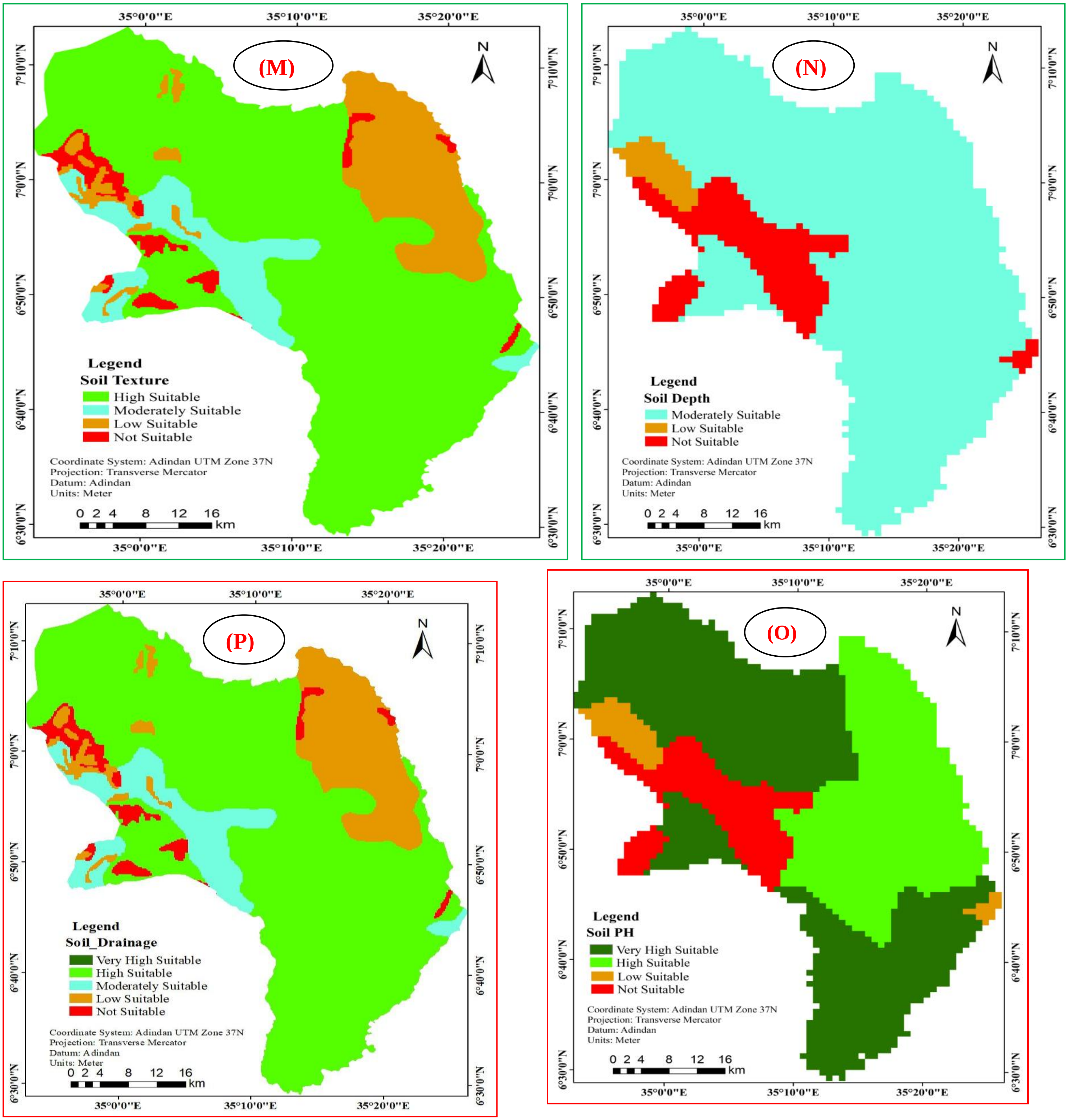


Figure 18: Standardized factor maps for coffee suitability analysis (M-soil texture, N- soil Depth, O-soil ph and P-soil drainage) of the study area

Table.9: Area coverage of soil drainage, texture, depth, and pH with respect to suitability classes.

Soil Texture					
Shape *	gridcode	SOIL_TYPE	Suitability Rank	Area (Ha)	Percentage (%)
Polygon	1	dystric nitisols/orthic acrisols	Very High Suitable	185033.29	72.23
Polygon	2	eutric cambisols	High Suitable	23486.98	9.16
Polygon	3	orthic solonchaks/leptosols	Moderately Suitable	39110.34	15.28
Polygon	4	calcic xerosols/gypsic yermosols/dystric gleysols	Low Suitable	8539.2	3.33
	Total			256169.81	100
Soil Drainage					
Shape *	Grid code	SOIL_TYPE	Suitability Rank	Area (Ha)	Percentage (%)
Polygon	1	dystric nitisols/orthic acrisols	Very High Suitable	185016.01	72.2
Polygon	2	orthic solonchaks/eutric cambisols	High Suitable	58020.94	22.6
Polygon	3	leptosols	Moderately Suitable	4690.43	1.9
Polygon	4	dystric gleysols	Low Suitable	3433.11	1.3
Polygon	5	calcic xerosols/gypsic yermosols	Not Suitable	5009.32	2
	Total			256169.81	100
Soil PH					
OBJECTID *	Shape *	gridcode	Suitability Rank	Area (Ha)	Percentage (%)
1	Polygon	1	Very High Suitable	137228.56	53.56
2	Polygon	2	High Suitable	80916.58	31.6
3	Polygon	4	Moderately Suitable	8761.92	3.42
4	Polygon	5	Not Suitable	29262.75	11.42
	Total			256169.81	100
Soil Depth					
OBJECTID *	Shape *	gridcode	Suitability Rank	Area (Ha)	Percentage (%)
1	Polygon	3	Moderately Suitable	218002.72	85.1
2	Polygon	4	Low Suitable	7029.47	2.75
3	Polygon	5	Not Suitable	31137.62	12.15
	Total			256169.81	100

- Reclassified Land use /Land cover

Finally, the raster data format of land use/land cover was reclassified in to a common scale in order of their suitability. Thus, from the reclassified version, 1 stands for the most suitable whereas 5 for the least suitable.

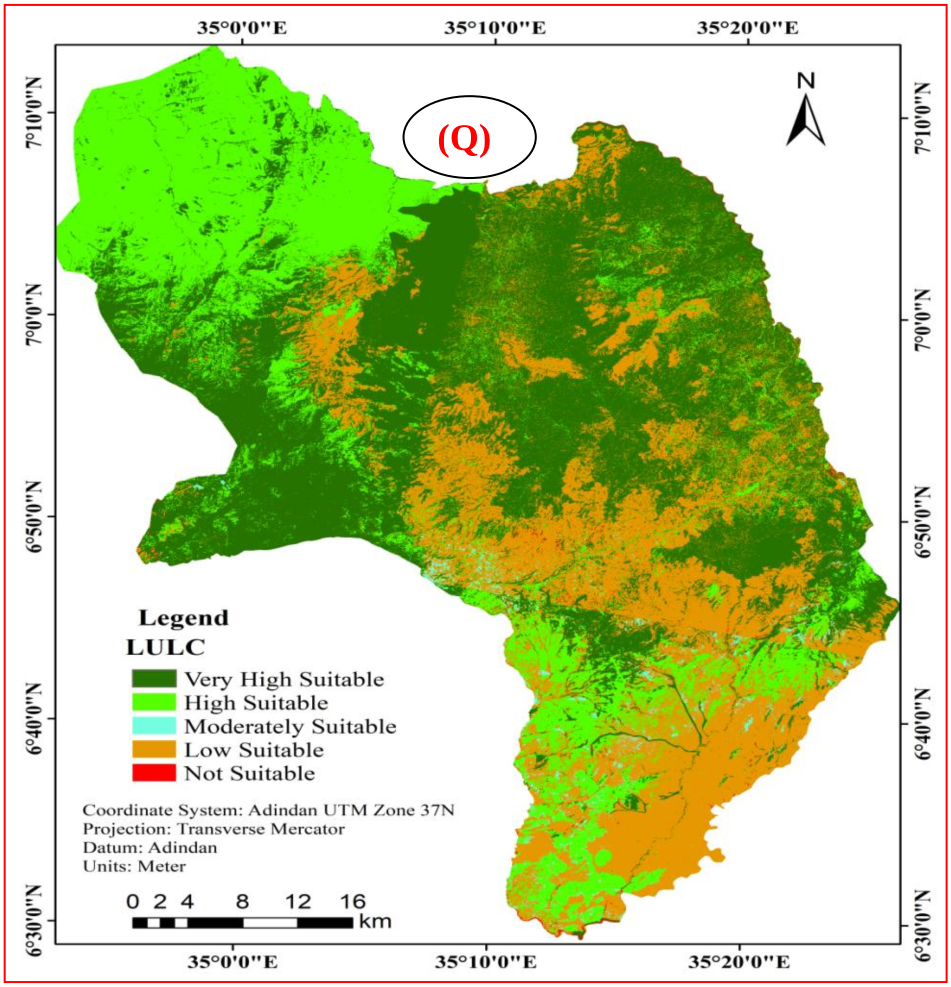


Figure 19: Standardized factor map for coffee suitability analysis (Q-LULC)

Table 10: Suitability classes versus area for LULC

LULC					
Shape *	Grid code	Class_Name	Suitability Rank	Area (Ha)	Percentage (%)
Polygon	1	Forest	Very High Suitable	115266.28	45
Polygon	2	Settlement/Shrub land	High Suitable	67225.83	26.24
Polygon	3	Grassland	Moderately Suitable	2329.08	1
Polygon	4	Farm Land	Low Suitable	70838.8	27.66
Polygon	5	Water Body	Not Suitable	509.82	0.1
	Total			256169.81	100

4.3. Assigning criterion weights

Spatial decision problems typically involve criteria of different importance to the decision maker's (Malczewski, 2000). Accordingly, information about the relative importance of the criteria is required. The derivation of weights is a central step in provoking/eliciting the decision maker's preferences. The Multi Criteria Evaluation (MCE) technique, weights can be obtained by taking the principal eigenvector of a square reciprocal matrix of pair wise comparisons between the criteria (Malczewski, 2003; Eastman, 2006).

Therefore, in IDRISI, the weight module uses the pair wise comparison method to support develop a set of factor weights that will sum to 1.0 (Table 11). In a pair wise comparison matrix, factors are compared two at a time in terms of their importance relative to the stated objective.

In developing weights, a person or a group associates any possible pairing and enters the ratings into a pair wise comparison matrix or *ratio matrix* (Eastman, 2006). Since the matrix is symmetrical, it is only important to simply fill in the lower triangle. The remaining cells are then essentially the lower triangle's reciprocals. To this end, after discussion and careful analysis of the set of evaluation criteria with experts, all the pair wise comparisons for the set of the considered criteria were made. After all possible combinations of two factors are compared; calculates a set of weights and, importantly, a consistency ratio. This ratio indicates any inconsistencies that may have been arisen during the pair wise comparison process. Second allows repeated adjustments to the pair wise comparisons and reports the new weights and consistency ratio. Figure 19 reveals the AHP weight derivation interface to derive the weights for the factors for coffee cultivation.

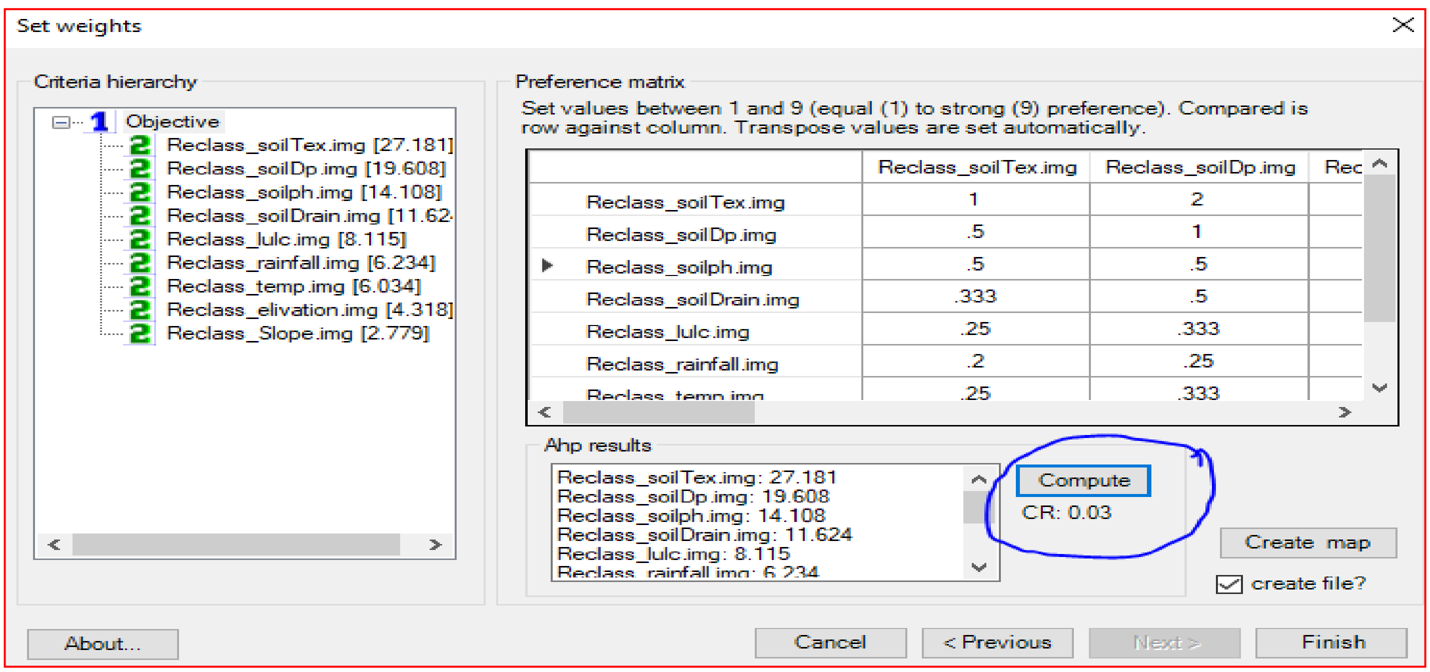


Fig.20: A pair wise comparison matrix for assessing a comparative importance of the factors for coffee growing suitability assessment.

Table 11: Pair wise Comparison Matrix of Coffee Growing Land Suitability.

	Soil Texture	Soil Depth	Soil Ph	Soil Drainage	LULC	Rf	Temperature	Elevation	Slope
Soil Texture	1	2	3	4	5	6	7	8	9
Soil Depth	0.5	1	2	3	4	5	6	7	8
soil Ph	0.5	0.5	1	2	3	4	5	6	7
Soil Drainage	0.333	0.5	0.5	1	2	3	4	5	6
LULC	0.25	0.333	0.5	0.5	1	2	3	4	5
Rainfall	0.2	0.25	0.333	0.333	0.5	1	2	3	4
Temperature	0.25	0.333	0.5	0.5	0.5	0.5	1	2	3
Elevation	0.25	0.25	0.333	0.333	0.5	0.5	0.5	1	2
Slope	0.143	0.2	0.25	0.25	0.333	0.333	0.333	0.5	1

4.4. Aggregating the criterion weights and the reclassified criterion maps

GIS can be used not only for automatically generate maps, but it is special or unique in its capability or ability for integration and spatial analysis of multisource datasets (Malczewski, 2003). These data are handled and investigated to obtain information useful for a particular application such as land suitability analysis. Once the criteria maps (factors and constraints) are developed (established), an evaluation (aggregation) stage is undertaken to combine (associate) the information from the various factors and constraints. In the background (context) of GIS, three decision rules i.e. weighted overlay, Boolean overlay, and ordered weighted averaging are common for MCE (Jiang and Eastman, 2000; Malczewski, 2000; Malczewski, 2003). The simplest (modest) type of aggregation is the Boolean intersection or logical AND. This method (process) is only used when factor maps are strictly grouped or categorized into suitable/unsuitable Boolean images with values of 1 and 0. The evaluation is simply (basically) the multiplication of all the images. The present study, however, adopts the weighted overlay technique for developing the suitability maps for each land use types and vector overlay analysis for deriving composite suitable land allocation map.

4.5. Buffer Analysis for constraints of coffee farming areas.

Buffer analysis is used for finding or identifying areas surrounding geographic features. The method involves creating or generating a buffer around existing geographic features and then identifying or selecting features based on whether they fall within (inside) or beyond (outside) the buffer boundary.

In this study to identify the best locations coffees farming suitable sites the constraints were extracted. **Constraints**: These are lands which are not important to be a part of the suitability. Those are towns, water bodies and roads. Coffee growing area far from 2km from towns to prevent towns from shading leafs, far from main roads in 10m and far from 5m from rivers and water bodies to prevent toxic gases and water logging respectively.

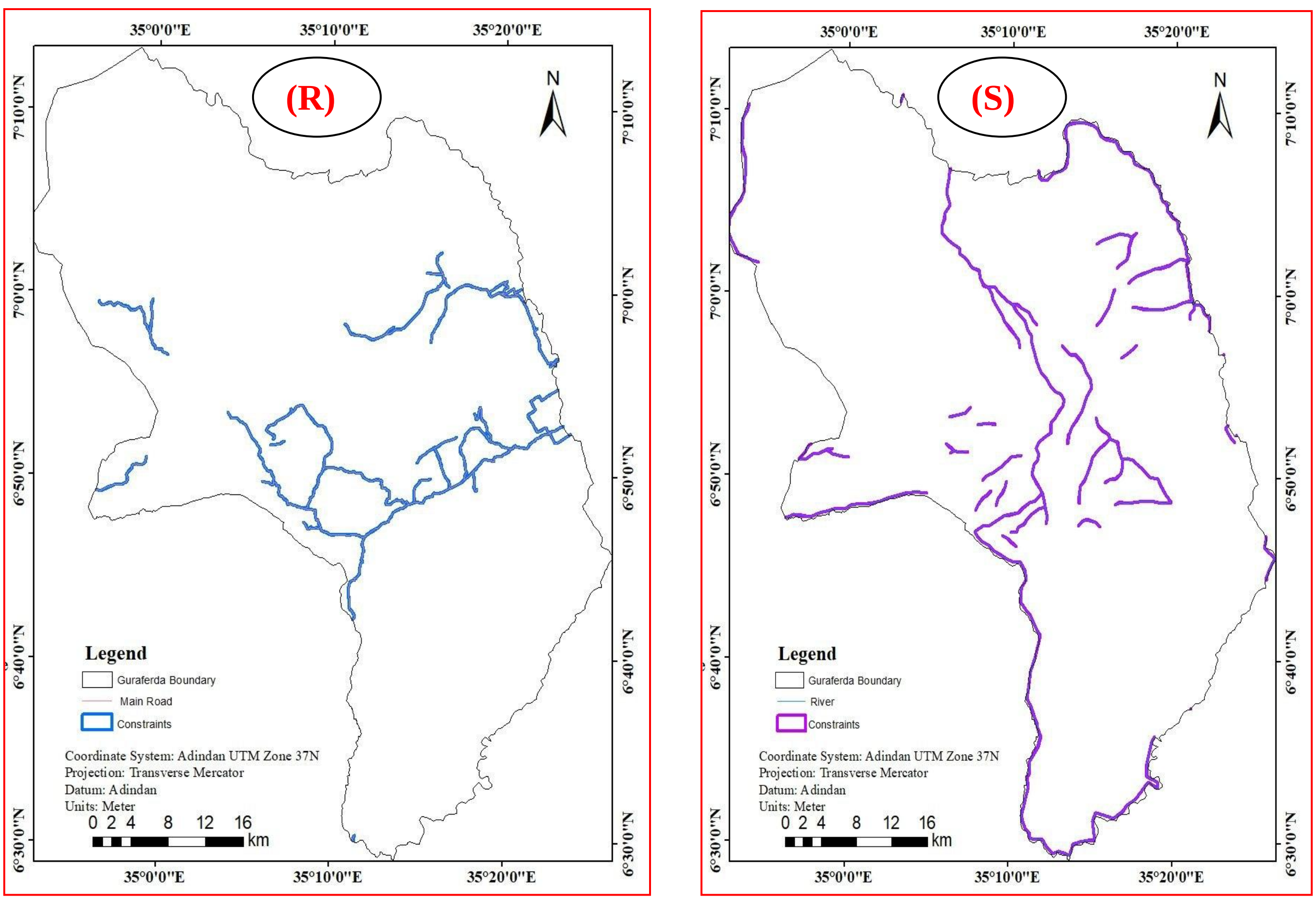


Figure 21: constraint maps with buffer (R= roads & S= water bodies)

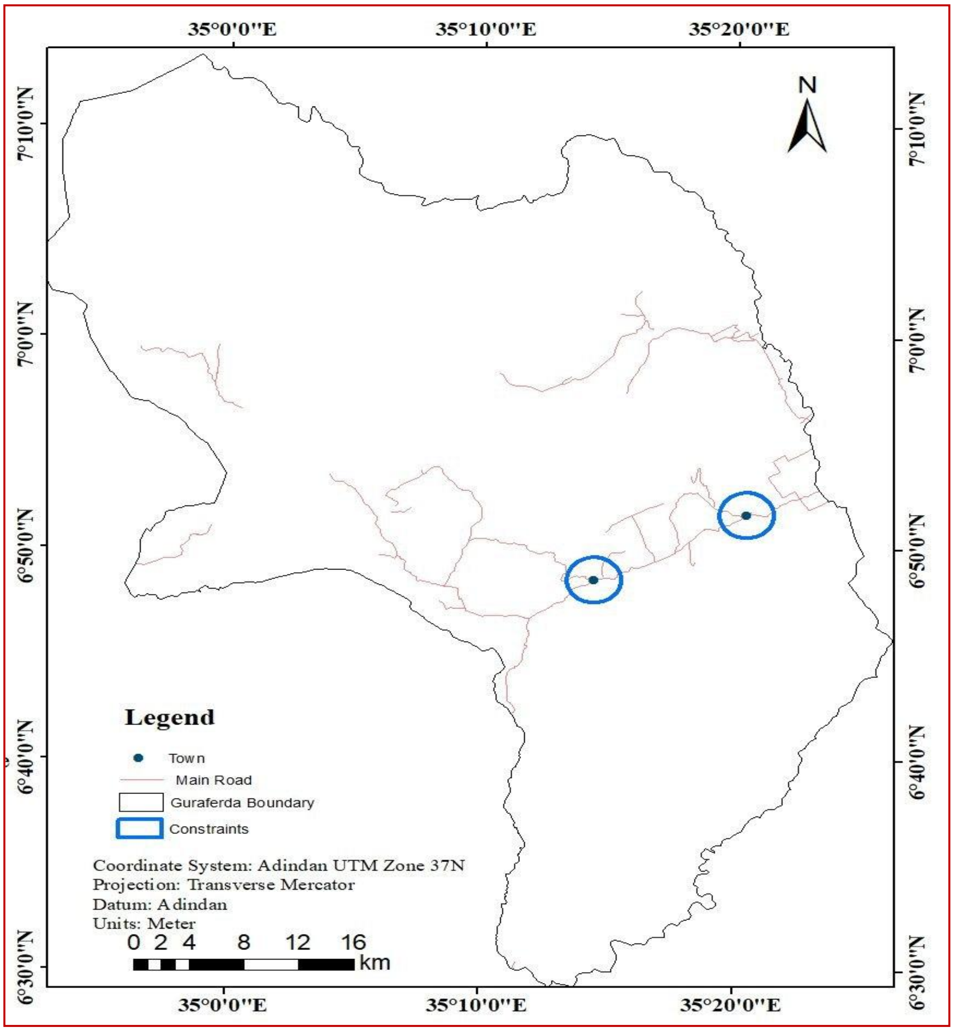


Figure 22: constraint maps with buffer T= towns)

4.6. Overlaying and suitable sites

AHP pair wise comparison matrix was created and criteria weights were calculated for each factor by comparing factors using a scale with values. The reclassified input datasets were assigned a weight value to express the importance of each criterion to the other criteria for suitable site selection for potential coffee growing area. In order to select suitable sites for coffee cultivation all the reclassified input datasets were overlaid using the weighted overlay tool or a raster calculator in ArcGIS by this final coffee suitability map was made.

4.7. Suitability Analysis Results for coffee growing areas.

The weighted overlay analysis result showed three classes of lands. These are: highly suitable, moderate suitability and Low suitable for potential coffee growing area of the study area (as shown in figure 17 below).

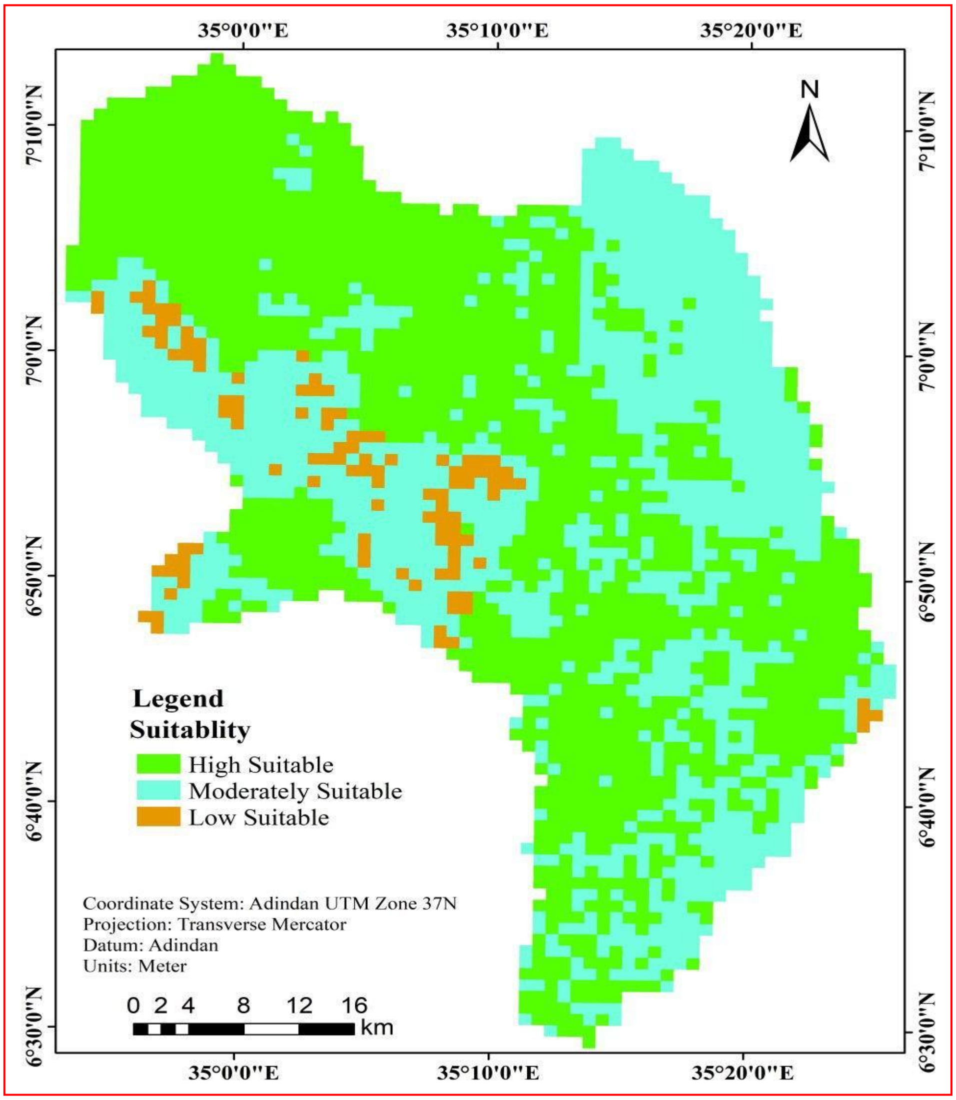


Figure 22: Final suitability map of the study area raster

The areal coverage of each suitability class for coffee growing area of study was calculated after converting the raster output of the weighted overlay to a polygon feature and dissolving the result in a GIS platform.

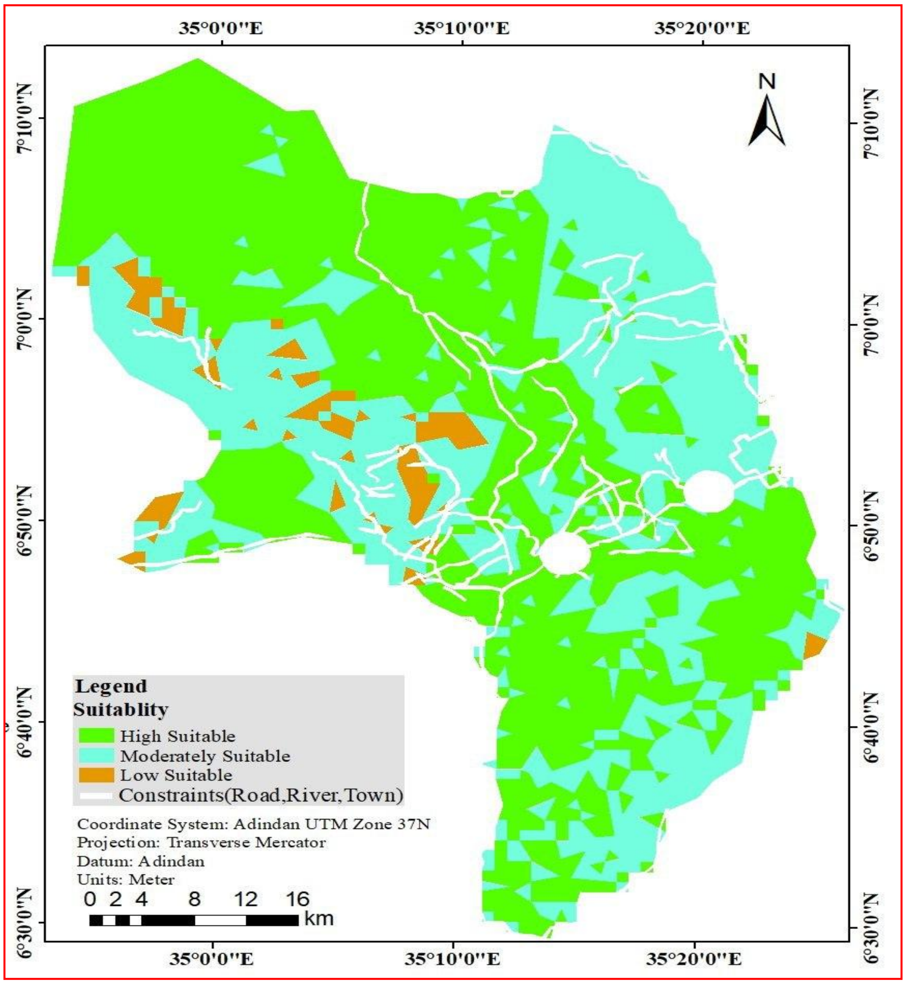


Figure 24, Final coffee suitability map of the study area.

According to GIS-based MCA, 146,519 and 101,233 hectares are highly suitable and moderately suitable for potential coffee growing area. The remaining the small portion area is less suitable for potential coffee growing which covers 3.3% % (8417 ha) of the area (Table 12).

Table 12: Suitability area and percent of total area coverage

FID	Shape *	grid code	Area	Percentage (%)
0	Polygon	High Suitable	146519.21	57.19
1	Polygon	Moderately Suitable	101233.33	39.51
2	Polygon	Low Suitable	8417.27	3.3
	Total		256169.81	100

According to Guraferda woreda Agriculture office report 28,000 hectors were covered by coffee plantation this is very much low compared to its suitability sites. That is 146519.21 hectares highly suitable and 101233.33 hectares moderately suitable.

CHAPTER FIVE

5. Conclusions and Recommendations

5.1. Conclusions

GIS and Remote Sensing -based land evaluation approach or method can provide thematic layers that enable the formulation of dynamic circumstances for integrating information. The integration process with geographic references is widely accepted (recognized) for implementing spatial decision support systems. Application of Remote Sensing (RS) and GIS techniques are vital important to identify suitable areas for coffee cultivation. The results obtained from this study indicate that the integration of Remote Sensing and GIS application of Multi-Criteria Evaluation using Pair wise Comparison Matrix could provide a superior database and guide map for decision makers.

The main aim of the study was to identify the suitable land parcels for coffee cultivation in Guraferda district. Integrating MCE with GIS for spatial decision making process is a worthwhile technique. The parameters used for the evaluation of land suitability for coffee potential growing area are soil (depth, drainage, texture, and pH), rainfall, Relative humidity, temperature, elevation, slope and land use/ land cover.

After setting the parameters and criteria's working different GIS based analysis were made, to identify the potential coffee growing areas of the district.

Integrating MCE with GIS for spatial decision making process is a worthwhile technique. The study used weighted overlay technique of MCE in a GIS platform to arrive at the final land suitability for favorable coffee growing sites. As per the suitability analysis result, 57% of the total study area is most suitable for the coffee cultivation. The current coffee cultivated land is very low as compared to the potential area of coffee suitability land. Furthermore, with regard to coffee suitability analysis, 39.51% of the study area is moderately suitable for coffee cultivation and the remaining 3.3% of the study area is low suitable. This means that 97% of the study area favorable for coffee growing area, while the remaining 3% of the total area is not more suitable.

5.2. Recommendations

- A parcel of land has to be examined to provide its optimum yield. Hence, land suitability analysis for coffee growing areas using multi-criteria evaluation in a GIS environment is one of the appropriate ways to increase export income of the country in general, and the study area in particular.
- Coffee cultivation fulfills the sustainable development elements (environmentally friendly or green environment, economically important and socially embedded with culture) then government give attention by identifying favorable coffee growing sites.
- The parameters used for land suitability analysis for coffee cultivation were focused based on the physical factors like soil, temperature, rainfall, land use/land cover and slope, for Specific requirement is more focused in this paper. But other parameters like human factors (security, labor, socio-economic, market, infrastructure etc. are recommended to be included.
- The LUTs considered in this study are limited only one cash crop (coffee). To increase the choice for the decision makers as well as for the stake holders, further analysis for different LUTs is necessary. Therefore, further research has to be conducted for different LUTs which include cereals, pulses, oilseeds, honey production, livestock, etc to identify the best alternative use for a specific parcel of land.
- Coffee in Ethiopia not only generating income but also deeply embedded in Ethiopian culture, identifying suitable coffee growing areas are important for the growth of national economy and its culture. So, coffee investors and other stakeholders use their land for coffee cultivation.
- The land suitability analysis of potential coffee growing area was conducted as the woreda or district level. Since, Ethiopia is the center of origin and genetic diversity of coffee and Coffee plays crucial role in generating foreign currency to the country at large level. Future studies should consider identifying favorable coffee growing areas as Regional level as well as the national level by adding some parameters.

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