10

ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
DEPARTMENT OF EARTH SCIENCE

LAND SUITABILITY AND CROP SUITABILITY ANALYSIS USING REMOTE SENSING AND GIS APPLICATION; A CASE STUDY IN LEGAMBO WOREDA, ETHIOPIA

BY HENOK MULUGETA

Dissertation Submitted for Partial Fulfillment of the Requirements for the Award of the Degree of Master of Science in Remote Sensing and Geographical Information Systems (GIS)

June, 2010
ADDIS ABABA, ETHIOPIA

ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

DEPARTMENT OF EARTH SCIENCE

LAND SUITABILITY AND CROP SUITABILITY ANALYSIS USING REMOTE SENSING AND GIS APPLICATION. A CASE STUDY IN LEGAMBO WOREDA

BY HENOK MULUGETA

Dissertation Submitted for Partial Fulfillment of the Requirements for the Award of the Degree of Master of Science in Remote Sensing and Geographical Information Systems (GIS)

Approved By Board of Examiners:

Dr. Balemwal Atnafu
Chairman, Department
Graduate Committee

Dr. Dagnachew Legesse
Advisor

Prof. M. Balakrishnan
Examiner

Dr. Mohammed Umer
Examiner

ACKNOWLEDGMENTS

I am greatly indebted to my Advisor, Dr. Dagnachew Legesse for his guidance and helpful advice to accomplish this study. His review and comments on the manuscript are highly appreciated. In addition, the discussion I made with him on this thesis was very important. I duly acknowledge his contribution to realize this study.

I would like also to thank the staff of Earth Sciences Department of Addis Ababa University, specially Dr. K.V. Suryabhagavan, who helped me to use the computer laboratory and materials at any time.

I wish to express my thanks to my friends, Hudad Barry, Merkebu Kassaw, Abiy Debay, Habtom Alem, Abenet Germa, Tsehay Getachew, Shewangezaw Kebede and Dawit Yerga, who have been the source of my strength and motivation starting from the beginning to the end of this research.

Words cannot express the feelings that I have for my parents, brothers and sisters. I am highly indebted to them for their blessings, guidance, advice, encouragement and support to accomplish my study.

Specal thanks goes to Senayet Sheferaw, Samson Debalke, Tekele Debalke and Meseret Debalke for their financial support , when I was in need.

Finally, I would like to thank my sponsor Rural Capacity Building Project for their financial and material support.

Contents

List of Tables

List of Figures

Lists of Acronyms

AHP	Analytic Hierarchy Process
DEM	Digital Elevation Model
EMA	Ethiopian Mapping Authority
ERDAS	Earth Resource Data Analysis System
EROS	Earth Resources Observation Systems
ETM+	Enhanced Thematic Mapper Plus
FAO	Food and Agriculture Organization
GIS	Geographic Information System
GPS	Global Positioning System
IDW	Inverse Distance Weighted
LU/LC	Landuse/ Land cover factor
LUTs	Land Utilization Types
m.a.s.l	Meter Above Sea Level
MCDM	Multi-Criteria Decision Making
MCE	Multi-Criteria Evaluation
MOA	Ministry of Agriculture
NMSA	National Meteorological Agency
SLC	Scan Line Corrector
USGC	United States Geological Survey
USDA	United States Department of Agriculture

Abstract

The present study was carried out to evaluate the suitability of the land for agricultural crop production by using Remote Sensing and GIS application. The evaluation of land in terms of suitability classes was based on the method described in FAO guideline for land evaluation. The factors that were considered for evaluation of the land suitability for crop production were slope, soil drainage, soil texture, soil depth, soil type and the present landuse of the study area. Multi-criteria decision evaluation method was used to evaluate the physical land characteristics of the study area for crop production. The techniques, which were used to weigh and standardized the factors were pair-wise comparison and weighted linear combination. After evaluating the physical land suitability for agricultural crop, land suitability map was developed. This map was classified in to five suitability classes based on FAO guidelines. From the total land of the study area 100 km^2 (9.2%) was very suitable, 257 km^2 (23.6%) was suitable, 293 km^2 (26.9%) was marginally suitable, 390 km^2 (35.8%) was not suitable and 49 km^2 (4.5%) was permanently unsuitable for agriculture. The land in the study area was also evaluated for suitability of wheat and maize production. In addition to the factors mentioned above, temperature and rainfall of the study area were used for crop suitability evaluation. Suitability maps for both wheat and maize were developed. The crops suitability maps were classified in to five suitability classes. The result shows that 82 km^2 (7.5%) was very suitable, 249 km^2 (23%) was suitable, 483 km^2 (44.4%) was marginally suitable, 240 km^2 (22%) was not suitable and 35 km^2 (3.1%) was permanently unsuitable for wheat production. Regarding suitability of maize 92 km^2 (8.5%) was very suitable, 299 km^2 (27.4 %) was suitable, 321 km^2 (29.4%) was marginally suitable, 262 km^2 (24.2%) was not suitable and 114 km^2 (10.5%) was permanently unsuitable. The evaluation of physical land qualities of the study area indicates that the study area has a potential for agricultural crops.

Keywords: Land suitability; Crop suitability; MCDM; Pair-wise comparison

Chapter One

1. Introduction

1.1 Background and Justification

Agriculture is a dominant sector in Ethiopia. It contributes 51 percent to the GDP, employs nearly 85 percent of the total labor force and generates the bulk of foreign exchange. Smallholder farms are predominant, account for more than 90 percent of agricultural production and over 95 percent of the total area under cultivation. However, given the poor performance of the agricultural sector in relation to the fast growing population, intensification of agriculture is critical. This calls for judicious planning of land resources to sustain agricultural production to meet the ever increasing demand for food, while achieving environmental protection.

The concept of sustainable agriculture involves producing quality crops in an environmentally friendly, socially acceptable and economically feasible way (Addeo et al. 2001). This implies optimum utilization of the available natural resource for efficient agricultural production. An efficient agricultural production system requires proper planning and timely management of available agricultural areas under an appropriate land allocating scheme. Obviously, such a scheme includes an evaluation of land capability and determination of suitability of each of these areas for different agricultural crops.

Agricultural crop production is determined by land characteristics namely elevation, slope, aspect, soil (pH, drainage and texture), landcover and climatic factors. All these factors collectively determine the suitability of a given area for a particular type of crop cultivation. Thus, in order to build up an efficient crop production system, evaluation of land suitability from time to time is essential.

The process of land suitability classification is the evaluation and grouping of specific areas of land in terms of their suitability for a defined use. This suitability is a function of crop requirements and soil/land characteristics. Matching the land characteristics with the crop requirements gives the suitability. Hence, suitability is a measure of how well the qualities of a land unit match the requirements of a particular form of landuse (FAO, 1976). According to the FAO methodology (1976), the land qualities such as erosion resistance, water availability, and flood hazard are not measurable. But, as these qualities derive from the "land characteristics", such as slope angle and length, rainfall and soil texture, which are measurable or estimable, it is advantageous to use these later values to study the suitability of the land for the intended use.

This thesis aims to identify the potential land suitability for agricultural crop production based on the physical properties of the land in accordance with the framework for land evaluation developed by Food and Agriculture Organization FAO, 1976) using Remote Sensing and GIS application as decision support system involving the integration of spatially referenced data in a problem solving environment.

1.2 Statement of the problem

The study area, Legambo Woreda, is one of the 52 chronically food insecure Woredas in the Amhara Regional State of Ethiopia that are regularly affected by drought. The topography of the Woreda is mountainous, rugged and undulated coupled with inappropriate landuse and land management practices reinforced by the population growth, which has led the Woreda to suffer from severe land degradation and consequent decline in crop and livestock production and productivity. As a result of the decline in agricultural productivity, the Woreda has been depending on food aid for more than 20 years.

The factors contributing in the decline of agricultural productivity are numerous, which are acting together to tighten the strings of deprivation of the farm households in the

Woreda. The crop plots are small and fragmented. The scarcity of cultivable land has enforced them to cultivate on very steep slope mountain cliffs and also to clear forest lands. This has led to soil erosion, flooding and natural resources degradation. Besides that, the agricultural lands are depleted of nutrients, due to improper landuse and land management practices.

1.3 Significance of the Study

The problems that limit the productive capacity of land resources in the study area can be categorized by climate, soil and land forms. In this regard, assessment of the land suitability can be an important tool for agricultural development planning. As it leads to an assessment of land suitability and potential productivity in terms of climate, soil and land forms condition. It is applicable in micro or local level planning mainly for rainfed agriculture. It assesses basically the yield potentialities of various crop conditions, evolves future plan of action involving crop diversification and determines suitability of different crops for optimizing landuse predictions.

In order to achieve sustainable and rapid agricultural development, it is necessary to identify real development opportunities for each land suitability classes so as to be able to fully utilize them. Therefore, this research is deemed necessary to resolve the study area problems mentioned above.

1.4 Limitation of the study

Due to shortage of data on the chemical properties of soils in the study area, the chemical properties of soil were not evaluated for land suitability and crops suitability analysis. Only the physical characteristics of the land under the study area were evaluated.

As there was no adequate time and budget to collect and analyze the soil physical and chemical characteristics of the study area, FAO soil map in 1:1 million scale obtained from the Ministry of Water Resource Development was used in this study.

1.5 Objectives

1.5.1 General objective

The general objective of the study was to evaluate the land physical characteristics and its quality for land suitability of main agricultural crops in Legambo Woreda.

1.5.2 Specific Objectives

- To examine the physical properties of the soil i.e. soil texture, soil drainage, soil depth and soil types found in the study area.
- To develop land suitability map of the study area.
- To develop crop suitability map of the study area
- To determine suitability of wheat and maize for land use optimization.

Chapter Two

2. Literature Review

2.1 Land Suitability Analysis

The process of land capability classification is the evaluation and grouping of specific areas of land in terms of their suitability for a defined use. The main objective of the land evaluation is the prediction of the inherent capacity of a land unit to support a specific land use for a long period of time without deterioration, in order to minimize the socio-economic and environmental costs (FAO, 2003). Land suitability analysis is an interdisciplinary approach by including the information from different domains like soil science, crop science, meteorology, social science, economics and management. Being interdisciplinary, land suitability analysis deals with information, which is measured in different scales like ordinal, nominal and ratio scale. Based on the scope of suitability, there are two types of classifications.

- **Current suitability**: This refers to the suitability for a defined use of land in its present condition, without any major improvements in it.
- **Potential suitability**: This refers for a defined use of the land units in their condition at some future date, after specified major improvements have been completed where necessary.

2.2 Land characteristics, land qualities and diagnostic criteria

A land characteristic is an attribute of land that can be measured or estimated. Slope angle, rainfall, soil texture, available water capacity and biomass of the vegetation are examples of land characteristics. Land mapping units, as determined by resource surveys, are normally described in terms of land characteristics. If land characteristics are employed directly in evaluation, problems arise from the interaction between characteristics. For example, the hazard of soil erosion is determined not by slope angle alone but by the interaction between slope angle, slope length, permeability, soil structure and rainfall intensity. Because of this problem of interaction, it is recommended that the comparison of land with land use should be carried out in terms of land qualities.

A land quality is a complex attribute of land which acts in a distinct manner in its influence on the suitability of land for a specific kind of use. Land qualities may be expressed in a positive or negative way. Examples are moisture availability, erosion resistance, flooding hazard, nutritive value of pastures and accessibility. Where data are available, aggregate land qualities may also be employed, e.g. crop yields and mean annual increments of timber species. A land quality is not necessarily restricted in its influence to one kind of use.

There are large number of land qualities, but only those relevant to landuse alternatives under consideration need be determined. A land quality is relevant to a given type of land use if it influences either the level of inputs required, or the magnitude of benefits obtained, or both. For example, capacity to retain fertilizers is a land quality relevant to most forms of agriculture, and one which influences both fertilizer inputs and crop yield. Erosion resistance affects the costs of soil conservation measures required for arable use, whilst the nutritive value of pastures affects the productivity of land under ranching.

Land qualities can be estimated or measured directly, but are frequently described by means of land characteristics. Qualities or characteristics employed to determine limits of land suitability classes or subclasses are known as diagnostic criteria. A diagnostic criterion is a variable, which has an understood influence upon the output from, or the required inputs to, a specified use, and which serves as a basis for assessing the suitability of a given area of land for that use. This variable may be a land quality, a land characteristic, or a function of several land characteristics. For every diagnostic criterion there will be a critical value or set of critical values, which are used to define suitability class limits.

2.3 Role of GIS and Remote Sensing in land suitability analysis

GIS is the tool for input, storage and retrieval, manipulation and analysis, and output of spatial data (Marble et al. 1984). GIS functionality can play a major role in spatial decision-making. Considerable effort is involved in information collection for the suitability analysis for crop production. This information should present both opportunities and constraints for the decision maker (Ghafari et al. 2000). GIS have the ability to perform numerous tasks utilizing both spatial and attribute data stored in it. It has the ability to integrate variety of geographic technologies like Global Positioning System (GPS) and Remote Sensing. The ultimate aim of GIS is to provide support for spatial decisions making process (Foote and Lynch 1996). In multi-criteria evaluation many data layers are to be handled in order to arrive at the suitability, which can be conveniently achieved using GIS.

Remote sensing provides the information about the various spatial criteria/factors under consideration. Remote sensing can provide us the information like land use/cover, drainage density and topography. Many of the non-spatial parameters can also be inferred by looking at the various spatial parameters. Remote sensing in combination with GIS will be a powerful tool to integrate and interpret real world situation in most realistic and transparent way. Integrated GIS and Remote Sensing technology apart from saving time and yielding good data quality have the ability to locate potential new cropland sites (Leingsakul et al. 1993).

It has long been recognized that land suitability is assessed as part of a 'rational' cropping system (FAO, 1976) and optimizing the use of a piece of land for a specified work should be based upon its attributes. Furthermore, land may be considered either in its present condition, or after specified improvements. Although criteria may vary, they are essentially based on climate, soil, topography and water availability, which are the most important categories of environmental information required for judging land suitability. Assessing the suitability of an area for crop production requires considerable efforts in terms of information that presents both opportunities and limitations to decision-makers. A GIS is used to match the suitability for crops based on the requirements of the crop and the quality and characteristics of land.

2.4 Multi-Criteria Decision Making (MCDM)

Agricultural crop suitability involves integration information from various streams of science. There are many criteria upon which land suitability depends. The suitability analysis evaluates many alternative land use types under the light of various criteria from various streams. Alternatives here are competing with one another; criteria are both qualitative and quantitative. Decisions have to be taken at various levels starting from selecting the land utilization types (LUTs) till the allocation of the LUTs for area that suit best. So the suitability analysis is a multiple criteria decision-making process.

Earlier, the multi-criteria land suitability was assessed more non-spatially, assuming the spatial homogeneity over the area under consideration. This, however, is unrealistic in cases like land suitability studies, where decisions are made using criteria which vary across in space (Malczewski 1999). Non-spatial conventional MCDM techniques average or total the impacts that are judged appropriate for the whole area under consideration (Tkach and Simonovic 1997). To address the spatial decision making, MCE and GIS can be integrated (Jankowski 1995). MCE seems to be applicable in GIS-based land suitability analysis (Pereira and Duckstein 1993) for different crops.

Widely used MCE methods in the land suitability and suitability analysis are ranking and rating. These methods lack theoretical foundation in deciding the weights and have assign the weights rather arbitrarily. They do not take comparison among the criteria and classes into considerations. Moreover, the outcome of such analysis is aggregated using simple Boolean overlay or weighted aggregation. Both methods are supposed to yield similar results, which they never do. The reason is being with the logic of aggregation. The Boolean method of characterizing the criteria is too black and white. Boolean intersection (AND) results in a very strict output, i.e. if it fails to fulfill single criteria a region will be excluded from the results (Black). In contrast, Boolean union

(OR) will include an area in the result if that area fulfils a single criteria (white). Whereas, in the weighted linear combination the higher score of the rest can compensate low score on one criterion (Jiang and Eastman 2000). These ranking and rating methods are criticized for not reflect the decision maker's views clearly and also for not having any rationale behind the approach.

Ceballos-Silva and Lopez-Blanco (2003) used a matrix Pair-wise comparison for land suitability analysis. This method overcomes the problem of determining the weights. But they have not taken into consideration the hierarchical organization of the criteria, which is the basic principle of Analytical Hierarchy Process (AHP). Hence it shows that they have just used the matrix Pair-wise comparison as a tool to derive weights. AHP is a widely used method in decision-making (Saaty 1977; Saaty and Vargas 2001). It is developed to select the best from a number of alternatives with respect to several criteria. AHP allows for both the inconsistency in the decision and provide the means to improve the consistency. Here the decision maker or the user will perform simple Pair-wise comparison i.e. he/she will compare two elements at a time. The values of the Pair-wise comparison are determined according to the scale introduced by Saaty (1977). The available values for the comparison are the member of the set: {9, 8, 7, 6, 5, 4, 3, 2, 1, 1/2, 1/3, 1/4, 1/5, 1/6, 1/7, 1/8, 1/9}, 9 representing absolute importance and 1/9 the absolute triviality (Saaty 1980; Triantaphyllou and Mann 1994). The AHP gained high popularity because of easiness in obtaining the weights and capacity to integrate heterogeneous data, and therefore, AHP is applied in a wide variety of decision making process.

MCDM methods deal with real world problems that are multi-dimensional in nature. When it comes to environmental issue, the methods have to deal with heterogeneous criteria that are both qualitative and quantitative in nature. In order to incorporate heterogeneous information with different measurement scales, one has to bring them into a common domain of measurement. This process is called Standardization, a basic operation in MCE. Criteria should be standardized keeping in mind the goal and alternatives that are under evaluation. Standardization can change the outputs entirely if proper attention is not paid. For environmental criteria, there is a lack of valid and reliable standardization processes.

Decision-making is a subjective process, as the perception regarding a problem can diverge from person to person. One cannot expect a decision maker or an expert to be highly consistent while dealing with such a subjective process. The real world problems are influenced by many natural factors and processes, which are difficult to measure and model precisely. The decision situations are surrounded by uncertainty. Sensitivity Analysis is a way to address this uncertainty in estimating the parameters (Malczewski 1999). After the problem is evaluated for optimum conditions, sensitivity analysis assesses different conditions near the optimum values to check for the sensitivity of the criteria. Many decision-making methods lack a valid approach towards sensitivity analysis. Sensitivity analysis also aids in understanding the interaction between the criteria, dominant criterion and its effect, i.e. the variation in the final results when the weight of that criterion is varied. Triantaphyllou and Sanchez (1997) reviewed the research on sensitivity analysis and presented a sensitivity analysis procedure in AHP, Weighted Product Model (WPM) and Weighted Sum Model (WSM). It is a complementary procedure that can be carried out together with the AHP method proposed by Masuda (1990). This method considers only the multiple levels of hierarchies, i.e. it considers only the single vector at a time and not the individual judgments.

2.6 Previous approach on land suitability assessment

There is significant amount of literature dealing with land suitability assessments. Anderson (1987) surveyed different methods of land capability/suitability analysis ranging in degrees of computational and analytical sophistication. Hopkins (1977) reported a comparative evaluation of alternative methods of assessing landuse suitability. More recently, Steiner (1983, 1987) reviewed land evaluation and site assessment (LESA) using USDA-recommended standards.

Land suitability analysis is inherently a multi-criteria problem. That is, land suitability analysis is an evaluation/decision problem involving several factors. In general, a generic model of site/land suitability can be described as:

$$S = f(x1, x2, \ldots, xn))$$

where S = suitability measure;

x1., x2, ..., xn = are the factors affecting the suitability of the site/land.

The principal problem of suitability analysis is to measure both the individual and cumulative effects of the different factors; x1, ..., xn. In other words, suitability analysis generally involves determining an appropriate approach to combine these factors. Some approaches to combining these factors include: 1) composite rating, including weighted composite ratings (Anderson 1987); 2) weighted factor method (Hopkins 1977); 3) various forms of multi-criteria approaches such as compromise programming (Pereira and Duckstein 1993); Prioritized Land Use Suitability (PLUS) by Xiang and Whitley (1994); use of effectiveness matrix (Jankowski and Richard 1994); modified weighted factor (Diamond and Wright 1988); and 4) the heuristic rules of combination expressed through verbal logic rather than in numeric terms (Hopkins 1977).

Another classical site suitability analysis approach is through formal functional relationships of the different factors. Most noTable among these approaches is regression analysis. Wildlife habitat suitability assessments, for example, commonly use regression analysis procedures to estimate habitat suitability indices (Pereira and Itami 1993).

2.6 Suitability Analysis and Analytic Hierarchy Process

This thesis proposes an alternative approach to land suitability analysis. Most of the suitability analysis techniques described above rely on significant amount of information to be useful, applicable, and effective. Regression analysis, for example, will require a cross-sectional database covering the wide range of suitability conditions as affected by different factors individually and collectively. If such data are available, formal analysis of the composite function such as regression analysis is warranted and also offers an accurate way to evaluate site suitability. On the other hand, if data are incomplete, or if significant information gaps exist in the cross-sectional database, then it may be more appropriate, practical, or convenient to adopt an alternative approach that does not rely on complete or comprehensive databases. One such approach is the Analytic Hierarchy Process (AHP) (Masuda 1990).

AHP offers some advantages over the classical site suitability analysis techniques. First, it provides a structured approach to measuring suitability by "decomposing" the suitability analysis problem into hierarchical units and levels. This allows a systematic and more in-depth analysis of the factors which may be better understood when "de-coupled" or "deconstructed" into their lower and more specific forms or indicators. Second, AHP relies less on the completeness of the data set, and more on "expert" opinions or observations about the different factors and their perceived effects on land suitability. Third, the approach is more transparent and hence more likely to be accepted especially when the suitability analysis will ultimately serve as a basis for land allocation. Fourth, AHP allows for the participation of both experts and stakeholders in providing the suitability measure of a land relative to a proposed land use. Such framework allows the incorporation and accommodation of both qualitative and quantitative criteria for land suitability assessment analysis. AHP is well documented in published literature (Mendoza 1989, 1997; Saaty 1980, 1995; Kangas 1992, 1993; Peterson et al. 1994; Reynolds and Holsten 1994; Pukkala and Kangas 1996).

Chapter Three

3. Materials and Methods

3.1 Site description

3.1.1 Location

The study area, Legambo Woreda is located in Amhara Region, South Wollo zone at $38^{0}55'$ to $39^{0}25'$ E longitudes and $10^{O}40'$ to $11^{O}00'$N latitudes. Legambo Woreda is one of the 19 Woredas in the South Wollo zone. It is bordered on the south by Kelala, on the southwest by Wegede, on the west by Debresina, on the northwest by Sayint, on the north by Tenta, on the northeast by Kutaber, on the east by Dessie Zuria, and on the southeast by Were Ilu Woredas (Figure 3.1).

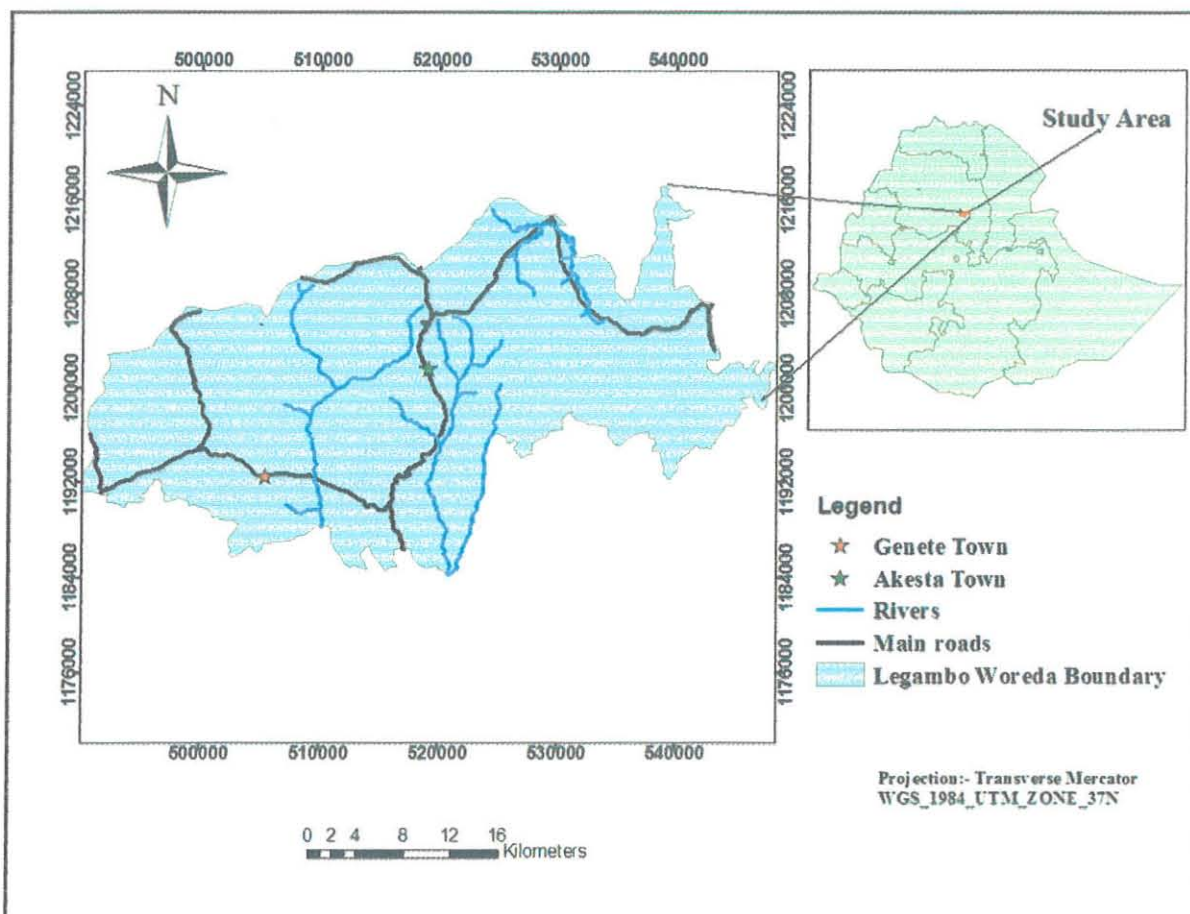

Figure 3.1 Map of the study area

3.1.2 Landuse

Legambo Woerda is characterized by crop-livestock based farming systems. The Woreda consists of 32 peasant associations (PAs) and 3 urban kebeles. Based on the information obtained from the Woreda Agricultural and Rural Development Office the total area of the Woreda is 1088 km^2 of which 42.75% is arable, 0.03% wet lands, 0.1% natural forest, 46.3% shrub and degraded land and 7 % grazing land.

Table 3. 1 Landuse types in Legambo Woreda (Source:- Legambo Woreda Agricultural and Rural Development Office).

Land Use Type	Hectare Coverage	%
Land Type		
Agricultural Land	46364	42.75
Waste Land	3039	2.8
Shrub and degraded land	50461	46.3
Natural Forest	657	0.06
Water Body	351	0.03
Grazing Land	8021	7.42

3.1.3 Climate

Legambo Woreda is divided into the following three major Agro-climatic zones based on altitude Weyena Dega, Dega and Wurch ranging from 1962 - 4221 m a.s.l. Weyena Dega Agro-climatic zone occupies 49.4%, Dega 48.4% and Wurch 2.2% of the area. Average annual temperature varies from 15 - 17 ^{O}C, while rainfall varies from 900-1100 mm.

Five meteorological stations that are found inside and around the study area i.e. Akesta, Kabe, Woreillu, Mekaneselam and Dessie were used to analyze rainfall data (Figure 3.2)

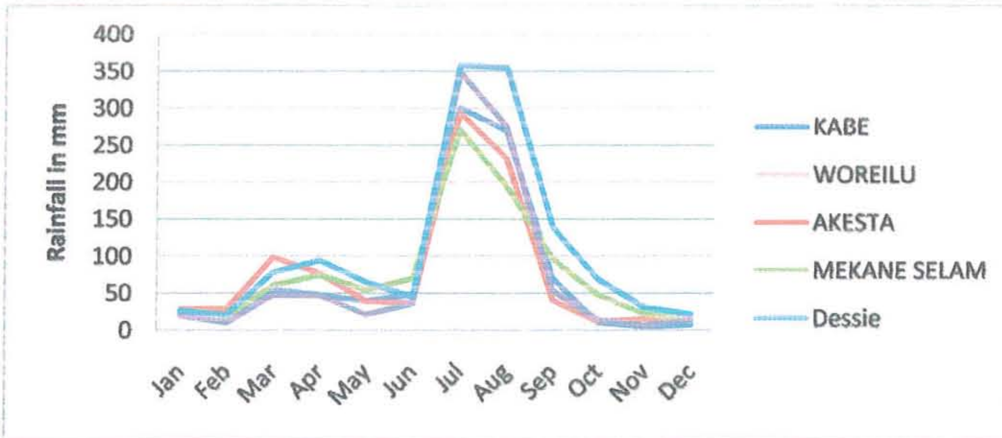

Figure 3.2 Mean monthly rainfall distribution of the five meteorological stations (1992-2007)

As there is no temperature data collection station inside the study area, temperature data were interpolated from three meteorological stations that are outside the study area (Woreillu Dessie and Mekane Selam). Fourteen years metrological data (1994 - 2007) were obtained from National Meteorological Service to make spatial distribution of temperature and rainfall (Fig.3.3).

Table 3.2 Monthly temperature distribution of the three meteorological stations (in °c)

Temp(°c)	Stationnam	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
MAX	Woreilu	22.2	23.01	22.84	22.65	22.87	23.05	20.02	20.02	20.89	21.15	20.75	20.90
	Dessie	20.2	18.6	19.9	20.5	19.8	19.6	18.6	19.2	20.3	18.6	18	21.2
	Mekane Selam	23.56	24.80	24.71	24.16	24.26	22.37	17.96	17.68	19.51	21.76	22.71	23.04
Min	Woreilu	7.40	8.13	8.95	9.65	10.06	9.93	9.57	8.74	9.31	8.99	7.97	7.46
	Dessie	10.2	9.8	11.1	10.3	10.7	11.7	10.1	9.4	9.8	8.2	9.3	9.6
	Mekane Selam	10.64	11.51	11.61	11.79	12.06	11.32	10.21	10.51	10.79	10.40	9.99	10.54
Mean	Woreilu	14.80	15.57	15.90	16.15	16.47	16.49	14.80	14.39	15.10	15.07	14.36	14.18
	Dessie	15.20	14.20	15.50	15.40	15.25	15.65	14.35	14.30	15.05	13.40	13.65	15.40
	Mekane Selam	17.10	18.16	18.16	17.98	18.16	16.85	14.09	14.10	15.15	16.08	16.35	16.79

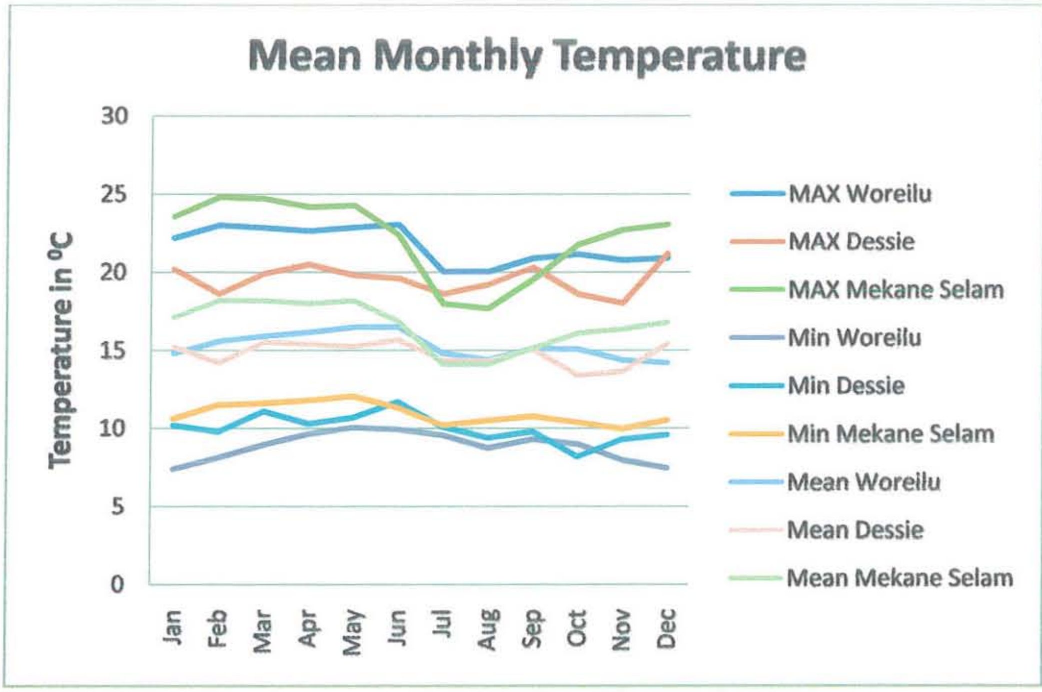

Figure 3.3 Monthly temperature distribution of the three stations

3.1.4 Population

Based on the Woreda Agricultural and Rural Development Office, the total population of the Woreda is 183,879, people of whom 90,420 men and 93,458 women; 6325 or 3.44% of its population are urban dwellers, which is less than the Zone average of 12.4%. With an estimated area of 1197 square kilometers, Legambo has an estimated population density of 184.5 people per square kilometer, which is greater than the Zone average of 173.56.

3.1.5 Topography, geology and soils

According to the Woreda Agricultural Office, the topography of the Woreda is 44% rugged, 27 % valley, 22% hilly and 7% plane. Pyroclastic rocks, basic and ultra basic rocks are the dominant geological features of the Woreda. Some examples of the rock types include basalt, alkali basalt, ignimbrite and dolerite.

As per FAO soil map, there are 4 types of soils in the study area. Of which, Eutric Cambisols is the dominant one followed Lithic Leptosols, Eutirc vertisols fluvic, and Eutric vertisols pellic, The spatial distribution of the soils are shown in Fig.3.6

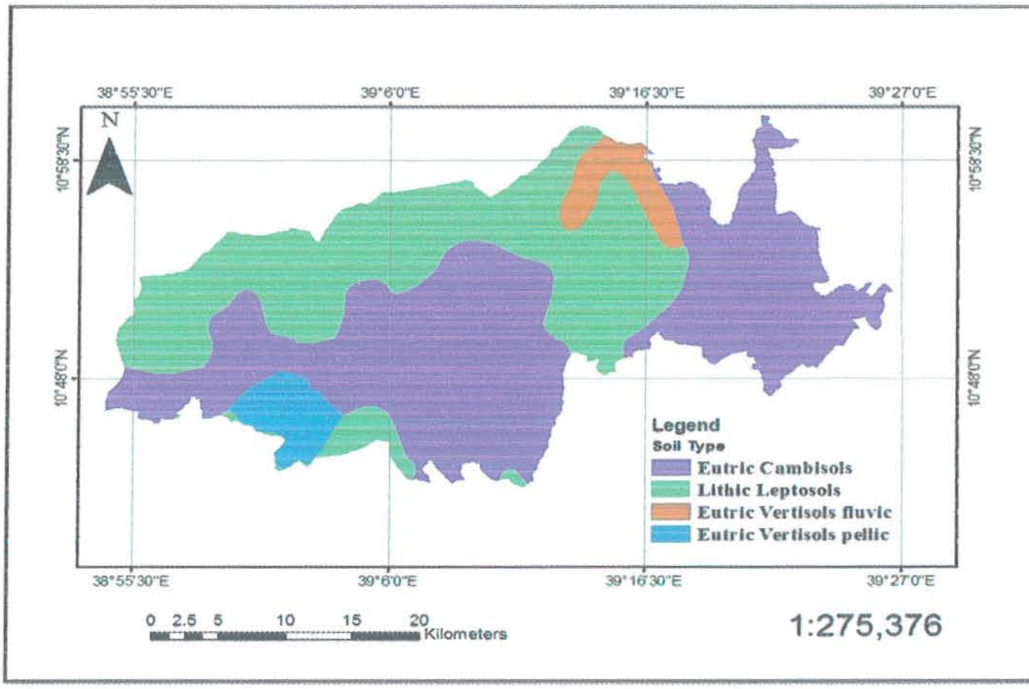

Figure 3. 4 Soil type map of the study area

3.1.6 Crop type and production

The major crops produced in the study area are cereals (teff, wheat, and barley), pulses (lentil, faba bean, chick pea, vetch and pea), oil seeds (linseed) and vegetables (garlic, onion, pepper, potato). Based on the information collected from Woreda Agriculture and Rural Development office, barley, wheat, and maize are the most important crops in terms of area coverage, production per hectare and market demand, followed by lentil, teff and faba bean (See Annex 1).

3.2 Materials

Materials used for the present study include;

- 1: 50,000 topographic maps used to generate DEM layer
- Global Positioning System (GPS) for collection of ground control points
- Landsat ETM+ SLC-off image acquired on January, 15 2010 used to develop landuse/landcover of the study area.
- The soil map of the study area, 1:1 million scales, obtained from Ethiopian Ministry of Water Resource Development.
- 10 years monthly maximum and minimum temperatures, 10 years average monthly rainfall data collected from National Meteorological Agency.

Different Software used in the study: -

- ArcGIS 9.3
- ERDAS 9.1,
- IDRISI Andes
- 3DEM and
- Global Mapper 11

3.3 Methods

The methodology used in this study is outlined in the flow diagram in Figure 3.5

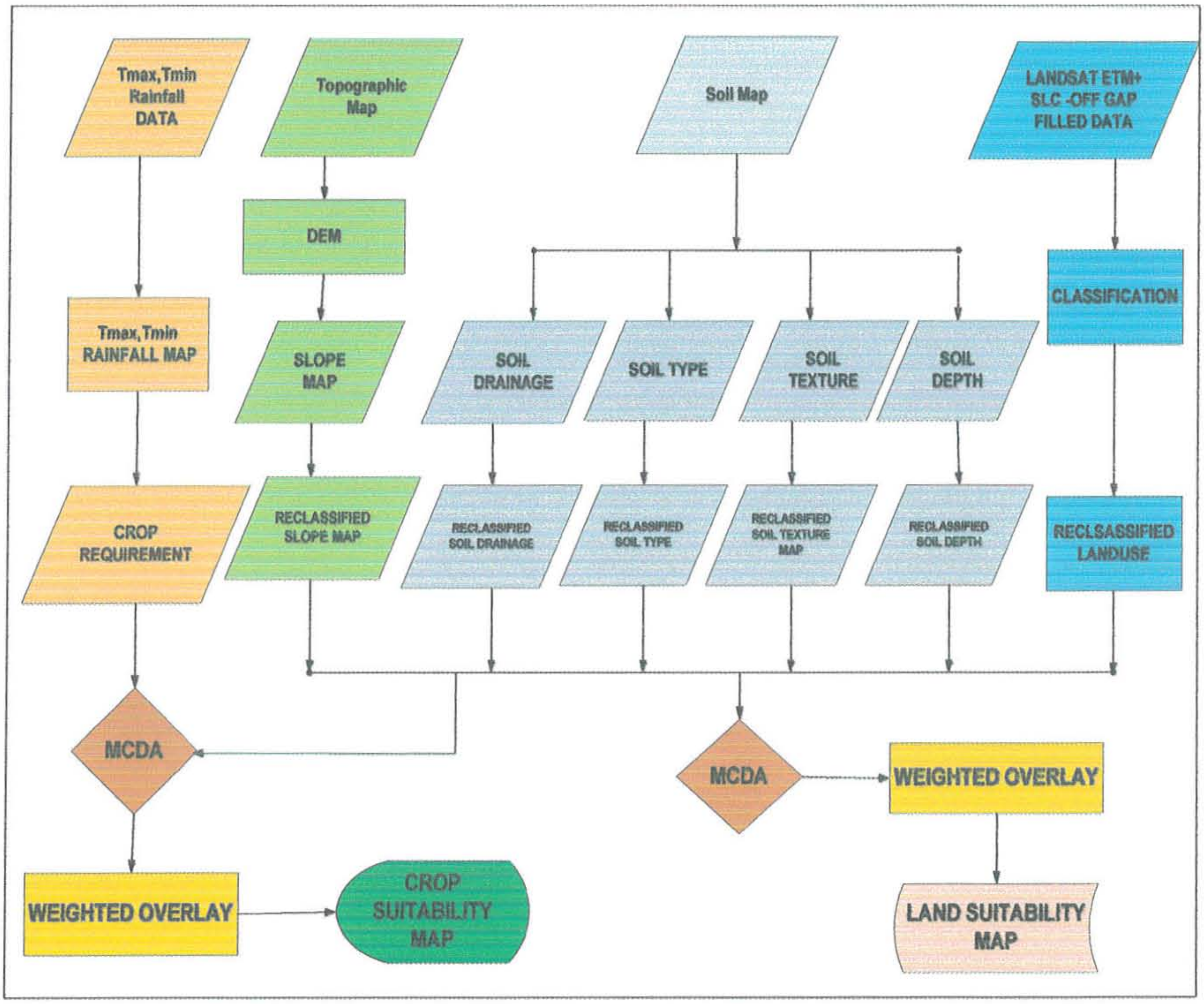

Figure 3. 5 Flow diagram of the method used for land and crop suitability

3.3.1 Digital image processing techniques

I. Gap filling

Orthorectified Landsat Enhanced Thematic Mapper Plus (ETM+) SLC-off image acquired on January 15, 2010 were downloaded from the United States Geological Survey (USGS) Earth Resources Observation Systems (EROS) data center under the Landsat Archive collection. It was difficult to use the image directly, due to the Landsat (ETM+) data acquired after May 31, 2003 Scan Line Corrector (SLC) failure, resulted in 22 percent of the data missing from each scene.

To fill the gap, a model was used "off-to-off" product, which combines an SLC-off image with one or more SLC-off scenes. For this combination Landsat ETM+ scene with the same path and row acquired on June 6, 2008 was used. By using model-maker in ERDAS IMAGINE 9.1 each band in Image 1 (Landsat ETM+ 2010 image) added to the corresponding band in Image 2 (Landsat ETM+ 2008 Image) using the following statement:-

"Where Image 1 > 0, use Image 1 data, otherwise, use Image 2"

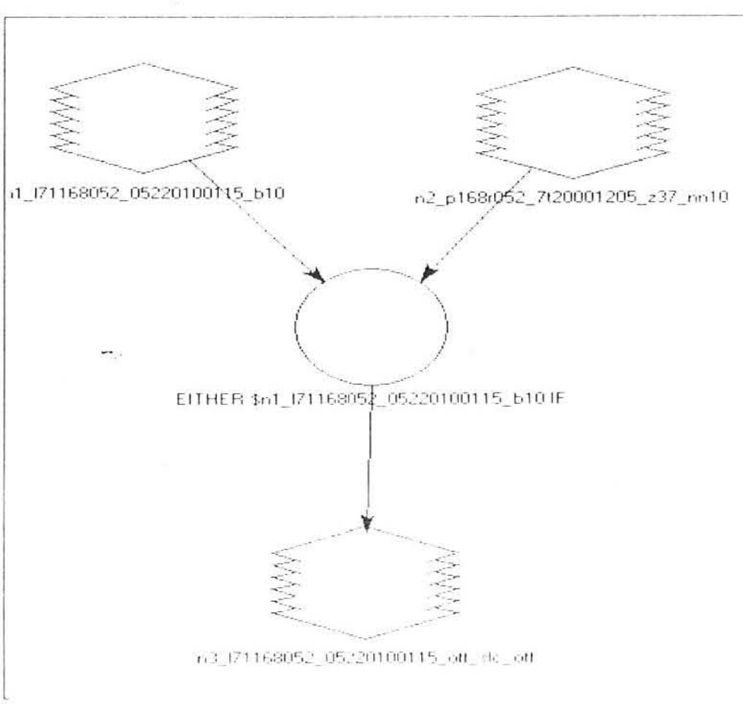

Figure 3. 6 Diagram of "off-to-off" model

Then all of the bands stacked into a single gap-filled product. Mosaic, feather overlapped, histogram matching color correction and radiometrical matching applied to the output image for more complete coverage. Image enhancement, rectification, moisaicing were applied on the raw images (Figure 3.7 and 3.8).

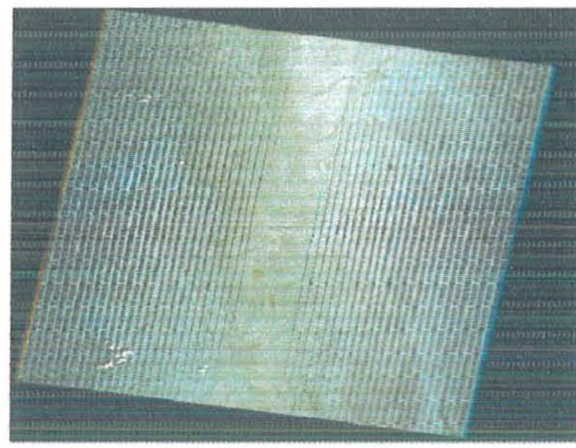

Figure 3.7 Original Landsat ETM+ SLC-off image

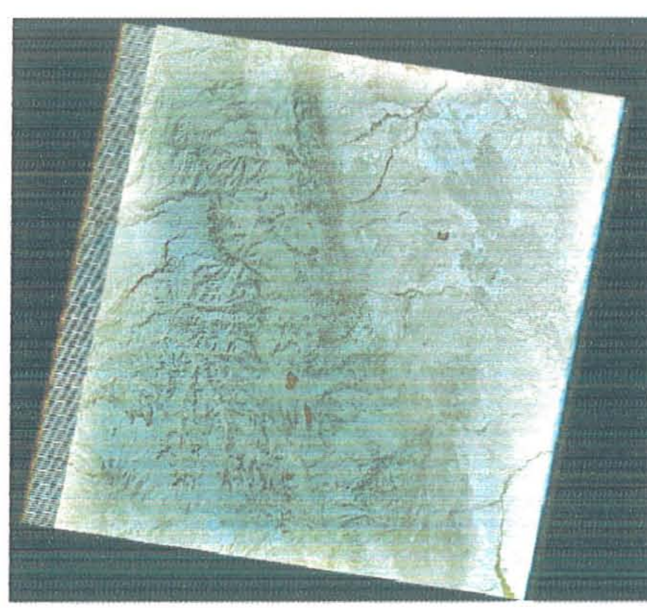

Figure 3.8 Landsat ETM+ SLC-off gap filled image

II. Image enhancement

These techniques are applied to images in order to more effectively display or record the data for subsequent visual interpretation. Contrast stretching is a technique to expand the narrow range of brightness values typically present in an output image over a wider range of gray value (Lillesand and Kiefer, 2000). The visual interpretability of the images used in this study is enhanced by using histogram equalization stretch. In this type of contrast enhancement, image values are assigned to the display levels on the basis of their frequency of occurrence.

III. Color composite

For the color composition many combination were checked to identify different landuse/landcover of the study area. False color composite that is red 4, green 3 and blue 2 were used to develop the land use/cover map of the study area.

3.3.2 Image classification

Image classification is the process of creating thematic maps from satellite imagery. A thematic map is an information representation of an image that shows the spatial distribution of particular theme (Lillesand and Kiefer 2000). There are two main spectrally oriented classification procedures for land cover mapping: unsupervised and supervised.

I. Unsupervised classification is more computer-automated. It enables user to satisfy some parameters that the computer uses to uncover statically patterns that are inherent in the data. These patterns are simply clusters of pixels with similar spectral characteristics. In some cases, it may be mere important to identify group of pixels with similar spectral characteristics than it is to sort pixels into recognizable categories (Lillesand and Kiefer 2000).

II. In supervised classification, the image analyst supervises the pixel categorization process by specifying, to the computer algorithm, numerical descriptors of the various land cover types present in a scene. To do this, representative sample sites of known cover type, called training areas are used to create the parametric signatures of each class. Each pixel in the data set is then compared numerically to each category in the interpretation key and labeled with the name of the category it 'looks like most like' (Lillesand and Kiefer 2000). In this study the different land cover classes in the image were classified based on the supervised classification with field work data and Google earth images support.

3.3.3 Spatial Multi-Criteria Decision Making

Spatial multi-criteria decision-making (MCDM) is a process where geographical data is combined and transformed into a decision. Multi-criteria decision-making involves input data, the decision maker's preferences and manipulation of both information using specified decision rules.

Spatial MCDM is more complex and difficult in contrast to conventional MCDM, as large numbers of factors need to be identified and considered, with high correlated relationships among the factors (Malczewski 1999). According to Malczewski (1999) a spatial decision problem is the difference between the desired state in a geographical system and an existing state in real world.

Spatial MCDM aims to achieve solutions for spatial decision problems, derived from multiple criteria. These criteria, also called attribute must be identified carefully to arrive at the objectives and final goal. The performance of an objective is measured with the help of these attributes. These objectives and underlying attributes form a structure of evaluation criteria for a particular decision problem. These evaluation criteria should be comprehensive and measurable.

Being a case of spatial multi-criteria decision-making process, land suitability evaluation demands for visualization of the impact of the alternatives and criteria in the form of maps. This demand can be accomplished effectively by the integration of spatial analysis and conventional multi-criteria evaluation techniques, as shown in Figure 3.11 Moreover, environmental decision problems are characterized of having multiple and often conflicting objectives. When evaluating such a complex phenomenon, the spatial dimension seems to be the big hurdle. Here, the integration of GIS and MCDM techniques becomes useful.

Most of the spatial decision problem area can be portrayed in many ways. Structuring a land use problem depends on the questions to be deal with (Malczewski 1999).

1. Given a desired activity, which sites might be best for that activity? (Where to put something?)
2. Given a site or sites, what kind of activity might be most suitable here? (What to put here?)

Accordingly, four major land use problems was identified:

- *Site (Location) Selection*: Given a set of specific landuse types, rank the set of sites for that landuse and order them based on priority.
- *Location Allocation*: Situation where the functional relationship between the attributes of a land and the goals of decision making is stated.
- *Landuse selection*: Given a set of sites, find the landuse types (LUTs) that suits best and order them based on the priority. It can also be called as Alternative Uses.
- *Landuse allocation*: Given a set of sites, which landuse is the best for that site. It addresses the surface of land that should be allocated to a specific land use.

From the discussion above it is clear that land suitability analysis for agricultural crops is a landuse selection problem where LUTs are to be rated on priority basis. Here, alternative land uses are rated based on a set of criteria. The aim is not to find the exclusively suitable landuse, but also to characterize and prioritize LUTs that suit the local condition. In the context of agricultural crop suitability it is not possible to characterize a landuse type that is suitable for a particular land explicitly.

3.3.4. Framework of land suitability decision making

The decision-making problem of land suitability analysis for agricultural crops is analyzed using the following flow chart. (Figure 3.9) which, depicts the conceptual flow of the research approach.

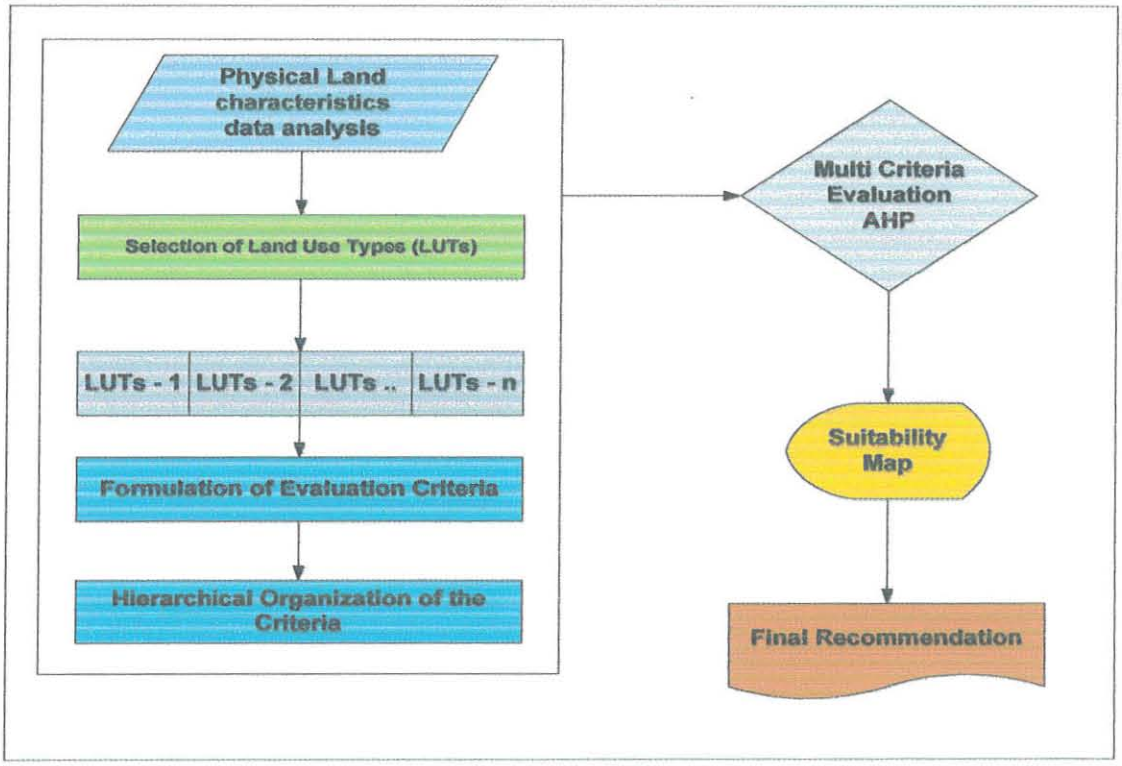

Figure 3. 9 Conceptual flow of research approach

3.3.5 Selection of landuse types

The parameters for selection of landuse types are agro-ecological zone, present landuse and cropping-system, topography and physical property of the soil. Experts from agriculture and rural development office and local policy-makers were consulted to decide upon the potential landuse types for the study area.

For this study area, the different landuse types (crops) for evaluation were:

- Barley
- Wheat
- Maize

- Teff

3.3.6 Selection of the evaluation criteria

The following evaluation criteria were considered to address the land suitability and crop suitability decision-making.

- Soil
    - Texture
    - Drainage
    - Depth
    - Soil Type
- Climate
    - Temperature
    - Rainfall
- Topographic
    - Slope
- Land use
    - Vegetations (Forest or bush land), Grass land and Cultivation land

3.3.7 Hierarchical organization of the criteria

Malczewiski (1999) states that relationship between the objectives and attributes have a hierarchical structure. At the highest level, one can distinguish the objectives and at lower levels, the attributes can be decomposed. Figure 3.10 shows the hierarchical structure used in this study.

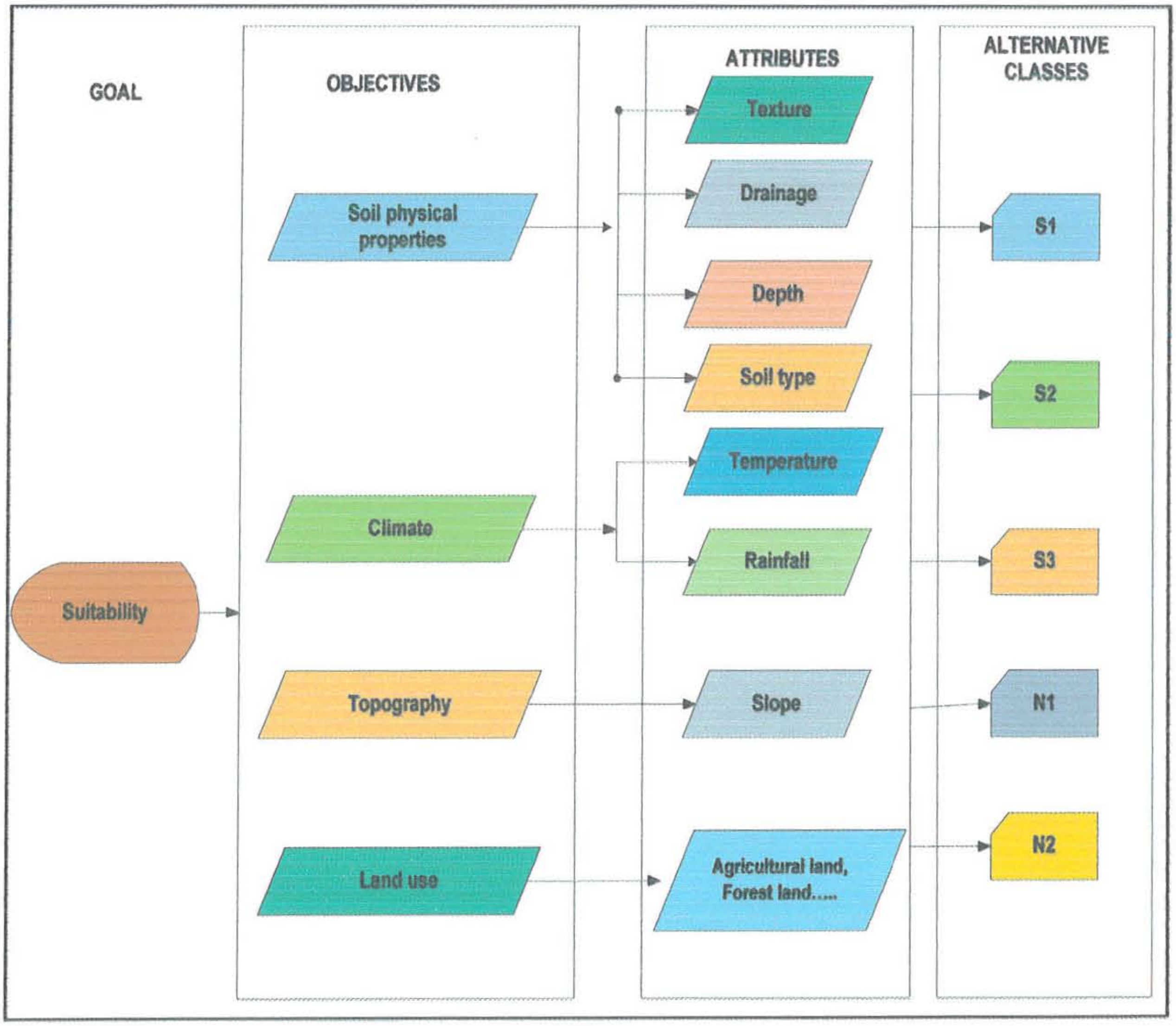

Figure 3. 10 Hierarchical organization of the criteria considered for the study

3.3.8 Method of land suitability evaluation

The method that was used to evaluate the land suitability for agricultural crop production was based on FAO guideline (FAO 1976). In simplified form, the procedures used were as follows:

1. Description of land-use types

A land-use type is a kind of land use described in terms of its products and management practices. Such descriptions serve two purposes. First, they are the basis for determining the requirements of a use. Second, the management specifications can be used as a basis for extension services and for planning necessary inputs. For this research the land-use types were consider for the selection of the land which are suitable for crops within the study area.

2. Selection of land qualities and land characteristics

Land-use requirements are described by the land qualities needed for sustained production. Land quality is a complex attribute of land that has a direct effect on land use. Most land qualities are determined by the interaction of several land characteristics and measurable attributes of the land. For example, the soil texture is determined by the requirement of crops. In any particular project, only a limited number of land qualities need to be selected for evaluation.

Criteria for selection should be:

- The quality must have a substantial effect either on performance or on the costs of production.
- Critical values of the quality must occur in the planning area.

3. Mapping of land units and their characteristics

After land units were identified in the above procedures (Step2) as a basis for the diagnosis of problems, land units have to be mapped in detail using GIS. Then compare the requirements of the land-use types with the properties of the land units to arrive at a land suitability classification using Pair-wise comparison rating scale technique in IDRIS software. This technique is used to compare the factors in order to give the weight for the factors that determine the land use types based on their requirements. Accordingly based on their weight given the suitability map of the land can be developed based on the requirements of the specified land use using spatial analyst in ArcGIS 9.3 by the technique called Weighted Linear Combination (WLC).

The suitability map of the land must be classified based on their land use quality priority for specified land use requirements. According to FAO (1976), generally land suitability map is classified in to two classes i.e. Suitable and not suitable. These classes are further classified based on their benefits and limitations (Table 3.3)

Table 3. 3 ***Structure of the land suitability classification (adopted from FAO guidelines)***

S	Suitable	The land can support the land use indefinitely and benefits justify inputs
S1	Highly suitable	Land without significant limitations. Include the best 20-30% of suitable land as S1. This land is not perfect but is the best that can be hoped.
S2	Moderately suitable	Land that is clearly suitable but which has limitations that either reduce productivity or increase the inputs needed to sustain productivity compared with those needed on S1 land.
S3	Marginally suitable	Land with limitations so severe that benefits are reduced and/or the inputs needed to sustain production are increased so that this cost is only marginally justified.
N	Not suitable	Land that cannot support the land use on a sustained basis, or land on which benefits do not justify necessary inputs.
N1	Permanently not suitable	Land with limitations to sustained use that cannot be overcome.

Chapter Four

4. Analysis and Result

4.1 Factors determining land suitability and crop suitability

Physical and chemical factors of the land as well as climate are the major factors that determine crop suitability of a given land (FAO. 1987). However, in this paper only physical land properties were evaluated to analyze the land suitability of the study area for agricultural crop production. The physical land properties of the study area, which were evaluated, include drainage, slope gradient, soil texture, soil depth, soil type, stoniness or rockiness and land use. Climate (Temperature and Rain fall) of the study area was also used for crop suitability analysis.

4.1.1 Slope gradient

Slope is important for soil formation and management because of its influence on runoff, soil drainage, erosion, use of machinery, and choice of crops. Slope is the incline or gradient of a surface and is commonly expressed in percent. DEM of the study area was digitized from topographic map using the Spatial Analysis tool in raster form. Slope derived from the DEM was classified based on the classification system by FAO, 1990 after some modification based on the purpose of the study.

The slope of study area was given in percent. The result obtained after the evaluation was that 3% of the study area was below 2%, 8.1% of the area was between 2% and 8%, 15.8 % of the study area was between 8% and 15%, 37% of the study area was between 15% and 30%, 26.8% of the area was between 30% and 50% and 8.9% of the study area was greater than 50%. This indicated that 11.1% of the study area was found to be very suitable for crop in terms of work efficiency and erosion control (Table 4.1, Fig 4.1).

Table 4. 1 Slope class Table

Slope class	% Range	Area in %
Flat almost flat	0 – 2	3.1
Undulation plain	2 - 8	8.16
Rolling to undulating	8 - 15	15.85
Hill to rolling	15 - 30	37.11
Steep	30 - 50	26.84
Very steep escarpment	>50	8.94

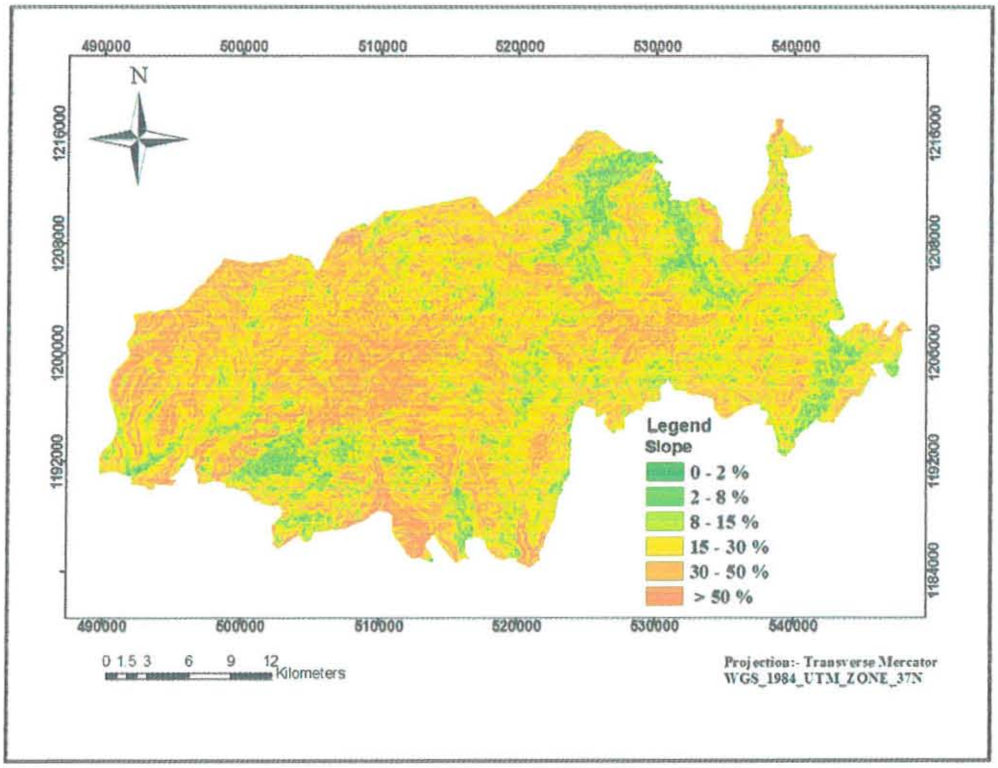

Figure 4. 1 Slope map of the study area

Slope suitability

As it was mentioned earlier, slope gradient has great impact on work efficiency, erosion control practices and crop adaptability. First Rating factors were given for each slope gradient of the study area based on literature review and FAO guidelines. Using this rating the study area was reclassified in to five classes according to its land qualities and characteristics of the slope for the selection of the land for suitability of crop production.

The classes include very suitable (S1), suitable (S2), marginally suitable (S3), not suitable (N) and permanently not suitable (N2).

Table 4. 2 Slope suitability class

No	Land form	Slope range (%)	Slope suitability class
1	Flat - Undulation plain	0 - 8	S1
2	Rolling to undulating	8 - 15	S2
3	Hill to rolling	15 - 30	S3
4	Steep	30 - 50	N1
5	Very steep escarpment	> 50	N2

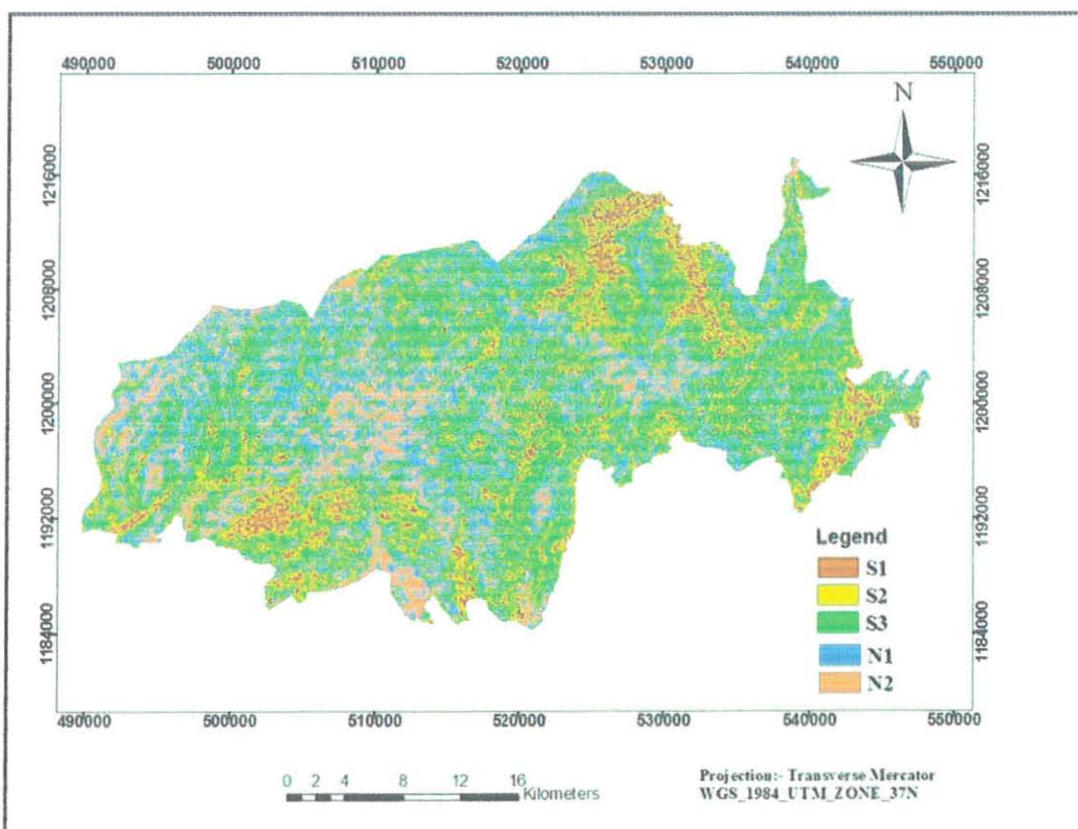

Figure 4. 2 Reclassified slope suitability class

4.1.2 Soil depth

A soil depth variation from place to place determines the growth of plants and also affects the growing of plant roots. The thickness of the soil materials, which give structural support, nutrients and water for crops, is referred as soil depth. The soil depth of the study area was classified in to four classes (Fig.4.3). Soil series were bedrock between 10 and 50 centimeters from the surface were described as shallow. Bedrock between 50 and 100 centimeters was described as moderately deep. 100 - 150 were deep and if it is greater than 150 cm it was very deep.

Table 4.3 Soil depth class Table

Soil depth class	Depth in cm
Very deep	>150
Deep	100 – 150
Moderately deep	50 - 100
Shallow	10 - 50
Very Shallow	< 10

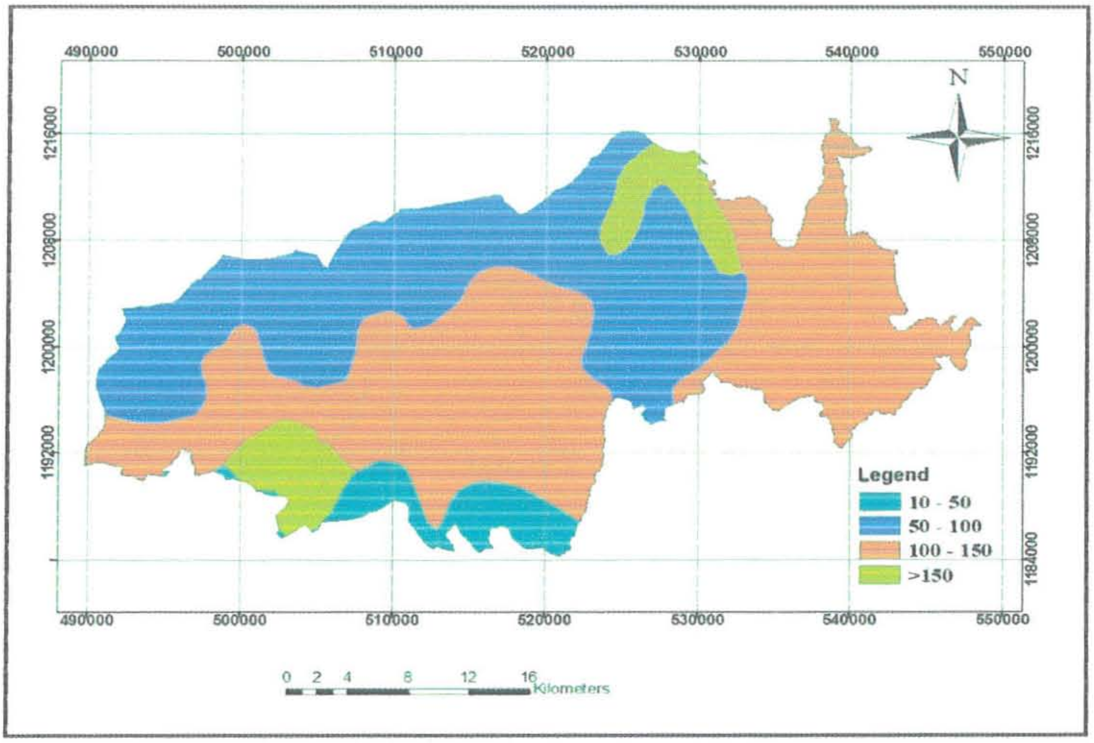

Figure 4. 3 Soil depth class of the study area

Soil depth suitability

Based on soil depth requirement of most common crops, soil depth of the study area was divided in to four suitability classes. Rating factor was given for the value of soil depth and weighting them to evaluate the suitability of the study area for crop production.

Table 4. 4 Soil depth suitability of the study area

No	Soil Depth	Soil depth (cm)	Soil depth suitability class
1	Very deep	> 150	S1
2	Deep	100 – 150	S2
3	Moderately deep	50 – 100	S3
4	Shallow	10 – 50	N1

Based on the given weighting factors for each soil depth of the study area, soil depth suitability map of the study area for crop production was developed (Fig 4.4)

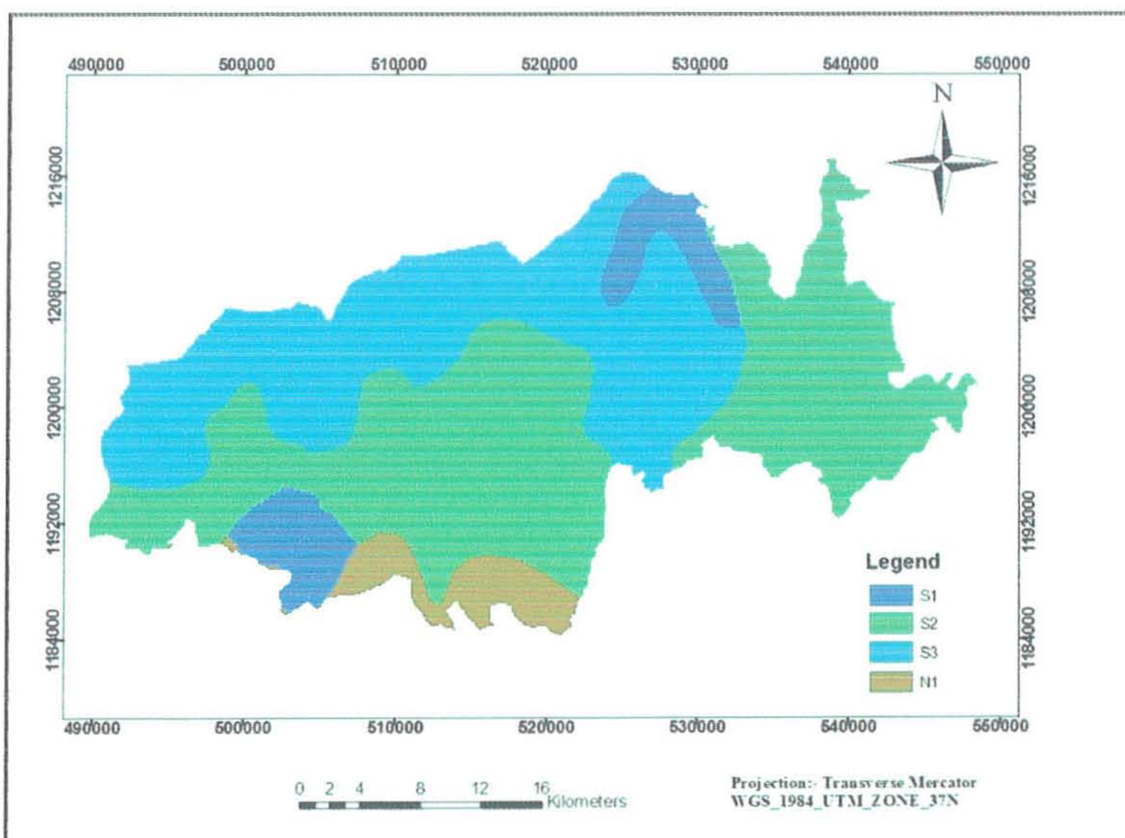

Figure 4. 4 Soil depth suitability of the study area

4.2.3 Soil texture

The soil texture of the study area was evaluated and classified in to clay, clay loam and loam. The dominant soil texture types of the study area are clay, loam and followed by clay loam (Fig.4.3).

Table 4. 5 Soil texture class

Textural group	Textural class
Coarse	Sand (S)
	Sandy Loam (SL)
	Loam (L)
Medium	Silt Loam (SiL)
	Clay Loam (CL)
Fine	Clay (C) or Silt Clay(SiC)
	Heavy Clay(C)

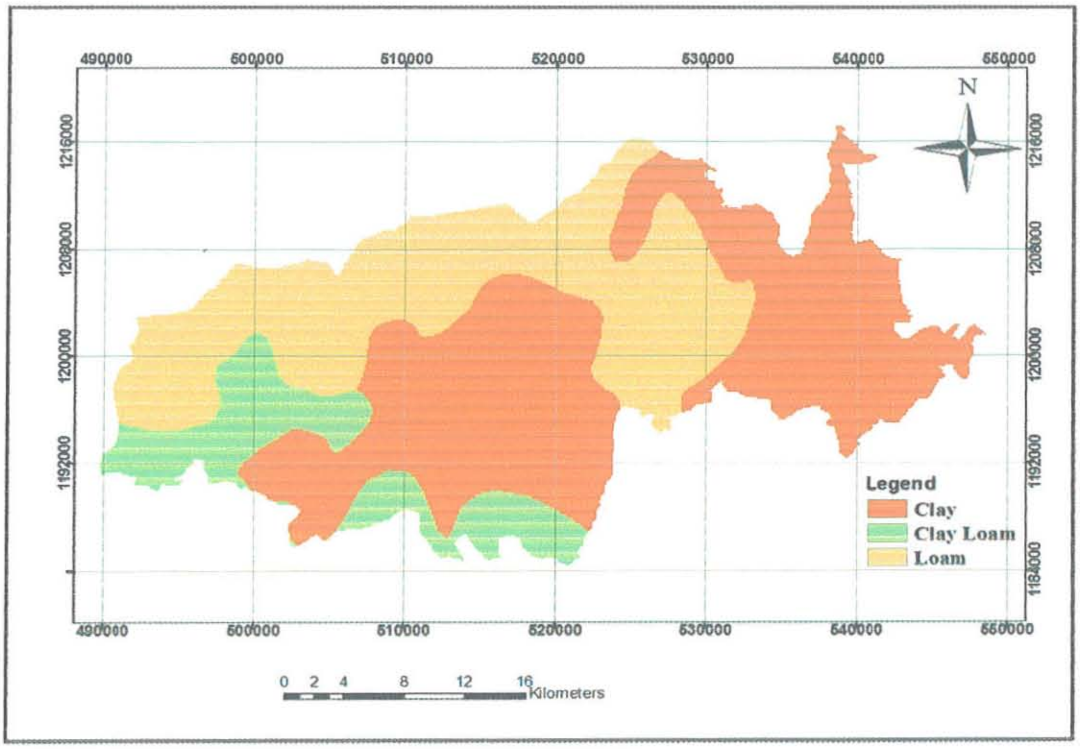

Figure 4. 5 Soil texture map of the study Area

Table 4.6 Soil texture suitability of the study area

No	Soil Depth	Soil depth suitability class
1	Loam	S1
2	Clay loam	S2
3	Clay	S3

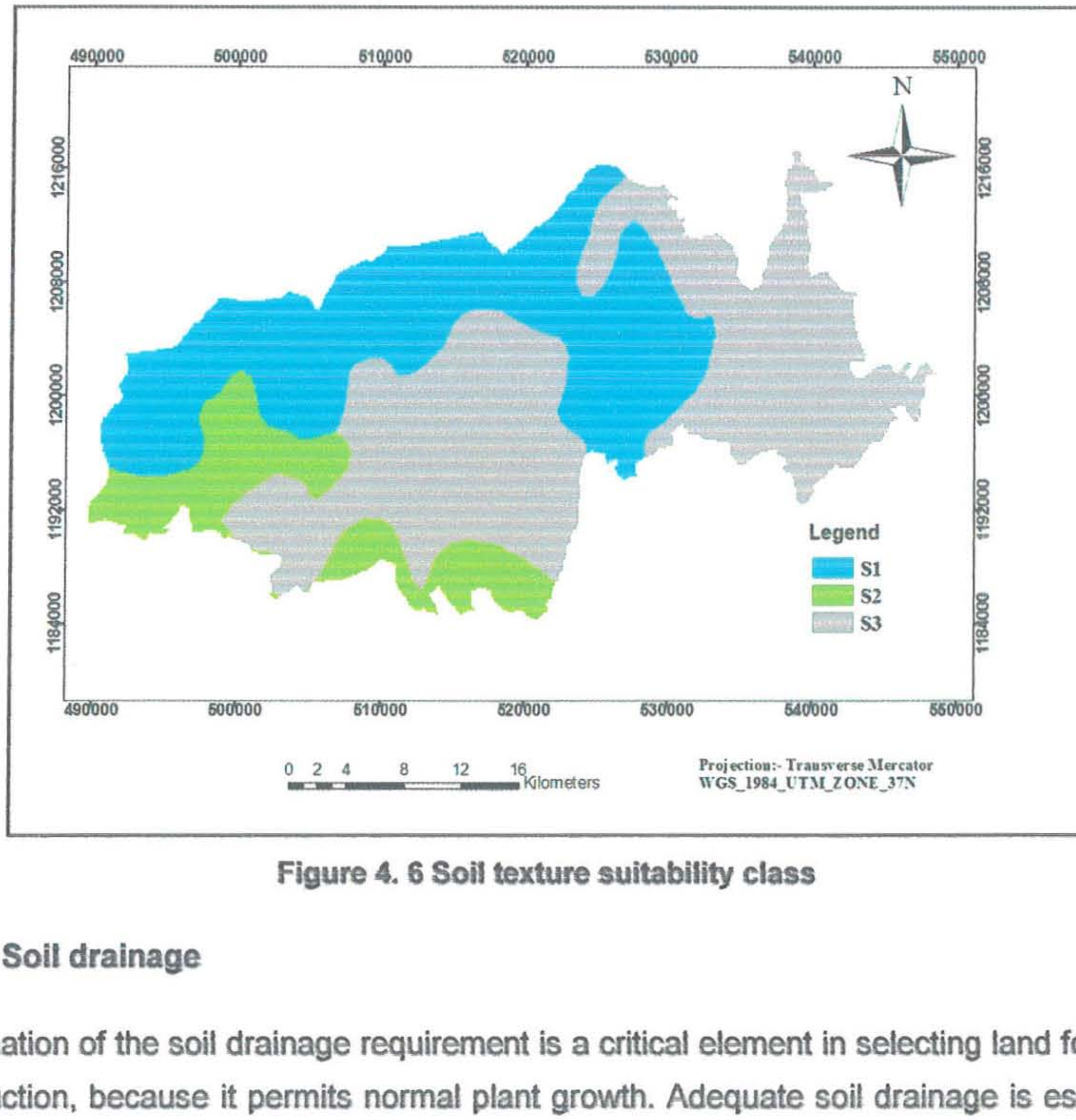

Figure 4. 6 Soil texture suitability class

4.2.4 Soil drainage

Evaluation of the soil drainage requirement is a critical element in selecting land for crop production, because it permits normal plant growth. Adequate soil drainage is essential to ensure sustained productivity and to allow efficiency in farming operations.

Soil permeability properties of the study area were classified as well drained, moderately well drained, poorly drained, very poorly drained and imperfectly drained (Table 4.7).

Table 4. 7 Soil drainage Class

Soil Drainage	Code
well drained	(W)
moderately well drained	(PW)
poorly drained	(P)
very poorly drained	(IP)
imperfectly drained	(I)

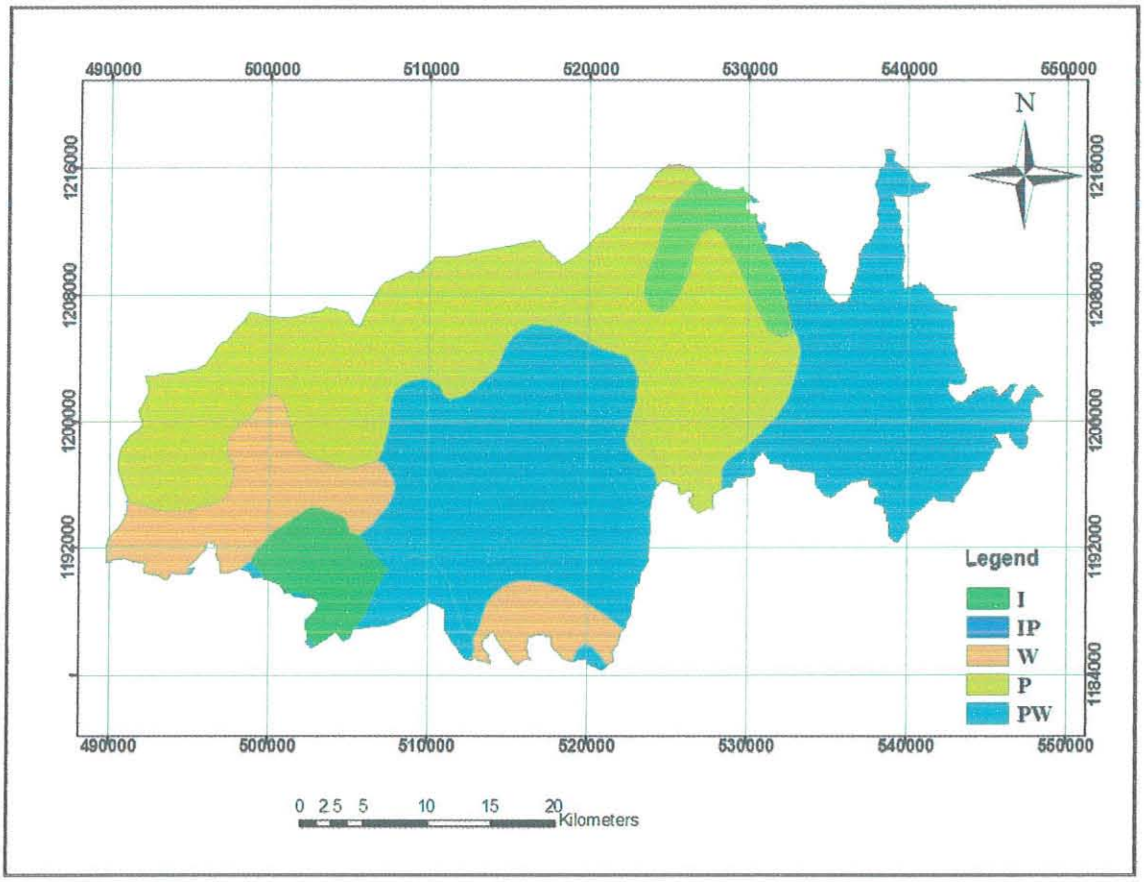

Figure 4. 7 Soil drainage class map of the study area

After conversion of soil drainage map of the study area in to raster form, the rasterized soil drainage map was reclassified based on crop requirements. As a result suitability map of soil drainage within the study area was developed. The value was changed in to suitable classes. The suitability classes were five i.e. very suitable, suitable, marginally suitable and not suitable and permanently not suitable (Fig.4.8).

Table 4.8 Soil drainage suitability of the study area

Soil Drainage	Suitability
well drained	S1
moderately well drained	S2
poorly drained	S3
very poorly drained	N1
imperfectly drained	N2

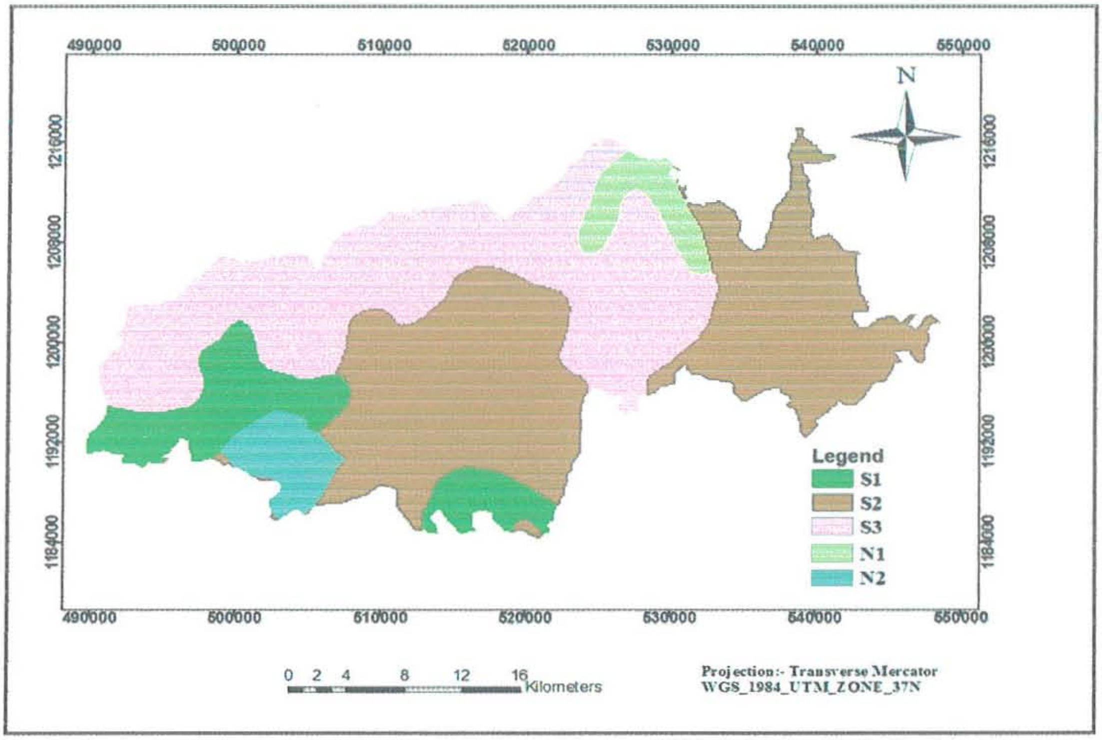

Figure 4.8 Soil drainage suitability map

4.2.5 Soil type

Soil type has an impact on determination of land suitability potential for suitable crop production. Thus, it was taken as one parameter to develop crop suitability map for the study area. Because all types of soils are not suitable for crops in production. The soil pattern of this study area includes four major soil groups: Eutric Cambisols, is the dominant one followed Lithic Leptosols Eutirc vertisols fluvic, and Eutric vertisols pellic.

A Cambisol in the FAO World Reference Base for Soil Resources is a soil with a beginning of soil formation. The horizon differentiation is weak. This is evident from weak, mostly brownish discoloration and/or structure formation in the soil profile. Cambisols are developed in medium and fine-textured materials derived from a wide range of rocks, mostly in alluvial, colluvial and aeolian deposits. Most of these soils make good agricultural land and are intensively used.

Leptosol is a very shallow soil over hard rock or highly calcareous material or a deeper soil that is extremely gravelly and/or stony. These soils are particularly common in mountain regions. They are very shallow, less than 10 cm deep, Lithic Leptosols in mountain regions are the most extensive Leptosols on eart.

In both the FAO and USA soil taxonomy, a vertisol is a soil in which there is a high content of expansive clay known as montmorillonite that forms deep cracks in drier seasons. Alternate shrinking and swelling causes self-mulching, where the soil material consistently mixes itself, causing vertisols to have an extremely deep A horizon and no B horizon. However, the shrink-swell activity allows rapid recovery from compaction. When irrigation is available, crops such as cotton, wheat, sorghum and rice can be grown. Vertisols are especially suitable for rice because they are almost impermeable when saturated. Rainfed farming is very difficult because vertisols can be worked only under a very narrow range of moisture conditions: they are very hard when dry and very sticky when wet. The soil types of the study area are shown in Figure 4.9.

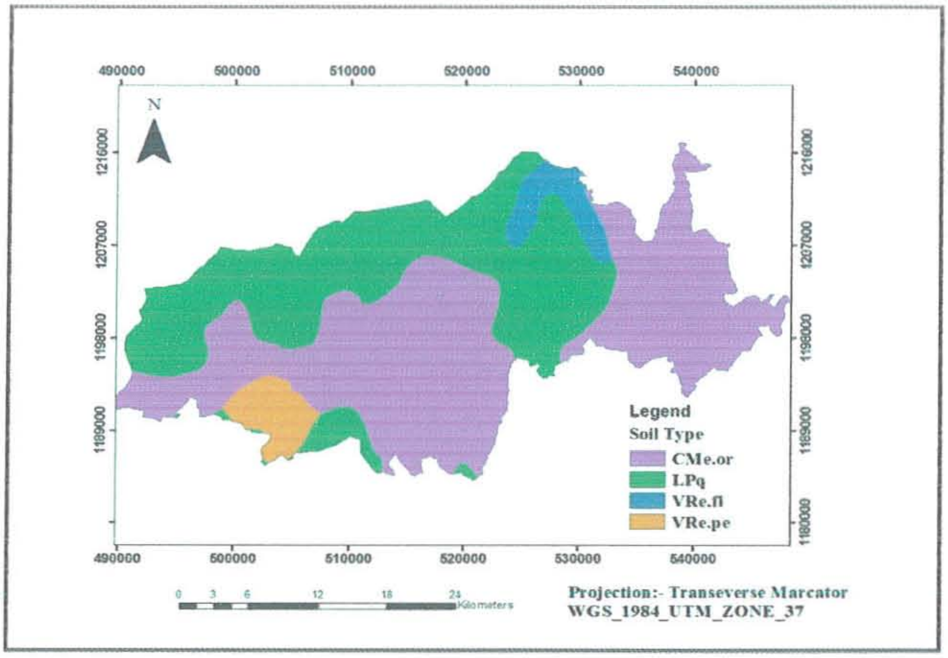

Figure 4.9 Soil type map of the study area

The rasterized soil type of the study area was reclassified based on crop requirement. (Fig 4.10).

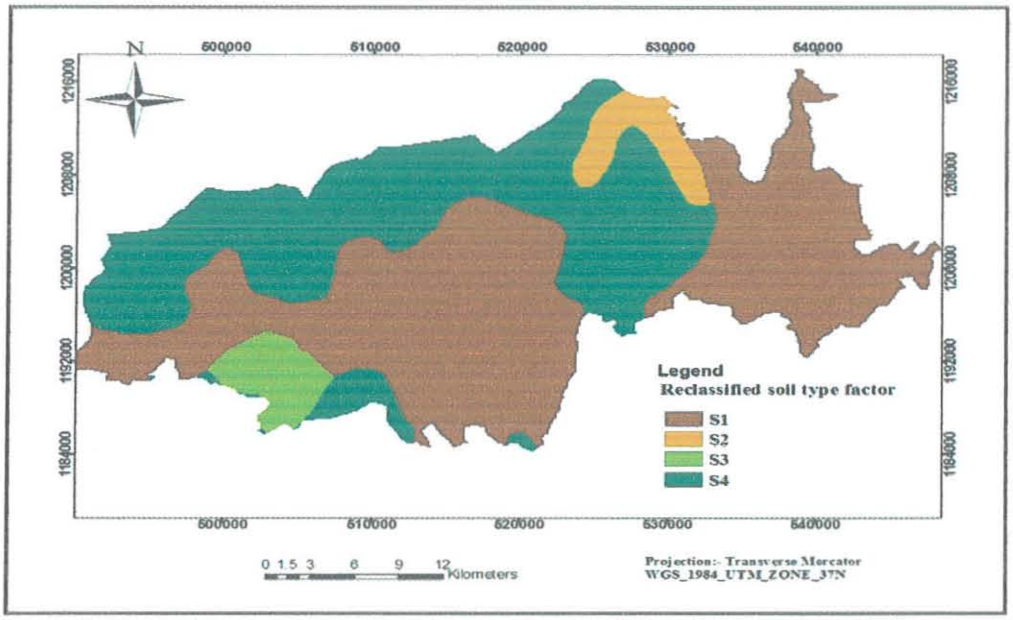

Figure 4.10 Reclassified soil type of the study area

4.2.8 Present landuse/landcover

The type of land use/land cover in the study area includes cultivated and fallow land, forest and wood land, grass land, water (river and valleys), Settlements area and degraded area (Table 4.9).

Table 4 9 Present landuse types of the study area

Land Use Type	Area in km^2	%
Settlement	47.25	4.34
River	28.29	2.6
Grass Land	236.24	21.7
Forest and shrub land	116.28	10.68
Bare/degraded land	185.35	17.02
Agriculture and Fallow land	475.52	43.67
Total	1088.93	

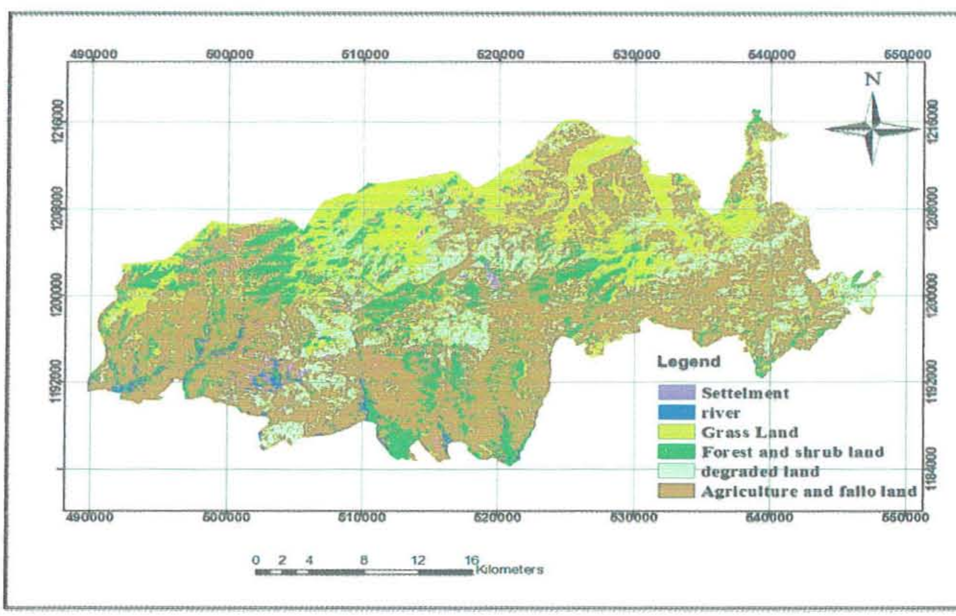

Figure 4. 11 Present landuse map of the study area

4.2.7 Climate

Crops need specific requirements of temperature and rainfall for growth. The study area climate is characterized by moist Weyena Dega and moist Dega. The mean annual temperature ranges between 15^0c to 16.5^0c (Figure 4.11).

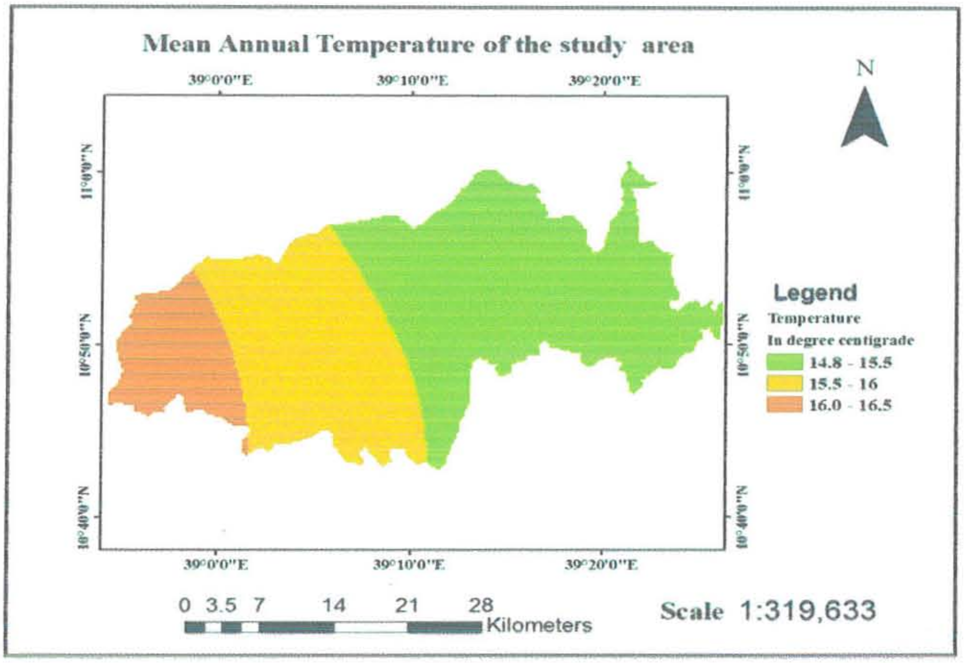

Figure 4.12 Mean annual temperature of the study area

The other major elements of climate, which is the major requirement for crops production was rainfall. From Inverse Distance Weighted (IDW) interpolation technique rainfall map of the study area were developed. The result shown in (Figure 4.12)

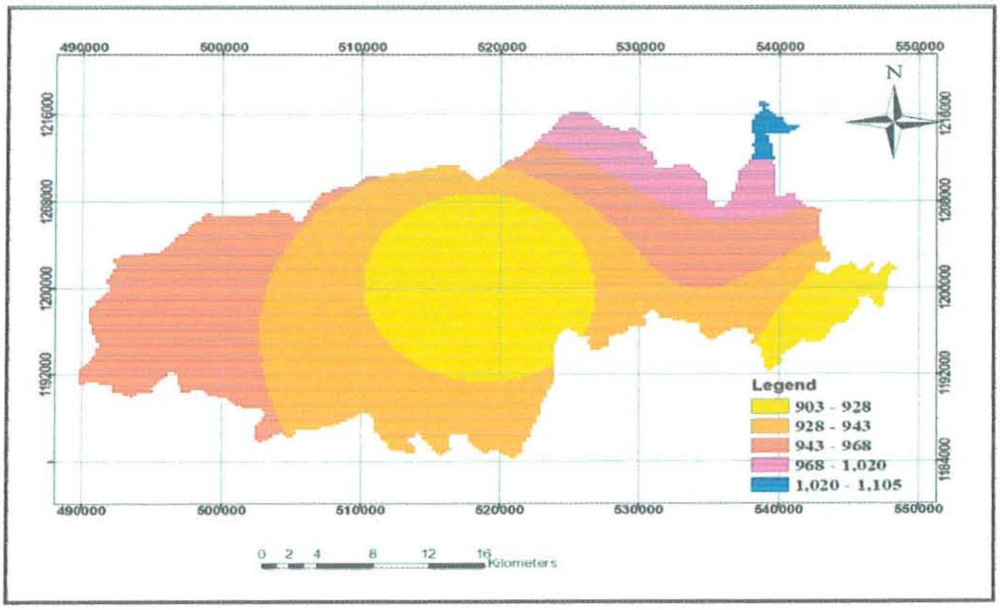

Figure 4.13 Mean annual rainfall of the study area (in mm)

4.3 Land suitability analysis

4.3.1 Multi-criteria decision evaluation

MCE is a set of procedures designed to facilitate decision-making. The basic purpose is to investigate a number of choice possibilities in the light of multiple criteria and conflicting objectives.

The primary issue in Multi-Criteria Evaluation is concerned with how to combine the information from several criteria to form a single index of evaluation. Weighted Linear Combination (WLC) is the most common technique used to create suitability map. Weight is used to develop a set of relative weights for a group of factors in a multi-criteria evaluation. The weights are developed by providing a series of Pair-wise comparisons of the relative importance of factors to the suitability of pixels for the activity being evaluated. These Pair-wise comparisons are then analyzed to produce a set of weights that sum to 1. The factors and their resulting weights can be used as input for the MCE module for weighted linear combination.

The procedure by which the weights are produced follows the logic developed by T. Saaty (1977) under the Analytical Hierarchy Process (AHP) with a weighted linear combination; applying a weight to each followed by a summation of the results to yield a suitability map, i.e., combines factors:

$$S = \sum WiXi$$

Where S = suitability

Wi = weight of factor i

Xi = criterion score of factor i

4.3.2 Establishing the criteria: factors and constraints

A. FACTORS

Factor is a criterion that enhances or detracts from the suitability of a specific alternative for the activity under consideration. It is therefore most commonly measured on a continuous scale.

For the evaluation of physical land suitability of the study area, sets of factors that influence the capability of physical land for the required purpose in the study area were first established. From these factors, the possibilities and constrains for agricultural crops were analyzed. The following factors were considered for the evaluation of the physical land suitability of the study area for agricultural crop production:

- Slope gradients
- Soil texture
- Soil depth
- Soil drainage
- Stoniness
- Soil type
- Present land use

4.3.3 Establishing the parameter weights

This is the second step in MCDE to establish a set of weights for each of the factors. The technique described here and implemented in IDRISI is that of Pair-wise comparisons developed by Saaty (1977) in the context of a decision making process known as the Analytical Hierarchy Process (AHP). In Saaty's technique, weights of this nature can be derived by taking the principal eigenvector of a square reciprocal matrix of Pair-wise comparisons between the criteria. The purpose of weighting is to express the importance or preference of each factor relative to other factor affect on crop yield and growth rate. Pair-wise comparisons are based on forming judgments between two particular elements rather than attempting to prioritize an entire list of elements. A matrix is constructed, where each factor is compared with the other factors, relative to its importance, on a scale from 1 to 9. Then, a weight estimate is calculated and used to derive a consistency ratio (CR) of the Pair-wise comparisons. If the CR > 0.10, then some Pair-wise values needs to be reconsidered and the process is repeated till the desired value of CR < 0.10 is reached.

All the Six factors, which were selected for the evaluation of Land suitability in the study area, were weighted using pair-wise comparison in Table 4.10. After the Pair-wise comparison matrices were filled, the weight module was used to identify consistency ratio and develop the best-fit weights. The consistency ratio (CR) was 0.07, which was accepTable for weighting the factors to evaluate the physical land suitability of the area.

Table 4.10 The standardized results and weight of all seven parameters of the physical land suitability of the study area.

Factors	Soil depth	Soil drainage	Slope	Soil texture	Soil type	Present land use
Soil depth	1					
Soil drainage	1/3	1				
Slope	1/3	1/3	1			
Soil texture	1/5	1/5	1/3	1		
Soil type	1/5	1/5	1/3	1/3	1	
Present land use	1/7	1/7	1/5	1/3	1/3	1

Consistency ratio = 0.07

Consistency is accepTable.

The eigenvector of weights is :

Soil depth factor: 0.3863

Soil drainage factor: 0.2638

Slop factor: 0.1584

Soil texture factor: 0.1004

Stoniness factor: 0.0582

Landuse factor: 0.0328

4.3.4 Undertaking the multi-criteria evaluation

After the criteria maps (factors and constraints) had been developed, an evaluation (or aggregation) stage was undertaken to combine the information from the factors and constraints. As it is widely used and mostly accepted by many researches, weighted linear combination (WLC) was used to evaluate the factors and constraints maps of the study area. After the weights were established, the module MCE (for Multi-Criteria Evaluation) was used to combine the factors and constraints in the form of a weighted linear combination (WLC-option).

$$S=\Sigma WiXj$$

$$\mathbf{S} = 0.3863\mathbf{D}+ 0.2638\mathbf{SD}+0.1584\ \mathbf{SP}+ 0.1004\ \mathbf{T}+0.0328\ \mathbf{L.U}+0.0582\ \mathbf{S.T}$$

Where:

S is the suitability area

SP is the Slope

SD is Soil drainage

D is the soil depth

T is the texture

L.U is the land use

S.T is the soil type

4.3.5 Land suitability class specification

According to FAO standards, which are widely used to classify land suitability for specified objectives of land utilization types, a land can be divided in to five classes. These include very suitable (S1), suitable (S2), marginally suitable (S3), not suitable (N1) and permanently not suitable (N2).

Class-determining factors are those factors, which affect the performance of the land utilization types on the land units under the study. These factors include slope gradient, soil drainage, soil depth, soil texture, soil type and land use of the study area.

The reclassified factor maps, which were used to evaluate land suitability of the study area for crop production, are listed in Figure 4.14.

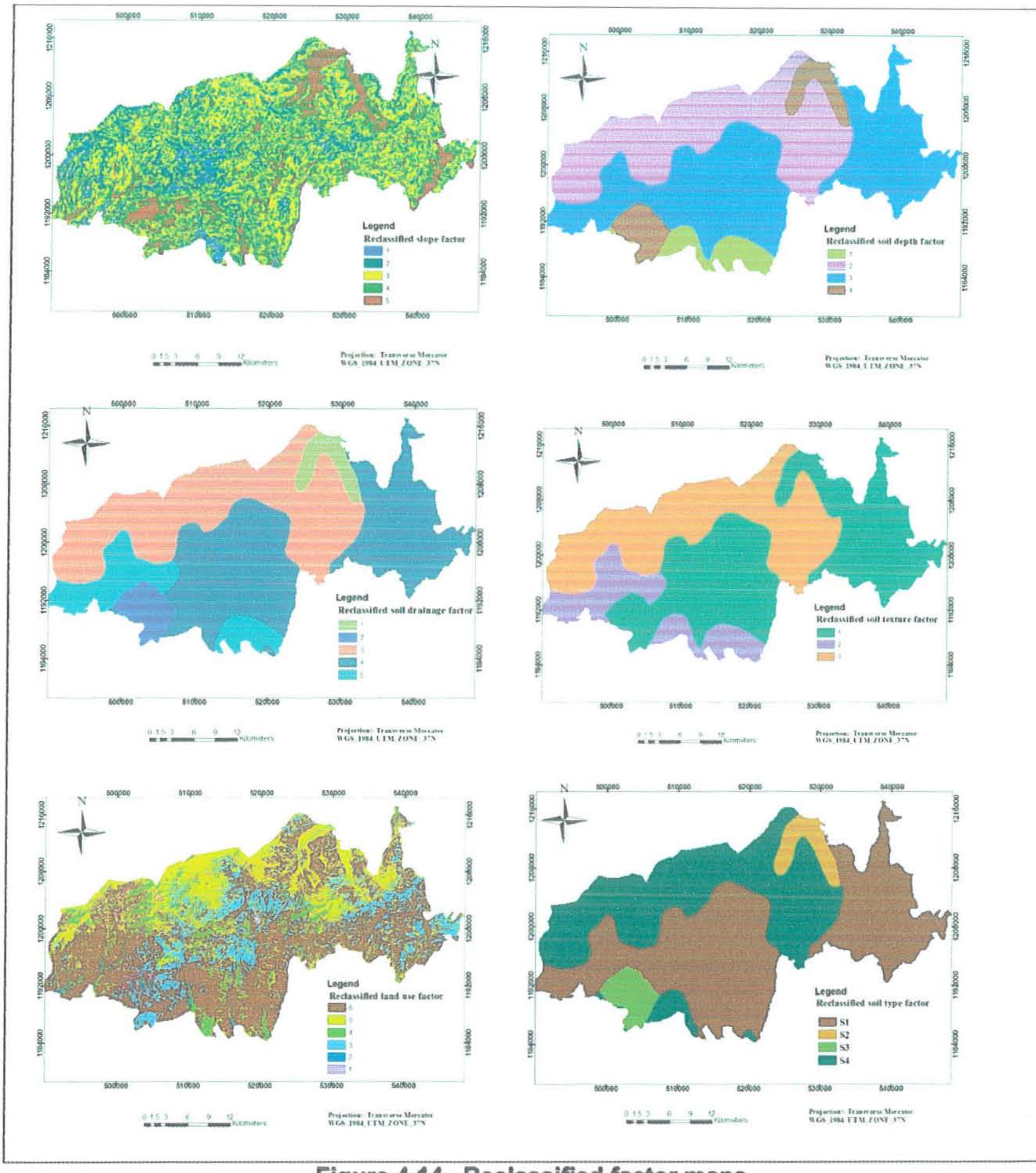

Figure 4.14. Reclassified factor maps

Multiplying the reclassified factors map based on the given weights and adding them by Raster calculator technique in spatial analyst module of ArcGIS 9.3 software, the final physical land suitability map the study area was developed. The values which are obtained from the result are classified in to five classes. These classes were converted to suitability classes (Fig 4.15). These were very suitable, suitable, marginally suitable, not suitable and permanently not suitable.

From the total land of the study area 99.68 km^2 (9.15%) was very suitable, 257.33 km^2 (23.63%) suitable, 292.99 km^2 (26.91%) marginally suitable, 390.04 km^2 (35.82%) not suitable and 48.893 hectare (4.49%) was permanently unsuitable for agricultural crop production (Table 4.11).

Table 4. 11 Land suitability of the study area for crop production

Suitability	Area in km^2	%
Very suitable	100	9.2
Suitable	257	23.6
Marginally suitable	293	26.9
Not Suitable	390	35.8
Permanently not Suitable	49	4.5
Total	1089	

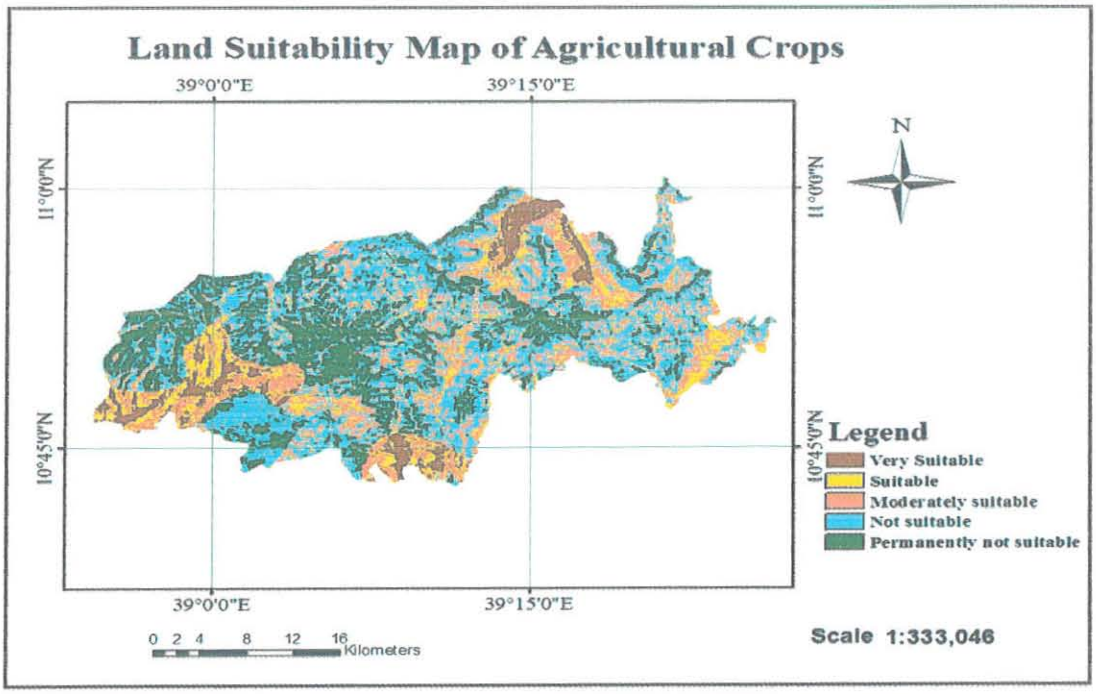

Figure 4.15 Land suitability map of the study area

4.4 Crops suitability map

4.4.1 Crop requirements

The factors, which are mentioned above, are the major physical factors, which were considered in determining the production of crops in the study area. All these factors do not have the same impacts on crops. Some crops need one factor more than the others. These factors bring different effects on production. Therefore weight given for the two crops were different based on their requirements (Table 4.12).

Wheat requires annual rainfall varying from 750 to 1000mm. The mean temperature during the growing season ranges from 21 to 28 ^{0}C and mean relative humidity during the growing season varies from 45 to 84 per cent. Deep (>100 cm), well drained, gentle sloppy, soils with clay to fine loamy texture are most preferred soil environments for the growth of wheat.

Maize requires an altitude between 1000-1800masl and 600 - 1200 mm rainfall, 18–33^{o}C temperature and clay loam or sandy loam soils.

Table 4.12 Criteria used in the evaluation of soil and terrain suitability for crops requirement (adopted from FAO guidelines modified for Ethiopian cases)

Crop	Depth m)	Temperature (^{o}c)	Rainfall (mm)	Drainage	Soil Type
Wheat	1-1.5	15-20(10-25)	750 – 1000	Well	Loam to clay Loam
Barley	1-1.5	15-20(10-25)	500 – 1000	Well	Light to medium texture
Maize	1-2	24-30(15-35)	600 – 1200	Well	Light to medium texture
Teff	1-1.5	15-20(12-25)	800 - 1000	Well	Silt to clay

4.4.2 Wheat suitability analysis

Wheat is highly adapted to cool dry temperate region which grows in medium to high altitude. It is tolerance to high water logging problem. Weight and ranking are given based on the specific requirement of wheat and there is also involvement of experts, decision makers and farmers as well (Table 4.13).

Table 4.13 Pair-wise comparison of factors for wheat suitability

Factors	Soil depth	Soil drainage	Slope	Soil texture	Temperature	Rainfall	Soil type	Land use
Soil depth	1							
Soil drainage	1/3	1						
Texture	1/3	1/3	1					
Slope	1/3	1/3	1/3	1				
Temperature	1/5	1/5	1/3	1/3	1			
Rainfall	1/5	1/5	1/3	1/3	1/3	1		
Soil type	1/7	1/7	1/5	1/5	1/3	1/3	1	
Land use	1/7	1/7	1/5	1/5	1/3	1/3	1/3	1

The eigenvector of weights is:

Soil drainage factor: 0.3227

Soil depth factor: 0.2423

Soil texture factor: 0.1497

Slope factor: 0.1125

Temperature factor: 0.0671

Rainfall factor: 0.0504

Soil type factor: 0.0316

Land use factor: 0.0237

Consistency ratio = 0.07

Consistency is accepTable

4.4.3 Maize suitability analysis

Maize requires an altitude between 1000-1800masl and 600 - 1200 mm rainfall, 18–33°C temperature and clay loam or sandy loam soils. Weight and ranking were given in the same way as it mentioned above (Table 4.14).

Table 4.14 Pair-wise comparison of factors for maize suitability

Factors	Soil drainage	Soil depth	Slope	Soil texture	Temperature	Rainfall	Soil type	Land use
Soil drainage	1							
Soil depth	1/3	1						
Slope	1/3	1/3	1					
Texture	1/3	1/3	1/3	1				
Temperature	1/3	1/3	1/3	1/3	1			
Rainfall	1/5	1/5	1/3	1/3	1/3	1		
Soil type	1/5	1/5	1/3	1/3	1/3	1/3	1	
Land use	1/7	1/7	1/5	1/5	1/5	1/3	1/3	1

The eigenvector of weights is:

Soil drainage factor: 0.3063

Soil depth factor: 0.2302

Slope factor: 0.1508

Texture factor: 0.1133

Temp factor: 0.0806

Rainfall maize: 0.0539

Soil type factor: 0.0405

Land use factor: 0.0243

Consistency ratio = 0.07

Consistency is accepTable.

The Pair-wise comparison method showed that the consistency ratios (CR) of crops were less than 0.1 - Wheat 0.07, maize0.07 (Table 4.13 & 4.14). This indicates that the comparisons of each factor were perfectly consistent, and the relative weights were suitable for use in the GIS multi-factor evaluation.

4.4.4 Developing suitability maps for the selected crops

In this step, Weighted Linear combination method was used to create the suitability map. In this technique, the eight important factors were mapped and reclassified in to five classes. These were very suitable (S1), suitable (S2), marginally suitable (S3), not suitable (N) and permanently unsuitable (PN). Each factors map was multiplied by weighting factors and sum together to get the suitability maps for the corresponding crops.

SW=ΣWiXj **S**M=ΣWiXj

SW = 0.2423 D + 0.3227 SD + 0.1497 T +0.1125 SP +0.0671 TP +0.0504 RF+0.00316 St + 0.0237 LU

SM =0.1508SP + 0.1133 T + 0.2302 SD + 0.3063 D + 0.0806 TP + 0.0539 RF + 0.0405 St + 0.0243 LU

Where:

SM = Suitability map for Maize

SW = Suitability map for wheat

SD = soil drainage

D= Soil depth

SP= Slope

RF =Rainfall

TP= Temperature

T = Soil texture

St = Soil type

LU = Land use

Suitability classes of wheat

From the total land of the study area 81.99 km^2 (7.5%) was very suitable, 249.61 km^2 (23%) suitable, 483.51 km^2 (44.4%) marginally suitable, 240.03 km^2 (22.0%) not suitable and 35km^2 (3.1%) was permanently unsuitable for Wheat production (Table 4.15).

Table 4.15 Extent of area suitable for wheat production in the study site

Suitability	Area in km^2	%
Very suitable	82	7.5
Suitable	249	23.0
Marginally suitable	483	44.4
Not Suitable	240	22.0
Permanently unsuitable	35	3.1
Total	1089	

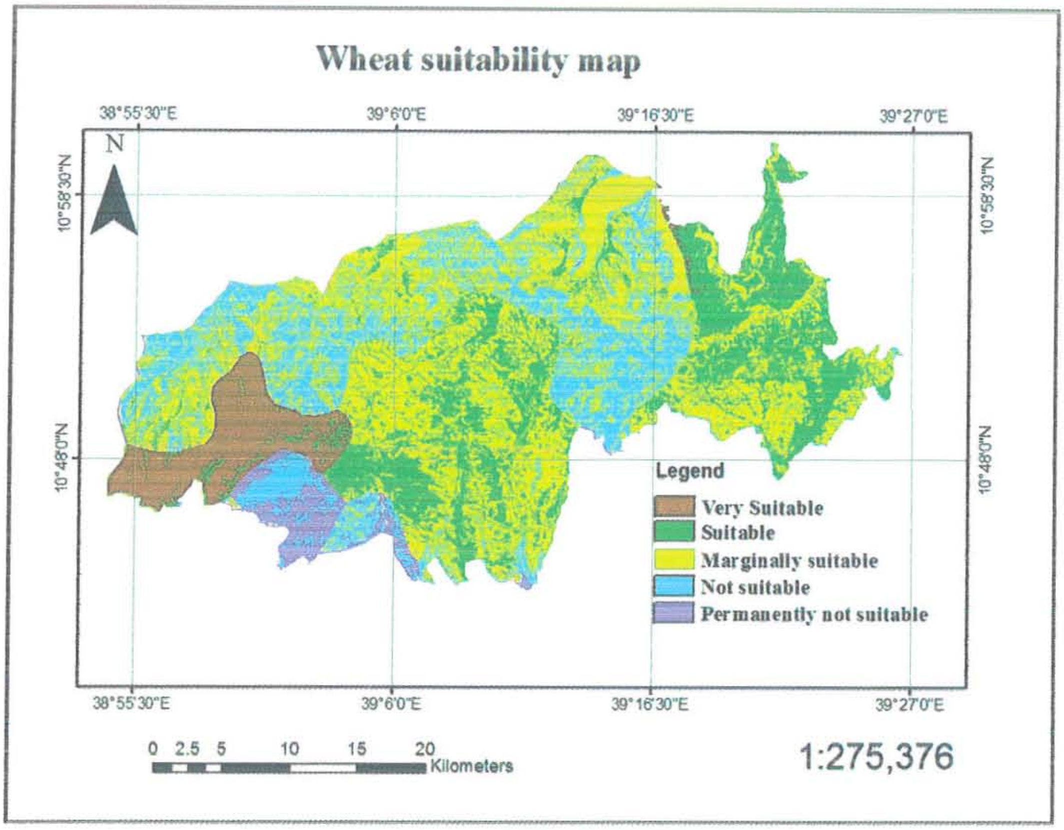

Figure 4. 16 Wheat suitability map of the study area

Suitability classes of maize

From the total land of the study area, 92.33 km^2 (8.48%) was very suitable, 299.07 km^2 (27.46 %) suitable, 321.49 km^2 (29.52%) marginally suitable, 261.89 km^2 (24.05%) not suitable and 114.15 km^2 (10.48%) was permanently unsuitable for maize production (Table 4.16).

Table 4.16 Extent of area suitable for maize production in the study site

Suitability	Area in km^2	%
Very suitable	92	8.5
Suitable	299	27.4
Marginally suitable	321	29.4
Not suitable	262	24.2
Permanently unsuitable	114	10.5
Total	1089	

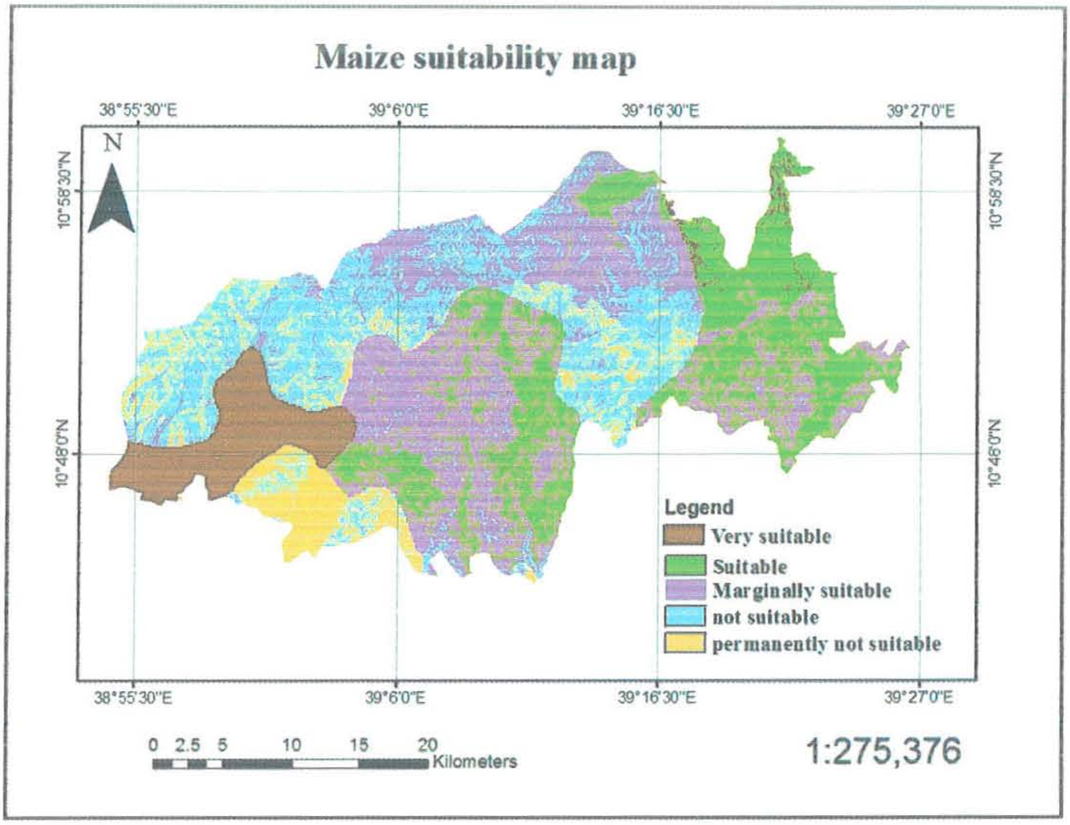

Figure 4.17 Maize suitability map of the study site

Chapter Five

5. Discussion

The results obtained from the land suitability assessment for wheat and maize seems to correspond with the realities of the study area. However, the land categorized as unsuitable for agricultural crop production is used by the farmers in the study area for agricultural. This is due to the shortage of cultivable land in the study area.

According to the results obtained, the western part of the study area is highly suitable for both the crops under review. The north-western part of the study area is suitable for crop cultivation due to soil drainage, soil depth and moisture availability. Along the central part, eastern part and northern part of the study area the land is marginally suitable for both crops. The steep slope areas with shallow soil depth coverage are unsuitable for both crops. Despite the fact that the gently slope with deep soil depth coverage in the south west part of the study area seems ideal for rain fed agriculture, the evaluation model classified as permanently unsuitable for both crops.

The unsuitability and permanently unsuitability of the above land units for the cultivation of the analyzed crops could be explained by their type of soils which are Lithic Leptosols and Vertisols with heavy clayey soil texture. However, this unsuitability is not entirely based on the soil type but on many other soil parameters associated with local soils conditions and water availability. The model has classified some land units as unsuitable but they are currently exploited for crop cultivation.

In conclusion, the case study has shown that 712 km^2 for maize and 814 km^2 of the study area are exploiTable for wheat production purposes. From this surface area:

- 82 km^2 and 92 km^2 is very suitable for wheat and maize production, respectively.
- 249 km^2 and 299 km^2 suitable for wheat and maize production, respectively.
- 483 km^2 and 321 km^2 marginally suitable for wheat and maize production, respectively

Considering the assumption behind the MCE procedure that factor maps should be non-redundant (independent), the results of this investigation were adequate in terms of the evaluation criteria set used here. The fuzzy membership function approach was useful to generate standardized factor maps. Thus, the final suitability map represents a more realistic outcome, given that it takes into account the gradients that exist in natural conditions. In this research, it was used land characteristics instead of land qualities to evaluate land suitability, because land quality information was not available for the study area. Land characteristics were used as a means to describe the land qualities.

Although the use of land characteristics in this form may present several disadvantages, for instance, the fact that they do not clearly identify the effect on crop growing, in this investigation this fact was attenuated by taking into account the knowledge and expertise of local agronomists. Furthermore, one of the main premises of the GIS-based land suitability analysis is that the method can help to minimize and even solve conflicts among competing interests regarding land use, by providing more, better data and information to resolve the problems. Besides, this investigation provides general alternatives for local farmers in the area of agricultural land management of a particular crop. In this MCE, the factors were selected based on agronomic knowledge of local experts and reviews of existing literature.

The feedback process involving local agronomic specialists was very useful, because results could be fine tune in light of their experience. Such an approach produced valuable information on the relative importance of the factors under evaluation and could be a useful precedent for future studies of wheat, maize and other crops. Additionally, the results of this study could be useful for other investigators who could use these results for diverse studies

6. Conclusion and Recommendations

6.1 Conclusion

The evaluation of physical land qualities of the study area indicates that the study area has a potential for agricultural crops. The factors which were considered for land suitability classification of the study area are slope of the land, soil depth, soil drainage, soil texture, soil type, land use land cover and climate. These factors were also used for suitability of crops under the study area. The selected crops for evaluation of physical land characteristics are maize and wheat.

Most types of crops require deep soil depth for their growth. Soil depth of the study area varies from place to place. Its depth is between less than 10cm and greater than 150cm. Those places having soil depth greater than 100cm is very suitable for crops. However it depends based on the requirements of crops. There is soil depth, which can be classified as very suitable for maize and wheat, which is above 100cm in the study area. In a specified area land having greater than 50cm soil depth can be recommended as suitable for most crop types. Hence, Legambo Woreda has a potential for agricultural crop production.

Clay is the dominant type of soil texture in the Legambo Woreda as the physical land characteristics of the study area was evaluated. Soil texture affects the infiltration rate of the soil. Coarse-textured soil type has great infiltration rate than fine-textured soil type. Clay texture soil has great retention (water holding capacity) or less infiltration rate. Therefore, more than half of the land of the study area is characterized by less infiltration rate.

The second dominant type of soil texture found in the study areas that determine the physical land suitability of land for crops suitability is loam. This type of soil is very suitable for many agricultural crops. The other type of soil texture is clay loam which is suitable for many crops next to loam texture soil.

Soil type of the land determines the physical land characteristics of the study area for crops suitability. Leptisols is the most dominant soil type in the study area. As it was evaluated the physical land suitability of the area for and crops suitability, the drainage properties of the study area are classified in to well, moderately well and imperfect drained area.

The total land under the study area which is suitable for agricultural production is 35701 hectare which is 32.78% of the study area. 29299.6 hectare 26.91% is moderately suitable for crop production. 43892.4 hectare 40.3% of area is not suitable for agricultural crop production.

6.2 Recommendations

As the land has been evaluated, the physical land suitability of the Legambo Woreda has great potential for Agricultural crop production. But land suitability was carried out only based on physical land qualities of the study area. Chemical properties of soils are also very necessary for crops suitability in a specified area. Therefore, a research should be conducted on the evaluation of chemical properties of the soil such as Ph, soil fertility, cation exchange capacity. under the study area.

The evaluation carried out in this paper is in terms of physical land suitability for agricultural crop production. But the effects of each alternatives use or classes should be appraised in environmental, economic and social terms.

It is recommended that appropriate physical and biological soil and water conservation structures should be implemented in moderately suitable areas for maximize crop production and to sustain the soil productive capacity of the study area.

Areas which are not suitable for agricultural crops should be used for forest production and area closure should be implemented to rehabilitate the degraded areas.

References

Addeo, G., G. Guastadisegni and M. Pisante (2001). Land and water quality for sustainable and precision farming. I World Congress on Conservation Agriculture, Madrid.

Anderson, L.T. 1987. Seven methods for calculating land capability/suitability. Planning Advisory Service (PAS) Report No. 402.

Beek, K. J., P. A. Burrough and D. E. McCormack (1987). "Quantified land evaluation procedures: Proceedings of the international workshop on quantified land evaluation procedures held in Washington, DC 27 April - 2 May 1986". International workshop on quantified land evaluation procedures, Washington, DC.

Belton, V. and T. Gear (1983). "On a short-coming of Saaty's method of Analytical Hierarchies." Omega 11: 228-230.

Ceballos-Silva, A. and J. Lopez-Blanco (2003). "Delineation of suitable areas for crops using a Multi-Criteria Evaluation approach and land use/cover mapping: a case study in Central Mexico." Agricultural Systems 77: 117-136.

D.W. Thorne and H.B. Peterson, 1949 Irrigated Soils, their fertility and Management, New York The Blackstone Company, Inc. Toronto.

Diamond, J.T., and J. Wright. 1988. Design of an integrated spatial information system for multi objective land use planning. Environment and Planning B: Planning and Design 15: 205–14.

FAO 2003.theoretical framework for land Evaluation. Geoderma 72: 165-190

FAO1976. A framework for land evaluation. Soils Bulletin, No. 32.FAO, Rome.

Foote, K. E. and M. Lynch (1996). Geographic information systems as an integrating technology: context, concepts and definition. University of Texas, Austin.

Ghafari, A., H. F.Cook and H. C. Lee (2000). Integrating climate, soil and crop information: a land suitability study using GIS. 4th International Conference on Integrating GIS and Environmental Modeling (GIS/EM4): Problems, Prospects and Research Needs, Banf, Alberta.

Hopkins, L.D. 1977. Methods of generating land suitability maps: A comparative evaluation. Journal of American Institute of Planners. 43: 386–400.

Jankowski, P. (1995). "Integrating geographical information systems and multiple criteria decision making methods." international Journal of geographic Information System 3: 251 273.

Jiang, H. and J. R. Eastman (2000). "Application of Fuzzy Measures in Multicriteria evaluation in GIS." International journal of Geographic Information Science 14: 73- 184.

Kangas, J. 1992. Multiple-use planning of forest resources by using the Analytic Hierarchy Process. Scand. Journal of Forest Research. 7:259–68.

Kangas, J. 1993. A multi-attribute preference model for evaluating the reforestation alternatives of a forest stand. Forest Ecology and Management. 59: 271–88.

Klingebiel, A.A. and Montgomery, P.H. (1961) Land-capability classification. Agricultural Handbook 210, Soil Conservation Service. U.S. Govt. Printing Office, Washington, D.C. 21 p.

Lai, S. (1995). "A preference-based interpretation of AHP." Omega 23: 453-462.

Leingsakul, M., S. Mekpaiboonwatana, P. Pramojanee, K. Bronsveld and H. Huizing (1993). "Use of GIS and remote sensing for soil mapping and for locating new sites for permanent cropland -a case study in the highlands of northern Thailand." Geoderma 60: 293-307.

Lillesand T.M and Keffer R.W, 2000; Remote sensing and image interpretation, 4th edition, John Wiley and Sons, Inc, New York.

Malczewski, J. (1999). GIS and Multicriteria decision Analysis. John Wiley &Sons, Inc, New York.

Marble, D. H., H. W. Calkins and D. J. Pequet (1984). Basic Readings in Geographic Information Systems. Williamsville, NY.

Masuda, T. (1990). "Hierarchical sensitivity analysis of the priorities used in the Analytic Hierarchy Process." Systems Science 21: 415-427.

Mendoza, G.A. 1997. Introduction to Analytic Hierarchy process: Theory and applications to Natural Resources Management. In Proceedings of 1997 ACSM/ASPRS Annual Convention. Vol 4. Resource Technology. April 7–10. Seattle, WA. pp.130–39.

Mendoza, G.A. and W. Sprouse. 1989. Forest planning and decision making under fuzzy environments: An overview and analysis. Forest Science 35: 481–502.

Mikhailov, L. (2003). "Deriving priorities from fuzzy Pair-wise comparison judgements." Fuzzy Sets and Systems 134: 365-385.

Pereira, J. M. C. and L. Duckstein (1993). "A multiple criteria decision-making approach to GIS based land suitability evaluation." International Journal of Geographical Information Science7: 407-424.

Pereira, J.M., and R. Itami. 1991. GIS-based habitat modeling using logistic multiple regression: A study of the Mt. Graham Red Squirrel. Photogrammetric Engineering and Remote Sensing, 57:1475–86.

Peterson, D.L., D. Silsbee, and D.L. Schmoldt. 1994. A case study of resource management planning with multiple objectives. Environmental Management. 18: 729–42.

Pukkala, T., and J. Kangas. 1996. A method of integrating risk and attitude toward risk into forest planning. Forest Science. 42: 198–205.

Reynolds, K.M., and E. Holsten. 1994. Relative importance of risk factors for spruce beetle outbreaks. Canada Journal of Forest Research, 24: 2089–95.

Saaty, T. L. (1977). "A Scaling Method for Priorities in Hierarchical Structure." Journal of Mathematical Psychology 15.3.New York

Saaty, T. L. (1980). The Analytic Hierarchy Process. McGraw-Hill International, New York.

Saaty, T. L. and L. G. Vargas, Eds. (2001). Models, Methods, Concepts & Applications of Analytical Hierarchy Process. International Series in Operations Research and Management Sciences, New York.

Steiner, F. 1983. Resource suitability: Methods for analysis. Environmental Management. 7: 401–20.

Steiner, F. 1987. Agricultural land evaluation and site assessment in the United States: An introduction. Environmental Management. 11: 375–77.

Tkach, R. J. and S. P. Simonovic (1997). "A New Approach to Multi-criteria Decision Making in Water Resources." Journal of Geographic Information and Decision Analysis 1: 25-44.

Triantaphyllou, E. (2001). "Two New Cases of Ranking Reversals When the AHP and Some of Its Additive Variants Are Used that do not occur with the Multiplicative AHP." Journal of Multi-Criteria Decision Analysis 10: 11-25.

Triantaphyllou, E. and A. Sanchez (1997). "A Sensity Analysis Approach for some Deterministic Multi-Criteria Decision Making Methods." Decision Sciences 28: 151- 194.

Triantaphyllou, E. and S. H. Mann (1994). Some Critical Issues in Making Decisions with Pair-wise Comparisons. Proceedings of the Third International Symposium on the Analytic Hierarchy Process, Washington, D.C.

Xiang, W. and D.L. Whitley. 1994. Weighting land suitability factors by the PLUS Method. Environment and Planning B: Planning and Design. 21:273–304.

ANNEX 1

Crop productivity of the study area

ser.no	Crop	Area (ha)	Yieald (qt/ha	Production(quintal)
1	barley	7821	16.5966667	89155.45
2	Wheat	9307.9	16.840625	103632.3
3	Teff	1763.9	10.4166667	13771.42
4	Oat	574.75	10.875	5655.625
5	Wild oat	1152	13.325	13134.65
6	Maize	8.9375	16.5	185.25
7	Sorgjum	246.81	12.875	2760
8	faba Bean	3370.8	12.47	32224.46
9	Field Pea	2528.9	10.33625	21344.83
10	Chick Pea	484.75	9.52	3766.5
11	Grass Pea	605	11.6475	5648.603
12	lentil	3106.5	10.2325	24851.9
13	Soyabean	0.5	2	4
14	fenu greek	470	7.75	2427.2
15	linseed	233	5.85	1167.5
16	Nug	9.625	2.22	40.25
17	Potato	52.875	79.25	4255.75
18	onion	90.75	51	2436
19	Papper	2	12.5	115
20	Carrot	21.5	42	735
21	Spices	1	20	12
22	total	31852		327323.6

ANNEX 2

Long Year climatic data for Five Stations

Element: Monthly Rainfall in mm
Region: WELLO
Station: AKESTA

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1982		5.9	91.1									
1992							177.7	239.4	63.1	17.7	20.5	13.4
1993	37.2	60.6	34.9	217.7	49.5	35.1	229.4	118.9	61.2	15.7	0.0	0.0
1994	0.0	25.1	207.2	43.3	3.8	17.2	343.5	236.2	83.8	5.1	5.2	7.0
1995	0.0	17.5	55.8	106.2	63.5	17.8	232.3	151.3	28.3	0.1	0.8	43.5
1996	125.5	12.7	111.0	79.3	130.8	52.8	178.1	249.1	18.5	0.0	40.7	6.9
1997	50.8	0.0	73.3	67.0	5.0	89.1	231.3	237.5	5.6	40.0	52.2	7.1
1998	32.7	65.9	133.0	48.6	100.5	24.1	456.7	244.4	48.4	41.0	0.0	0.0
1999	25.1	0.0	4.1	0.0	0.9	18.7	423.1	342.6	63.5	20.5	0.0	5.6
2000	0.0	0.0	17.0	104.8	42.4	27.1	343.5	246.7	48.5	12.6	41.6	x
2001	0.1	115.5	159.8	20.6	63.6	32.3	432.0	293.1	29.8	12.6	0.0	29.7
2002	78.5	7.9	85.9	50.8	20.4	18.7	354.3	201.7	40.9	0.0	0.0	21.3
2003	9.8	59.2	180.7	72.3	16.7	35.1	208.5	158.8	36.2	0.0	11.5	24.4
2004	7.8	9.5	54.5	88.6	2.0	75.0	307.1	292.4	14.0	0.5	5.0	37.4
2005	42.7	0.0	74.1	56.4	x	76.0	298.9	166.3	11.1	0.0	1.8	0.0
2006	8.9	39.9	132.9	134.7	64.8	2.9	232.7	344.5	72.8	15.3	36.7	x
2007				93.6	1.0							

Element: Monthly Rainfall in mm
Region: WELLO
Station: KABE

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1986	X	x	x	x	35.8	190.3	237.3	152.8	78.3	11.8		19.1
1987	0.0	41.7	180.7	81.9	130.1	x	0.0	75.3	31.1	21.0	0.0	4.6
1988	16.7	x	1.3	256.9	x	x	254.0	266.1	95.5	7.1	0.0	0.0
1989	0.0	x	54.3	116.1	7.0	53.0	260.9	x	x	x	x	x
1992	X	9.5	34.9	18.3	14.8	16.9	197.1	278.6	67.9	6.7	17.6	6.4
1993	11.5	63.0	37.5	103.2	41.5	2.3	x	x	x	0.0	0.0	0.0
1994	0.0		68.8	37.2	14.6	x	x	x	x	x	x	x
1995	1.6	17.2	32.0	94.5	35.2	25.6	339.1	244.4	58.4	1.5	0.0	31.8
1996	59.0	4.1	77.5	10.9	117.4	28.9	263.4	332.5	40.7	2.7	8.8	4.3
1997	49.7	0.0	46.1	37.7	4.9	97.8	222.1	x	x	x	x	0.3
1998	15.5		70.1	1.1	39.9	2.9	373.4	371.4	49.3	18.2	0.0	0.0
1999	X	x	x	x	x	x	354.3	349.1	77.5	43.4	0.0	4.1
2000	0.0	0.0	3.5	93.5	17.7	37.5	405.9	282.8	75.3	29.7	19.9	0.4
2001	0.0	6.5	106.3	3.2	51.8	49.0	455.1	289.8	48.1	4.6	0.0	0.0
2002	67.0	15.0	59.5	71.2	5.9	11.9	235.2	257.8	85.3	3.7	2.5	16.3
2003	13.6	24.3	15.6	75.3	13.6	45.1	282.6	283.3	82.1	0.0	0.0	19.1

Element: Monthly Rainfall in mm
Region: WELO
Station: WEREILU

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1994	0.0	0.0	47.8	41.5	0.0	25.4	442.3	307.4	45.4	0.0	0.9	0.0
1995	0.0	37.6	23.5	49.9	26.5	26.7	316.8	203.0	77.5	0.0	0.0	29.[illegible]
1996	31.1	0.0	60.3	13.9	62.9	6.0	114.2	143.5	39.8	0.0	28.3	0.0
1997	35.3	0.0	56.8	44.8	6.8	99.8	328.7	180.4	12.9	38.5	4.6	0.0
1998	45.2	4.5	88.2	23.3	38.5	9.1	426.4	375.3	51.3	12.7	0.0	0.0
1999	13.7	0.0	23.1	12.4	0.0	11.3	568.0	426.9	71.3	0.0	38.0	3.0
2000	0.0	0.0	12.1	59.4	47.6	47.0	479.4	369.1	97.1	9.5		13.4
2001	0	6.2	123.4	12.1	43.6	26	601.8	301.1	23.8	0	0	10.7
2002	63.4	13.2	51.5	28.8	3.9	43.4	242.1	322.7	32.4	5.7	0	15.6
2003	21.9	21.8	43.4	56.6	3.2	56.5	306.5	250.2	74.4	0	2.2	38
2004	13.3	15.9	46.9	50.8	2.9	42.3	229	225.8	50.4	4	7.9	0
2005	38.6										2	
2006							263.1					
2007			12.6	73.5	2.4							

Element: Monthly Rainfall in mm
Region: WELLO
Station: MEKANE SELAM

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1993	X	4.6	35.1	205.3	53.3	98.3	x	x	146.7	x	10.4	0
1994	0	21.9	63.8	44.5	41.9	69.4	192.2	97.5	74.2	8.1	19	0
1995	0	26.4	58	101.7	98.6	18.7	320.1	226.1	55.4	0.4	0	24.5
1996	32.8	1.6	63.8	102.6	83.1	135	243.6	194.5	78.2	0.2	23.3	6.5
1997	48.9	2.2	62.5	73.9	49.4	94.7	201.7	137.9	43	110.2	100.2	17
1998	23.2	3.7	102.8	48	70.2	70.9	319	264.7	123.7	118.1	19.3	0
1999		0	2.4	63.9	24	33.1	265.1	220.2	80.7	90.1		9.8
2000	0	0	12.5	127.8	43.8	84.1	286.1	185	111.3	74.7	36.5	9
2001	0.4	27.3	133.9	55.1	58.4	104.8	319.2	168.7	45.2	62.2	0.9	20.8
2002	55.3	14.8	60.3	38.6	41.5	57.1	276.6	212.5	91	0	7.1	28.1
2003	15.2	47.1	77.8	55	8.8	80.2	245.1	150.6		0	4	9.3
2004	0.8	0.9	29.4	44.6	21.3	95.9	184.2	181.5	51.7	41	3.4	0
2005	12.2	0	61	55.2	86.3	60.2	207.1	150.9	122.4	32.9	5	0
2006								251.5				
2007			0	58.1	79.8							

Element: Monthly Rainfall in mm
Region: WELLO
Station: DESSIE

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1995	0	57.6	61.3	275.1	95.5	64.8	303.5	253.9	100	70	0	53
1996	42.6	35.4	138.3	82.8	144.2	58.7	214.2	413.3	80.2	2.2	104.3	4.5

1997	50.6	0	116.3	57.7	29.5	116.9	234.5	278.2	60.9	172.5	13
1998	80.9	62.6	55.1	38.9	79.8	0	555	407.2	114.7	92.1	
1999	44	0	40.1	0	11.4	15.3	469.6	444.3	223	122	
2000	0	0	5	75.9	57.6	50	425.7	329.3	210.8	102	6
2001	1.3	0	136.4	35.2	106.8	43.7	416.9	309.9	148	40.7	
2002	34.3	16.8	90.1	132.4	21.8	6	334.8	389.4	164.8	21.7	
2003	42.8	35.8	42.9	187.1	9.3	58.5	177.3	352.6	180.2	2.3	
2004	2.3	14.9	11.5	70.6	5.1	46.3	283.6	264.9	92.6	97	5
2005	16	18.9	124.3	116.5	120.3	47.7	355.2	398.3	79.4	37.5	
2006	2.3	3	116.4	56.9	102.2	30.6	530.8	418.3	218.7	65.8	x

DECLARATION

I hereby declare that the thesis entitled "**LAND SUITABILITY AND CROP SUITABILITY ANALYSIS USING REMOTE SENSING AND GIS APPLICATION; A CASE STUDY IN LEGAMBO WOREDA, ETHIOPIA**" has been carried out by me under the supervision of Dr. Dagnachew Legessse, Department of Earth Sciences, Addis Ababa University, Addis Ababa during the year 2010 as a part of Master of Science program in Remote Sensing and GIS. I further declare that this work has not been submitted to any other University or Institution for the award of any degree or diploma.

Henok Mulugeta

Signature: ____________________

Place: Addis Ababa

Date: June, 2010