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GIS AND REMOTE SENSING BASED LAND SUITABILITY ANALYSIS FOR AGRICULTURAL CROPS IN MOJO WATERSHED, UPPER AWASH SUB-BASIN, ETHIOPIA

BY

DULA WAKASSA DUGUMA

AAU

JUNE, 2010

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A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES OF ADDIS ABABA UNIVERSITY, IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEM

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DULA WAKASSA DUGUMA

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(Remote Sensing and GIS Stream)

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Approved by Board of Examiners

Dr. Balemewal Atnafu Chairman, Department Head Graduate Committe	______________________________
Dr.Dagnachew Legesse Advisor	______________________________
Dr. Makuria Argaw Examiner	______________________________
Dr. Mohamed Umer Examiner	______________________________

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Acronyms

AHP	Analytical Hierarchy Process
CR	Consistency Ratio
DEM	Digital Elevation Model
EMA	Ethiopian Mapping Agency
ERDAS	Earth Resource Data Analysis
ETM^+	Enhanced Thematic Mapper Plus
FAO	Food and Agricultural Organization of the United Nations
GCPs	Ground Control Points
GIS	Geographical Information System
GPS	Global Positioning System
IDW	Inverse Distance Weighted
LQ	Land Quality
LU/LC	Land use / Land cover
LURs	Land Use Requirements
LUTs	Land Utilization Types
MCA	Multi-Criteria Analysis
MCDA	Multi-Criteria Decision Analysis
MCE	Multi-Criteria Evaluation
NASA	National Aeronautics and Space Administration
NMSA	National Metrological Service Agency
OWWDSE	Oromia Water Works Design and Supervision Enterprise
PCM	Pairwise Comparison Matrix
SMCDM	Spatial Multi-Criteria Decision Making
SRTM	Shutlle Radar Topographic Mission
UTM	Universal Transverse Mercator
WGS	World Geodetic System
WOA	Weighted Overlay Analysis

Abstract

Land suitability analysis is the evaluation and grouping of specific areas of land in terms of their suitability for a defined use. Land suitability potential evaluation for agricultural crops is an important step for sustainable land use planning. Improper land use results in land degradation and decline in agricultural productivity. Hence, in order to get the optimum benefit out of the land, proper utilization of its resources is inevitable. GIS and remote sensing offer a convenient and powerful platform to integrate spatially complex and different land attributes for performing land suitability analysis and allocations. This study intended to analyze and map suitable land areas for agricultural crops in Mojo Watershed using GIS and remote sensing techniques. The study used weighted overlay technique of MCE in a GIS platform to arrive at the final land suitability for agricultural crops. In addition a vector overlay (union) was used for suitable land allocation for the evaluated crops. The factors that were considered for evaluation of the land suitability analysis for agricultural crops are soil (depth, drainage, texture, organic matter, and pH), rainfall, temperature, slope and land use/land cover. The result showed that 27.3%, 35.4%, and 15.7% of the study area are classified as highly suitable for teff, wheat, and chickpea production, respectively. In addition, 65.2%, 60.9%, 77.9% and 80.2% were found to be moderately suitable while 4.1%, 0.6%, 3.3% and 16.5% is marginally suitable land for teff, wheat, chickpea and lentil, respectively. The result indicated that, there is no land that is classified as currently not suitable for wheat. However 0.3%, 0.03% and 0.04% of the study area is classified as currently not suitable for teff, chickpea and lentil, respectively. The vector overlay result indicated that 4.0% of land is highly suitable for both teff and wheat; 11.2% is highly suitable for wheat and chickpea; 2.6 % is highly suitable for teff, wheat and chickpea. In the same manner, 26.8% of the study area is moderately suitable for teff, wheat, chickpea and lentil. Therefore, integrating MCE with GIS for land suitability analysis for agricultural crops for spatial decision making process is a worthwhile technique. Hence, to increase the choice for the stakeholders and decision makers, further analysis for different LUTs is necessary.

Keywords: Mojo Watershed, Land suitability analysis, GIS and Remote Sensing techniques, Multi-criteria Evaluation, Suitable land allocation

1. Introduction

1.1 General Background

Agriculture is one of the world's most important activities supporting human life. On a global scale, agriculture has the proven potential to increase food supplies faster than the growth of the population, a pattern to be expected in the foreseeable future (Davidson, 1992). By the year 2025, 83 % of the expected global population of 8.5 billion is expected to live in developing countries. Yet the capacity of available resources and technologies to satisfy the demands of this growing population for food and other agricultural commodities remains uncertain (FAO, 1993). There is growing concern about food security in Africa and especially in sub-Saharan Africa. While the aggregate global food supply/demand picture is relatively good, there will be a worsening in food security in sub-Saharan Africa (FAO, 1993)

Evaluation of land suitability which has great physical and chemical land qualities is very needed to contribute to the world's food production in general and the country, Ethiopia, in particular to improve food security. Land suitability is the fitness of a given type of land for a defined use. The process of land suitability classification is the appraisal and grouping of specific areas of land in terms of their suitability for defined uses (FAO, 1976). Agricultural productivity in Ethiopia has not kept pace with population increase, and the region is now in a worse position nutritionally than it was 30 years ago: food production has achieved a growth of about 2.5% per year, while population has risen at a rate of over 3% per year (Hailu Beyene, 2008). With the increase in population, as well as human activities, pressure on land has been intensified. Farming activities in the watersheds without proper management practices, such as the replenishment of nutrients using organic matter applications, rainwater harvesting, measures to reduce soil losses due to soil erosion, etc. lead to degradation of farmlands (Hailu Beyene, 2008). In rain-fed agriculture production systems, natural resources need to be used in such a manner that the productivity potential of the watershed is optimized. The sustained land use planning, therefore, involves the decision of land use so that available resources are put into use according to the assessed potentiality.

In Ethiopia, agricultural land suitability analysis is very important since agriculture accounts on average for about 46.3% of Growth Domestic Product, 83.9 % of exports and 80 % of the labour force (MoFED, 2009). The same source indicated that Ethiopia has great agricultural potential because of its vast areas of fertile land, diverse climate, generally adequate rainfall, and large labour pool. Despite this potential, however, Ethiopian agriculture has remained underdeveloped because of drought, a poor economic base, and low level of technologies on agricultural application.

GIS, geo-spatial mapping ,and remote sensing technologies are central to achieving a successful transition from traditional environmental and resource management practices to sustainable development because of their integrative quality (linking social, economic and environmental data) and their place-based quality (addressing relationships among places at local, national, regional and global levels) (World Bank, 2006).

For instance, there is a growing recognition by decision makers that problems at the intersection of agriculture and environmental management, climate change, and land vegetative cover change, with their attendant social and economic consequences, will be at the forefront in the new century. Technological advances in GIS fostering the integration of satellite imagery with other data (such as socioeconomic or health data) are opening new ways to synthesis complex and diverse geographic data sets, creating new opportunities for collaboration among natural and social scientists and decision makers at all levels (World Bank, 2006).

Various approaches of land evaluation have been developed, and each has a specific methodological procedure (FAO, 1976; Davidson, 1992). The qualitative systems are empirical assessment systems and are based on the knowledge and understanding of the area. The Food and Agricultural Organisation (FAO, 1976) recommended an approach for land suitability evaluation for crops in terms of suitability ratings ranging from highly suitable to not suitable based on climatic and terrain data and soil properties. However, Davidson (1992) used an approach of land capability evaluation for general agricultural purpose rather than for specific land use types. Sys and Verheye (1972) cited in Bandyopadhyay et al. (2009) proposed a capability index, based on multiple parameters, related to soil properties and, subsequently, Sys (1985) proposed a range of capability indexes to denote soil limitations for crop production.

With advances in information and communication technology, computer based decision support models have been developed towards land evaluation (De la Rosa et al., 1992; Shim et al., 2002; cited in Bandyopadhyay et al., 2009). Land evaluation through map analysis techniques has been accomplished using a geographical information system (GIS) (Malczewski, 2003).

In many countries the pressure on land is ever increasing which leads to a decrease in the area of agricultural land. Many developing countries, especially in Africa, need to increase their agricultural production in order to feed a growing urban and rural population and to produce raw materials for local industry and export in sufficient quantities to sustain a healthy economy (World Bank, 2006).

In Ethiopia, as in many developing countries, current land use practices is not based on suitability analysis; therefore, there is an urgent need to use land in the most rational and possible way. One of the most important and urgent problems in Ethiopia is to improve agricultural land management and cropping patterns to increase the agricultural production with efficient use of land resources (Hailu Beyene, 2008). In this sense, GIS and remote sensing technology offers a dynamic tool for multidimensional process of land use. This study applied multi-criteria evaluation (MCE) integrating with GIS to delineate the suitable areas for agricultural crops (teff, wheat, chick pea and lentil) using the relevant variables of soil, climate, land use/ land cover and topographic factors through the MCE technique within a GIS context to improve crop production and allocate the land to the most suitable use type.

1.2 Statement of the Problem

Land suitability analysis is needed for various purposes in Mojo watershed regarding the situation of the agriculture in this area. The livelihood of people of this area is highly dependent on rain fed agriculture with small amount of land. Crop-land suitability analysis is a prerequisite to achieve optimum utilization of the available land resources for sustainable agricultural production. Agriculture is the main source of income and form of survival for peoples of this area and cereals and pulses are the major food but the production is very low. In particular the cereal production of the study area does not meet the demands due to its rapidly growing population. Pressure on land continuously increased because of population growth. Improper land use results in land degradation and decline in agricultural productivity. This further exacerbates food insecurity of the place which further leads to another land for agricultural activity. To serve increasing demands, it is necessary to struggle for sustainable land use.

Land use practice in this study area is not based on the matching of crop environmental requirement to land qualities. Hence, land suitability potential evaluation for agricultural crops is an important step for sustainable land use planning and to increase agricultural productivity, since it involves the matching of crop requirement to land quality. It deals with the assessment of land performances for the specific use.

Due to this fact land suitability study for this specific area is necessary. It is obvious that land use planning has to be adapted. A thorough analysis of potentials and constraints of land for land use alternatives is needed before rational decisions can be made. Therefore, it becomes clear that in determining the best modes of sustainable land use, land suitability assessment for a particular use has an important role to play.

Hence, in order to get the optimum benefit out of the land, proper utilization of its resources is inevitable. As a result, a land use plan which incorporates different land characteristics has a paramount importance. GIS and Remote sensing offer a convenient and powerful platform to integrate spatially complex and different land attributes for performing land suitability analysis and allocations.

1.3 Objectives

1.3.1 General Objective

The main objective of the study is to evaluate the land suitability using multi-criteria evaluation technique for agricultural crops and produce land allocation map for sustainable land use.

1.3.2 Specific Objectives

Specific objectives include:

- To examine some of the physical and chemical properties of soils (depth, texture, drainage, organic matter, and pH) for agricultural crops.
- To evaluate the suitability of soils for agricultural crops.
- To produce thematic maps of land suitability for different agricultural crops (teff, wheat, lentil, and chickpea).
- To produce appropriate land allocation maps for sustainable land use and management.
- To produce thematic map and examine the existing land use/ land cover of the study area.

2. Literature Review

2.1 Land Suitability Analysis

The management of natural resource is a cross boundary issue that should be emphasized in all planning processes within multi-sectoral approach (administrative and geographical). Land suitability is part of land use planning methodology and defines possible options for the future land use and helps to describe these interactions (policies, institutions and information management) (Ignas, 2004). Land suitability is the fitness of a given type of land for a defined use (FAO, 1976). The process of land suitability classification is the appraisal and grouping of specific areas of land in terms of their suitability for defined uses (FAO, 1976; 2007)

The way the people use the land is based on the available skills, knowledge, culture and experiences. The land use attitude changes when the income of land changes through e.g. improved technology (Ignas, 2004). Land suitability assessment is similar to choosing an appropriate location, except that the goal is not to isolate the best alternatives, but to map a suitability index for the entire study area. Senes and Toccolini (1998) combine UET (Ultimate Environmental Threshold) method with map overlays to evaluate land suitability for development. Hall et al. (1992) cited in Malczewski (2006) also use map overlays to define a homogeneous zones, but then they apply classification techniques to assess the agricultural land suitability level of each zone. Combining GIS and MCDA is also a powerful approach to land suitability assessments (Florent et al., 2001).

The development of land suitability maps also presents an opportunity for all governmental departments involved in land management to compare their points of view and coordinate their policies. Furthermore, subject to the agreement of the decision makers, all the interested stakeholders (e.g. the public, construction enterprises, environmental NGOs) could also be involved in the procedure. In such a case, the land suitability maps could be widely accepted and the population at large would more easily endorse decisions based on these maps (Florent et al., 2001)

FAO (1985) analyzed land suitability mainly based on the land quality. Land quality is a complex attribute of land that has a direct effect on land use (FAO, 1993). These attributes are availability of water and nutrients, rooting condition and erosion hazards.

Most land qualities are determined by interaction of several land characteristics, which are measurable attributes of the land. The value of land quality is the function of the assessment and grouping of land types in to orders and classes in the framework of their fitness. Generally, land suitability is categorized as suitable (S) and not suitable (N). Whereas, S features lands suitable for use with good benefits, N denotes land qualities which do not allow considered type of use, or are not enough for suitable outcomes (FAO, 1985).Land suitability is primarily the potential biological productivity of land (FAO, 1985). Productivity of land can be determined by environmental components such as climate, local topography (roughness, steepness, and exposure), soil type and existing vegetation. Land suitability classification is developed by considering different factors of land characteristics. Based on suitability of each land use, a weighted value ranging from 5 (unsuitable) to 1 (most Suitable) are given. The weighted value of each factors were reclassified for each land use. Each parameter is given a value based on its suitability for each land use type. The weighted value of each land characteristics factors is added and the average value of them is taken to determine the suitability of land for each land use type. The average value of them is categorized in to five suitable classes to get the final suitability for each land uses.

Table 1. Suitability classes (FAO, 1993).

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

Land suitability analysis using a scientific procedure is essential to assess the potential and constraints of a given land parcel for agricultural purposes (Rossiter, 1996). In the recent past, the ill-effects of land use on the environment and environmental sustainability of agricultural production systems have become an issue of concern. The problems of declining soil fertility, stagnant yield level and unfettered soil erosion are associated with intensive agriculture in industrialized countries, while over-exploitation of natural resources and scarcity of inputs like chemical fertilizers denote intensive agriculture in the developing areas (Martin and Saha, 2009). Land evaluation and crop suitability analysis using GIS and remote sensing would resolve these issues while providing better land-use options to the farmers. Hence, analysis of crop suitability under various systems that could be grown in a given area is essential. GIS is an important aid for spatial decision making (Carver, 1991; Pereira and Duckesstien, 1993). Developments in GIS have led to significant improvements in its capability for decision making processes in land allocation and environmental management (Jiang and Eastman, 2000). MCE is one of the most important procedures for GIS-based decision making processes (Jankowski, 1995; Malczewski, 2000).

Site /Land suitability assessment is inherently a multi-criteria problem (Mendoza, 2004). That is, land suitability analysis is an evaluation/decision problem involving several factors. According to Mendoza (2004), 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. Suitability analysis is a methodology or a set of analytical procedures that simulate real world conditions within a GIS using their spatial relationships of geographic features to locate optimally suitable geographic areas for a specific land use. In order to locate optimally suitable geographic areas for a specific land use, criteria development is crucial. Criteria can be of two kinds: factors and constraints. Constraints are Boolean criteria that constrain (i.e. limit) the analysis to a particular geographical regions. In contrast, factors are criteria that define some degree of suitability for all geographic regions (Eastman, 2006). The composite effect of physical parameters determines the degree of suitability and also helps in further categorising the land into different classes of development. Moreover, the process of suitability assessment is very much dependent upon the prevalent conditions, such as pressure on land.

2.2 Role of GIS and Remote Sensing for Land Suitability Analysis

2.2.1 Role of GIS for Land Suitability Analysis

The distinguishing feature of Geographic Information System (GIS) is its capability to perform an integrated analysis of spatial and attributes data. GIS can be used not only for automatically producing maps, but it is unique in its capacity for integration and spatial analysis of multi-source datasets such as data on land use, population, topography, hydrology, climate, vegetation, transportation network, public infrastructure, etc. The data are manipulated and analyzed to obtain information useful for a particular application such as land-use suitability analysis (Malczewski, 2003).

According to Foote and Lynch (1996) cited in Prakash (2003), the ultimate aim of GIS is to provide support for spatial decisions making process. In multi-criteria evaluation many data layers are to be handled in order to arrive at the suitability, which can be achieved conveniently using GIS. In the context of land suitability analysis, GIS helps the user to determine what locations are most/least suitable for specific purpose. In this way the results of GIS analysis can provide support for decision making. It also enables to create and modify any land suitability analysis that makes the best use of available data.

2.2.2 Role of Remote Sensing for Land Suitability Analysis

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

Remote sensing data are used for estimating biophysical parameters and indices besides cropping systems analysis, and land use and land cover estimations during different seasons (Martin and Saha, 2009). However, Remote Sensing data alone cannot suggest crop suitability for an area unless the data are integrated with the site-specific soil and climate data. Remote Sensing data can be used to delineate various physiographic units besides deriving ancillary information about site characteristics like slope, direction and aspect of the study area. Land use /land cover mapping from satellite imageries of remotely sensed data are one of the advantages of remote sensing.

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

Image classification serves a specific goal, i.e., converting image data in to thematic data. The resulting classified image is comprised of a mosaic of pixels, each of which belong to a particular theme, and is essentially a thematic map of the original image. In the application context, one is reasonably interested in thematic characteristics of an area rather than in the reflection values. Thematic characteristics such as land use / land cover can be used for further analysis and input into GIS based models. In addition, image classification can also be considered as data reduction: the n multispectral bands result in a single band raster file. As far as classification of image is considered, there are two common classification types: unsupervised and supervised classifications (Lillesand et al., 2004). However, the current study used the supervised classification technique to categorize the image in to different land use / land cover categories.

2.3 Spatial Multi-Criteria Decision Making (SMCDM)

An important advantage in using a GIS to perform a spatial MCDM study is the ease with which one can develop valuation criteria based on neighbourhood analysis operations (Pereira and Duckesstien, 1993; Malczewski, 2006). The quality of a site for a specific use often lies not only on the values of environmental variables at the site, but also on its vicinity. Land suitability evaluation, conceptualized as an MCDM problem, implies the assignment of values to alternatives that are evaluated along multiple dimensions or criteria. Specifically for land suitability evaluation in a raster GIS environment, each grid cell in the database is taken as an alternative to be evaluated in its quality or appropriateness for a given end, and each thematic layer represents a criterion for the process or evaluation (Pereira and Duckesstien, 1993).

Spatial multi-criteria decision problems typically involve a set of geographically-defined alternatives (events) from which a choice of one or more alternatives is made with respect to a given set of evaluation criteria (Jankowski, 1995; Malczewski, 1996). Spatial multi-criteria analysis is vastly different from conventional MCDM techniques due to inclusion of an explicit geographic component. In contrast to conventional MCDM analysis, spatial multi-criteria analysis requires information on criterion values and the geographical locations of alternatives in addition to the decision makers' preferences with respect to a set of evaluation criteria (James et al., 2002). This means analysis results depend not only on the geographical distribution of attributes, but also on the value judgments involved in the decision making process. Therefore, two considerations are of paramount importance for spatial multi-criteria decision analysis: (1) the GIS component (e.g., data acquisition, storage, retrieval, manipulation, and analysis capability); and (2) the MCDM analysis component (e.g., aggregation of spatial data and decision makers' preferences into discrete decision alternatives) (Carver, 1991; and Jankowski, 1995).

The general objective of MCDM is to assist the decision-maker in selecting the 'best' alternative from the number of feasible choice-alternatives under the presence of multiple choice criteria and diverse criterion priorities (Jankowski, 1995). The problem of multi-criterion (multi-objective) choice in decision making is the paramount challenge faced by individuals, public, and private corporations. The challenge of multi-criterion choice can be attributed to many spatial decision making problems involving search and location/allocation of resources. These problems, often analysed in GIS, include location/site selection (Jankowski, 1995). Hence, Site suitability assessment is inherently a multi-criteria problem. That is, land suitability analysis is an evaluation/decision problem involving several factors. SMCDM which refers to the application of Multi-Criteria Analysis (MCA) deal with these spatial decision problems.

Chakhar and Mousseau (2008) defined spatial decision problem as those problems in which the decision implies the selection among several potential alternatives that are associated with some specific locations in space. Spatial decision problems typically involve a large set of feasible alternatives and multiple, conflicting and incommensurate evaluation criteria (Malczewiski, 2006). The alternatives are often evaluated by a number of individuals (decision makers, managers, stake-holders, interest groups). The individuals are typically characterized by unique preferences with respect to the relative importance of criteria on the basis of which the alternatives are evaluated.

MCDM problems involve criteria of varying importance to decision makers and information about the relative importance of the criteria is required (Malczewski, 2000). This is usually obtained by assigning a weight to each criterion. The derivation of weights is a central step in defining the decision maker's preferences. A weight can be defined as a value assigned to an evaluation criterion indicative of its importance relative to other criteria under consideration. The larger the weight, the more important is the criterion in the overall utility (Malczewski, 1999; cited in Drobne and Lisec, 2009). In the procedure of MCE, weights can be derived by taking the principal eigenvector of a square reciprocal matrix of pairwise comparisons between the criteria (Malczewski, 2003; Eastman, 2006). The comparisons deal with the relative importance of the two criteria involved in determining suitability for the stated objective. Accordingly, many spatial decision problems give rise to the GIS-based multi-criteria decision analysis (GIS-MCDA) (Malczewiski, 2006).

GIS and MCDA can benefit from each other (Laaribi et al., 1996; Malczewiski, 1999; Thill, 1999; and Chakhar and Martel, 2003; Cited in Malczewiski, 2006). On the one hand, GIS techniques and procedures have an important role to play in analyzing decision problems. Indeed, GIS is often recognized as a decision support system involving the integration of spatially referenced data in problem solving environment.

On the other hand, MCDA provides a rich collection of techniques and procedures for structuring decision problems, and designing, evaluating, and prioritizing alternative decision (Malczewiski, 2006)

It is important to note, however, that GIS and MCE techniques are merely tools which provide a means to an end. Without knowledge and expertise of the operator and decision maker, and without appropriate data, such tools will be useless (Carver, 1991). Nevertheless, GIS-MCE applications appear to represent potentially fruitful areas for further research and development.

2.4 Crop Requirement

Crop requirements are conditions of a given land necessary or desirable for a successful and sustained practice of a defined land use type (FAO, 1983). Evaluation of crop requirements is a useful tool in assessing crop adaptability and suitability in a given area.

Bio-physical crop requirements refer to the need for favourable climatic and soil attributes. The climatic requirement is concerned with attributes such as temperature, rainfall, length of growing period, frost hazard, drought hazard, etc. The soil requirements refers to conditions of rooting, wetness, fertility, excess salt, ease of cultivation, mechanization potential, etc. Management conditions may, however, change the relative impact of these attributes. In practice, it is very difficult if not impossible to include in any evaluation all the environmental requirements that affect crop performance.

3. Methods and Materials

3.1 Description of the Study Area

3.1.1 Location

The study area, Mojo watershed (which is a watershed of upper Awash Sub-basin), is located in East and North Shewa zones. Out of the total area of the watershed, 94.6 % is located in East Shewa zone whereas the rest 5.4% is found in North Shewa zone. The watershed incorporate most parts of Adea, Gimbichu and Lume woredas, whereas few parts of Akaki, Boset, Liben Chukala and Berek woredas are also incorporated in this watershed. The area coverage of the study area in each wereda is indicated as follows (Table 2).

Table 2. Area Coverage of the Study Area

Study Area	Zones	Woredas	Area (km2)	Area (%)
Mojo Watershed	East Shewa	Adea	617.7	39.1
		Akaki	27.6	1.8
		Bishoftu Town	40.0	2.5
		Boset	0.4	0.1
		Gimbichu	418.3	26.5
		Liben Chukala	20.8	1.3
		Lume	368.5	23.3
	Total Area		1493.3	94.6
	North Shewa	Berek	85.5	5.4
	Total Area		85.5	5.4
Total Area			1578.8	100.00

The geographical extent of Mojo watershed ranges form 08^{0}29’ to 09^{0}06’ north, and 38^{0}54’ to 39^{0}17’ east. Its area coverage is 1578.8 square kilometres. Figure 1 below indicates location map of the study area.

As indicated in Table 2, the study area incorporates seven woredas (Adea, Akaki, Berek, Boset, Gimbichu, Liben Chukala, and Lume). Table 3 indicates portion of the weredas within the watershed. Hence, 69.8%, 59.0%, and 54.8% of the Adea, Gimbichu and Lume woreda falls within this study area, respectively. Similarly, 11.6%, 4.7% and 3.0% of Berek, Akaki and Liben Chukala woredas are incorporated within this watershed, respectively. Very small portion (0.003%) of the Boset woreda is also covered by the study area.

Table 3. Portion of the woredas in the watershed

Woredas	Area of the woreda (Km2)	Portion of the woreda within the watershed	
		Area (km2)	Area (%)
Adea	937.0	654.3	69.8
Akaki	582.6	27.6	4.7
Bereh	736.6	85.5	11.6
Boset	1434.3	0.04	0.003
Gimbichu	707.1	416.9	59.0
Liben Chukala	703.6	20.8	3.0
Lume	681.3	373.6	54.8
Total Area of the watershed		1578.8	

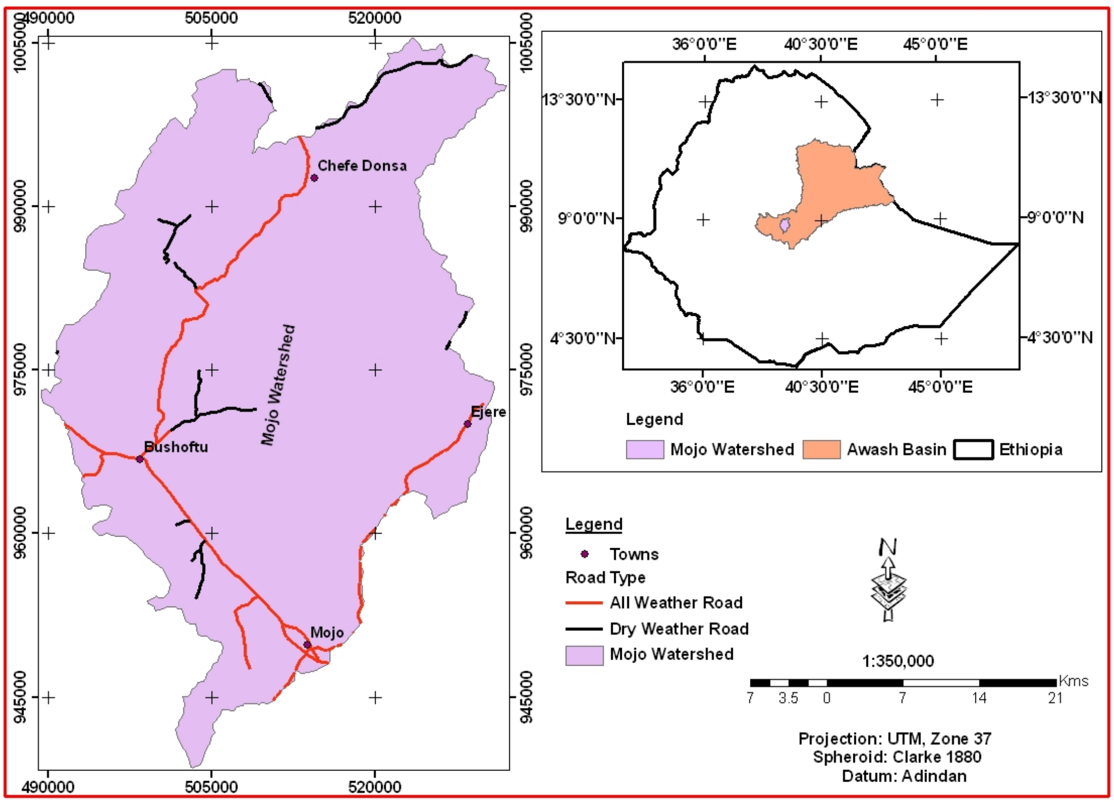


Fig. 1. Location Map of the Study Area.

3.1.2 Physiography

Mojo Watershed is located in central eastern part of Ethiopia plateau. The general elevation of the study area ranges between 1611 to 3000 meters above sea level. Mojo Watershed is found with in the upper part of Awash basin. The main rivers found in the study area are *Mojo Guda, Mojo Jala, Belbela, Charecha, and Wadecha* rivers. There are also other tributaries that join to the main rivers. The area is characterized by dendrite and parallel pattern drainages. Figure 2 below indicates the drainage map of the study area. The main Mojo River divides the watershed in to two, i.e. the eastern and western part. Besides the study area is characterized by the flat land of Adea plain in its central part, which covers the majority of the study area, and the ups and downs of the Gimbichu highland in its upper part.

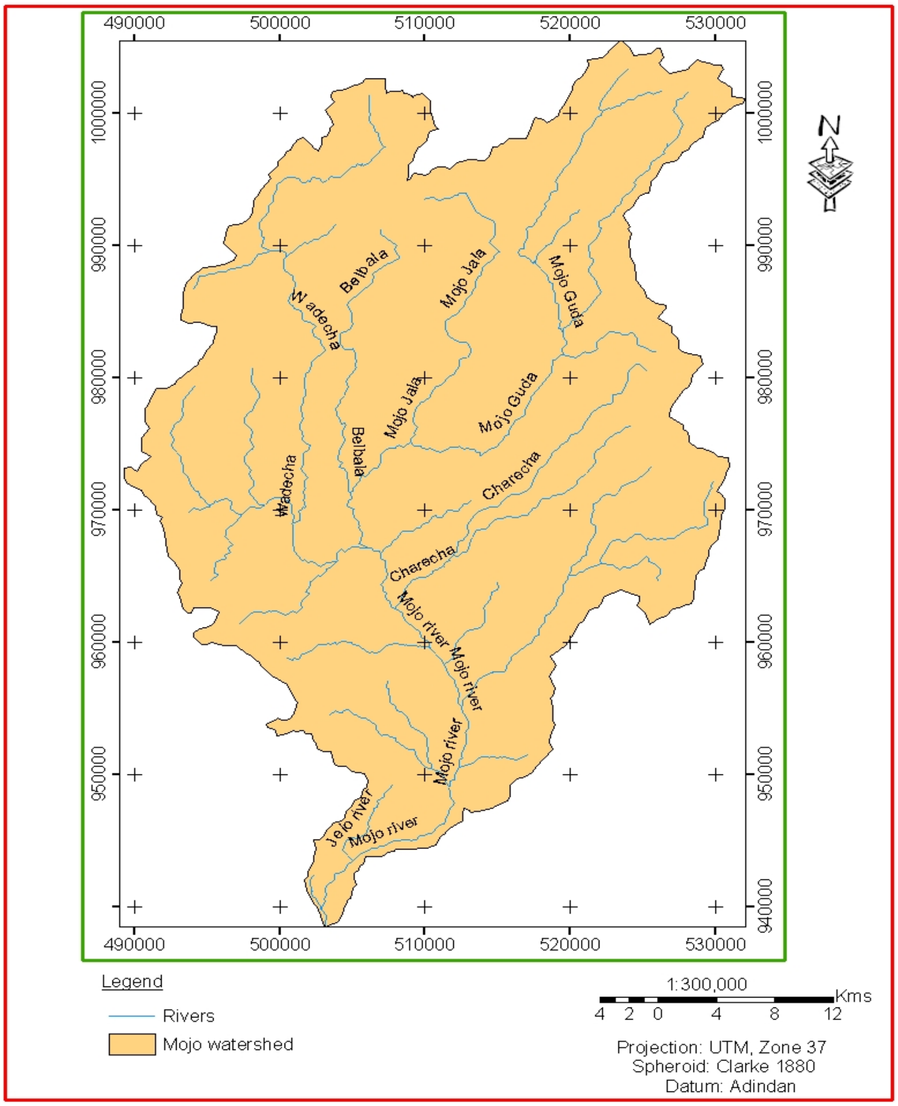


Fig. 2. Drainage of Map of the Study Area.

3.1.3 Soil

Soil is defined by Davidson (1980) as a natural body consisting of layers or horizons of mineral and / or organic constituents of variable thickness, which differ from the parent material in their morphological, physical, and chemical properties and their biological characteristics.

The types of major soil found in the study area, as extracted from Soils and Geomorphology of FAO, are Pellic Vertisol, Vertic Cambisol, Chromic Luvisols, Luvic Phaeozems, and Lithosols (FAO, 1988). The study area is dominantly characterized by Pellic Vertisols and Vertic Cambisols. These two soil groups have dominantly vertic properties and they are clay soils. According to FAO (1988) Vertisols are characterized by their high clay content. They are often dark coloured. According to FAO (1988) Vertisols type soils are characterized by their high clay content. They are often dark colored. Due to their semitite clay mineralogy, they are very hard and crack when dry, but becomes sticky and plastic (often impassable) when wet. These are chemically rich soils, but they may develop on an undulating micro relief, which hampers mechanization. Vertisols have great agricultural potential, but special management practices are required. Vertic Cambisols generally make good agricultural land and are used intensively. More acid cambisols, although less fertile, are used for mixed areable farming, and as grazing and forest land.

Luvisols are soils that have higher clay content in the subsoil than in the topsoil as a result of pedogenetic processes. They are most common in flat or gently sloping land and the parent material constitute a wide variety of unconsolidated materials including glacial till, and aeolian, alluvial and colluvial deposits. Most luvisols are fertile soils and suitable for a wide range of agricultural uses. Luvisols with a high silt content are susceptible to structure deterioration where tilled when wet or with heavy machinery (FAO, 2006).

Phaeozems are dark soils rich in organic matter which develop on eolian (loess), glacial till and other unconsolidated parent materials. Environmentally, they are mostly found in flat to undulating land in warm to cool (e.g. tropical highland) regions, humid enough that there is, in most years, some percolation of the soil, but also with periods in which the soil dries out. Phaeozems are fertile soils; they are planted to irrigated cereals and pulses or are used for cattle rearing and fattening on improved pasture (FAO, 2006).

Table 4. Major soil types in the study area (from FAO).

Major Soils	Area (km2)	Area (%)
Chromic Luvisols	102.7	6.5
Lithosols	29.0	1.8
Luvic Phaeozems	55.8	3.5
Pellic Vertisols	699.1	44.4
Vertic Cambisols	692.2	43.8

Figure 3 below indicates the major soil map of the study area adopted from FAO, 1988. In terms of the landform, the study area is dominantly covered by volcanic landform (in its lower part) and structural landform (in its upper part), although there are minor alluvial and residual landforms (FAO, 1988).

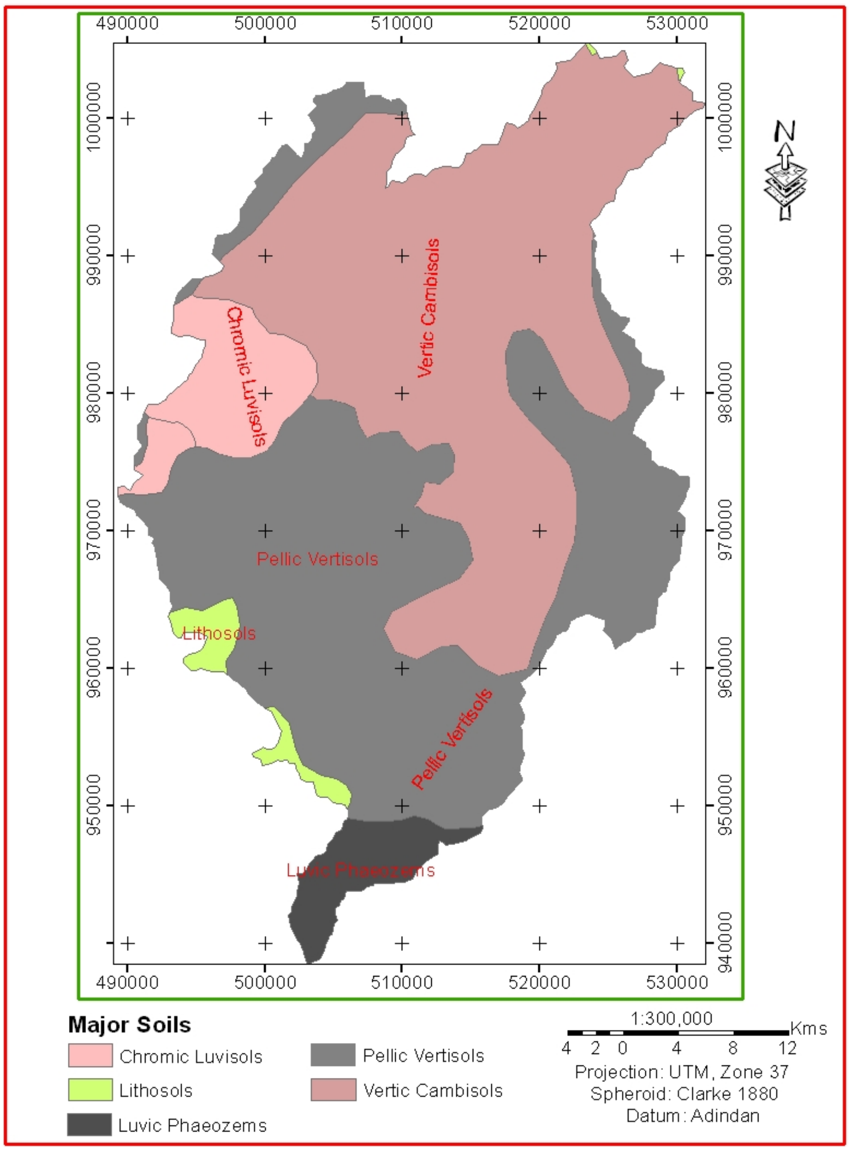


Fig. 3. Major soils map of the study area.

3.1.4 Climate

Climate influences the physical and cultural environments, the types of vegetation, animals reared and crops to be grown, the land use patterns and ultimately the economy. Agricultural activities and land use patterns are closely related to the temporal and spatial patterns of climatic elements, and success of land use strongly depends on climatic situation of an area. Rainfall and temperature are the major climatic factors influencing the physical and agricultural processes. Therefore, in the land suitability evaluation climatic variables should be considered as a diagnostic land qualities/ or land characteristics.

Temperature and rainfall are the most important elements in characterizing the climatic condition of a given region. There are four metrological stations in the study area which are Bishoftu, Chafe Donsa, Mojo, and Ejere, which are considered for analysis of the climatic factor. Besides, nine stations out side the study area are considered for the same purpose. These stations are Akaki Baska, Addis Ababa, Sandafa, Belchi, Walenchit, Adama, Wanji, Koka, and Zukala. Figure 4 and 5 below shows the mean monthly rainfall and temperature of bishoftu, chafe Donsa and Mojo stations, respectively.

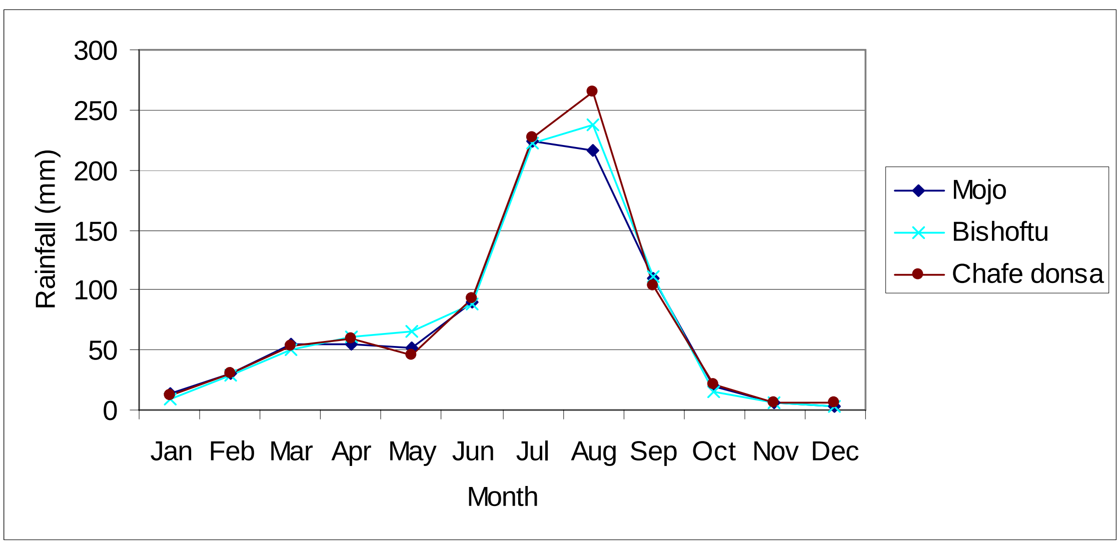


Fig. 4. Mean monthly rainfall at Bishoftu, Chafe Donsa, and Mojo stations from 1989 to 2008.

For instance, the total average annual rainfall for 20 years at Chafe Donsa station is 922.4mm, while the minimum and maximum total average is obtained at the month of December and August which is 5.7mm and 265.2mm, respectively with coefficient of variation 23%. Similarly for Bishoftu station the total average annual rainfall is 897.1mm and the minimum and maximum total averages are obtained at the months of December and August with a value of 2.9mm and 237.0mm, respectively with coefficient of variation 19%. However, the minimum and maximum rainfall during the length of growing period (LGP) is 81.64mm and 250.52mm for Chafe Donsa station at months of June and July, 66.06mm and 222.66mm for Bishoftu station at months of April and August, and 52.5mm and 2237.7mm for Mojo station at months of May and July, respectively.

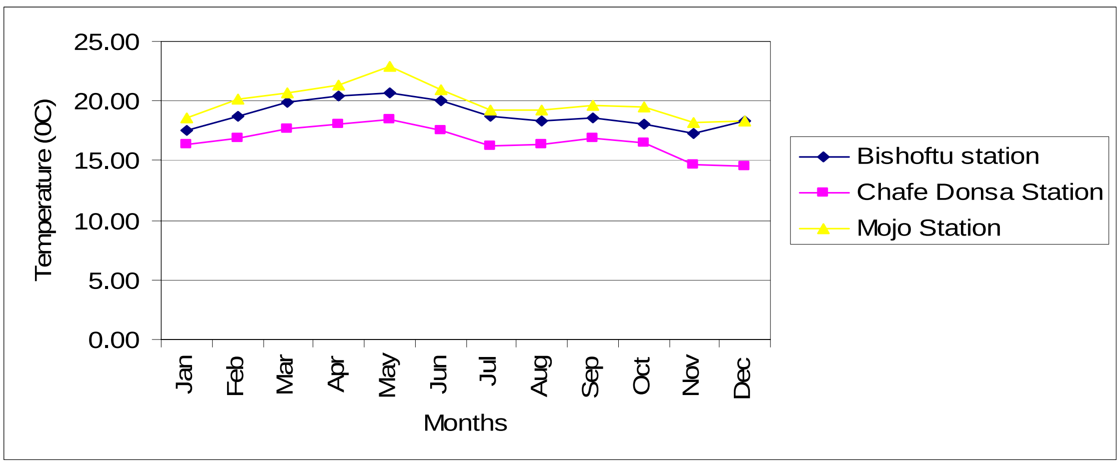


Fig. 5. Mean monthly temperature at Bishoftu, Chafe Donsa, and Mojo stations from 1989 to 2008.

The mean annual temperature for Bishoftu station is 18.0^{0}c, where as the minimum and maximum mean temperatures for this station are 17.2^{0}c and 20.6^{0}c, respectively. Similarly, the mean annual temperature is 15.5^{0}c and 18.5^{0}c, and the minimum and maximum mean temperatures are 14.5^{0}c and 18.5^{0}c, and 18.2^{0}c and 22.9^{0}c for Chafe Donsa and Mojo stations, respectively.

3.1.5 Crop production

The majority of the study area is covered by three woredas: Adea, Gimbichu and Lume (Table 2). Hence, the major crops produced in this woredas can represent that of the study area (Mojo watershed). Thus, the major crops produced in the watershed are cereals (teff, wheat, and barley), pulses (chickpea, lentil, faba bean, vetch and pea), oil seeds (linseed) and vegetables (garlic, onion, green pepper, potato). Cereals are produced mainly for consumption and market. Pulses (mainly chick pea and lentil) are produced largely for market and they are considered as valuable cash crop for the study area. Based on the information collected from Woreda Agriculture and Rural Development offices, teff, wheat, chick pea and lentil are the most important crops in terms of area coverage, production per hectare and market demand. Table 5 indicates the major crops produced and their yield in quintal (q) per hectares (ha) in three woredas for three consecutive years. As the information obtained from Woreda Agriculture and Rural Development offices, the farmers use a usual practice of crop rotation from cereals to pulses, mainly. Crop rotation is a biological means of maintaining soil fertility and controlling diseases and pest.

Table 5. Major crops produced in three woredas.

Cropping calendar: 1998/99								
	Teff		Wheat		Chickpea		Lentil	
Woreda	Land (ha)	Yield (q/ha)	Land (ha)	Yeild (q/ha)	Land (ha)	Yield (q/ha)	Land (ha)	Yeild (q/ha)
Adea	24013	1666205	36231	833403	1558	39610	4346	156817
Gimbichu	27622	1182376	2383	42900	7230	151236	2008	49984
Lume	19171	920208	17131	308358	356	5696	2392	86112
Cropping Calendar: 1999/2000								
	Teff		wheat		Chickpea		Lentil	
Woreda	Land (ha)	Yield (q/ha)	Land (ha)	Yeild (q/ha)	Land (ha)	Yield (q/ha)	Land (ha)	Yeild (q/ha)
Adea	32124	1540992	38162	860661	1863	58483	4938	77768
Gimbichu	27042	1147265	2394	43084	7833	166930	1984	45736
Lume	19422	1013625	17080	324520	385	6930	2614	94106
Cropping Calendar: 2000/2001								
	Teff		Wheat		Chickpea		Lentil	
Woreda	Land (ha)	Yield (q/ha)	Land (ha)	Yeild (q/ha)	Land (ha)	Yield (q/ha)	Land (ha)	Yeild (q/ha)
Adea	35912	861960	31795	1748739	5429	192526	1566	56843
Gimbichu	2844	54196	22372	1034491	2220	58548	11894	27218
Lume	16538	330760	19676	1062504	2658	107656	401	8451

3.2. Methods

3.2.1 Data Source

The following table (Table 6) indicates the softwares and materials used for this specific study.

Table 6. Details of materials and softwares used in the current study.

S/N	Type	Description	Source
1	Maps	Topographic maps	EMA
		Digital soil maps	FAO, OWWDSE
		Woredas and Kebele Shapefiles	CSA
2	Softwares	ArcGIS 9.2, ERDAS IMAGINE 9.1, IDRISI Andes 15.0, Global Mapper, 3DEM	AAU, GIS Lab
3	Instruments	GPS (GARMIN), Digital Camera	OWWDSE

The success of any GIS application depends on the quality of the geographic data used (LO and Yeung, 2002). Collecting high quality geographic data for input for GIS, therefore, marks a critical stage. Data collection is one of the most time-consuming and expensive, yet important for GIS-base studies. GIS can contain a wide variety of geographic data types originating from many diverse sources. To achieve the above objectives of this study, both primary and secondary raster and vector data were used. The methodology that was used to evaluate land suitability for different Land Utilization Types (LUTs) was based on FAO guidelines (FAO, 1976). This guideline is standard and is accepted by many researchers. It has procedures to evaluate the suitability of the land for intended land use.

Soil data like depth, drainage, texture, organic matter, and pH were obtained from Oromia Water Works Design and Supervision Enterprise (OWWDSE), Land Use Planning and Natural Resource Study Division. Climatic data such as mean monthly temperature and rainfall were collected from National Meteorological Service Agency (NMSA). A surface interpolation was carried out in a GIS Environment using Spatial Analyst's Tool by Inverse Distance Weighted (IDW) method. Land use /land cover were mapped from 2005 satellite imageries of Landsat ETM^+ after intensive field surveys. The image was acquired in the month of January. In addition Global Positioning System

(GPS) was used to collect Ground Control Points (GCPs). Furthermore, slope is essential for land suitability analysis. It was derived from Digital Elevation Model (DEM), which was extracted from 30 meter resolution Shuttle Radar Topographic Mission (SRTM) data of NASA satellite. Weighted Overlay Analysis (WOA) in a GIS environment was used to map the land suitability for each LUTs after weights are calculated in Analytical Hierarchy Process (AHP)-weight derivation module of IDRISI Andes 15.0. Furthermore, suitable land allocation map based on the results of land suitability of each LUTs was produced using vector overlay analysis in a GIS environment. Figure 6 below indicates the general methodology flow chart followed throughout the work of this research.

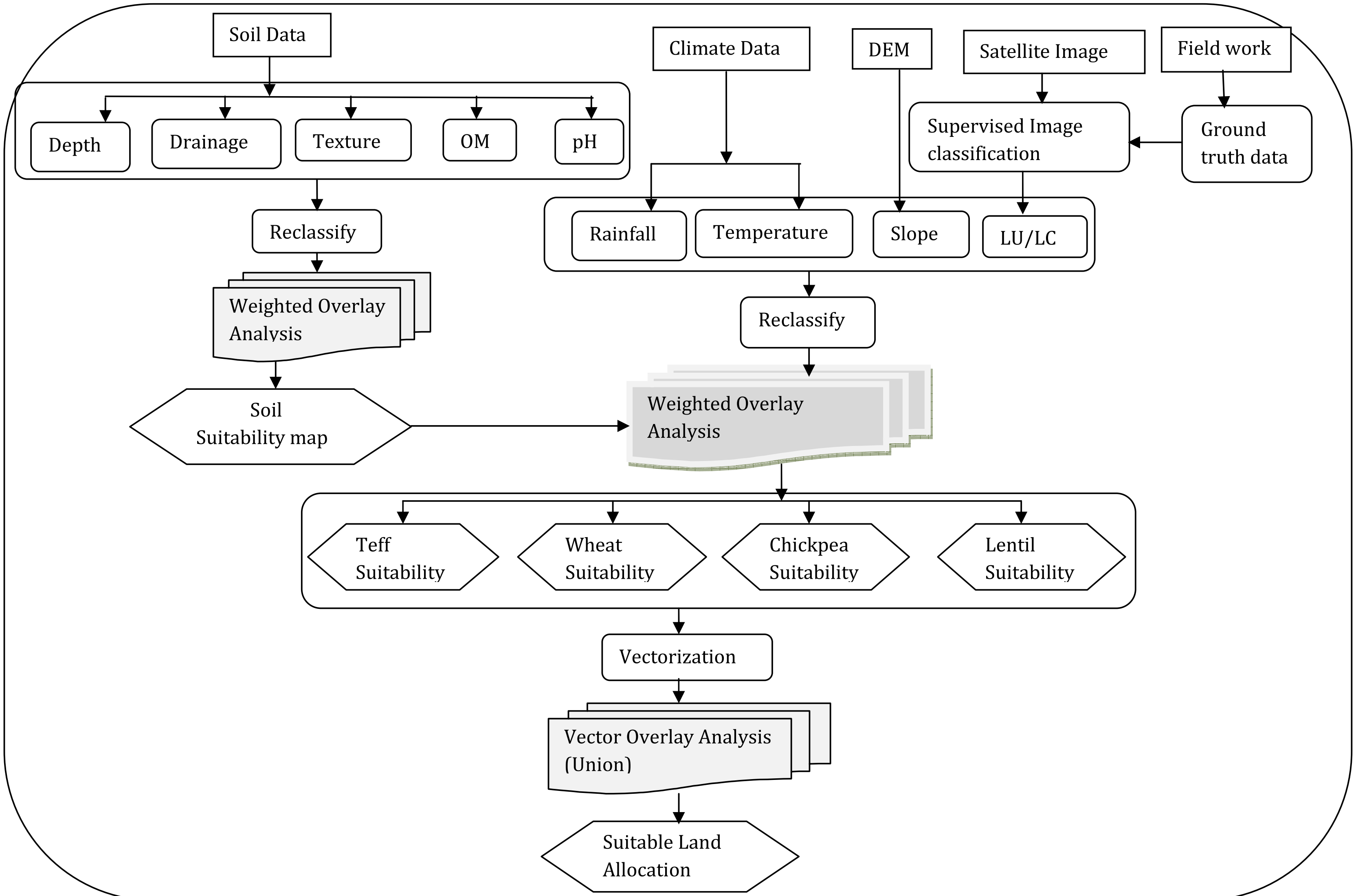


Fig. 6. Methodology Flow Chart.

3.2.3 Selection of Crop Types

There are certain factors that were considered during the identification of land use types. In selecting the LUTs for the study area, present Land use and cropping-system, topography, physical and chemical property of the soils, cultivation practices, crop calendar, and market were considered. Experts in the fields of agriculture, soil science, agronomists, agro-ecologists, and land use planners are consulted to decide upon the potential land use types for the study area. Besides, selection of LUTs was based on data availability on the crop environmental requirement and crop altitude adaptability. For this study area, the different land use types (crops) for evaluation that are considered are: teff, wheat, chickpea and lentil. These crops are considered as current and potential crops to be cultivated in the study area.

3.2.4 Selection of Evaluation Criteria

Criteria are measurable basis on which decisions about land quality and its suitability for a specified use can be made (Eastman et al., 1995). After the determination of the problem, the set of evaluation criteria which includes attributes and objectives should be designated (Keeney and Raiffa, 1976; cited in Jankowski, 1995). This stage involves specifying a comprehensive set of objectives that reflects all concerns relevant to the decision problem and measures for achieving those objectives which are defined as attributes. Because the evaluation criteria are related to geographical entities and the relationships between them, they can be represented in the form of maps which are referred as attribute maps. GIS data handling and analyzing capabilities are used to generate inputs to spatial decision making analysis (Malczewski, 1999; cited in Malczewski, 2006).

Identification of criteria is a technical activity, which is based on theory, empirical research or common sense. Evaluation criteria, objectives and attributes, should be identified with respect to the problem situation. A set of criteria selected should adequately represent the decision making environment and must contribute towards the final goal. Criteria identification can be done using the participatory approach by a group of experts from various disciplines. FAO (1976) has given a framework for land suitability analysis for crops in terms of suitability classes from highly suitable to not suitable based on the crop specific soil, climate and topographic data. In this study, criteria identification was done by the author with assistance of a group of professionals, who included an agronomist, agro-ecologist, economist, land use planner, and soil scientists based on this guideline and data availability. Hence, the following evaluation criteria are considered to address the suitability of the land for agricultural crops in the study area. These are:

- Soil physical properties (Depth, Drainage and Texture)
- Soil Chemical properties (Organic matter and pH)
- Climate factors (Temperature and Rainfall)
- Topographic factor (Slope)
- Current Land use / Land cover

3.2.5 Hierarchical Organization of the Criteria

Malczewski (1999) cited in Prakash (2003) states that relationship between objectives and attributes has a hierarchical structure. At the highest level one can distinguish the objectives and at the lower levels, the attributes can be decomposed. Figure 7 below shows the hierarchical organization of the criteria used in this study.

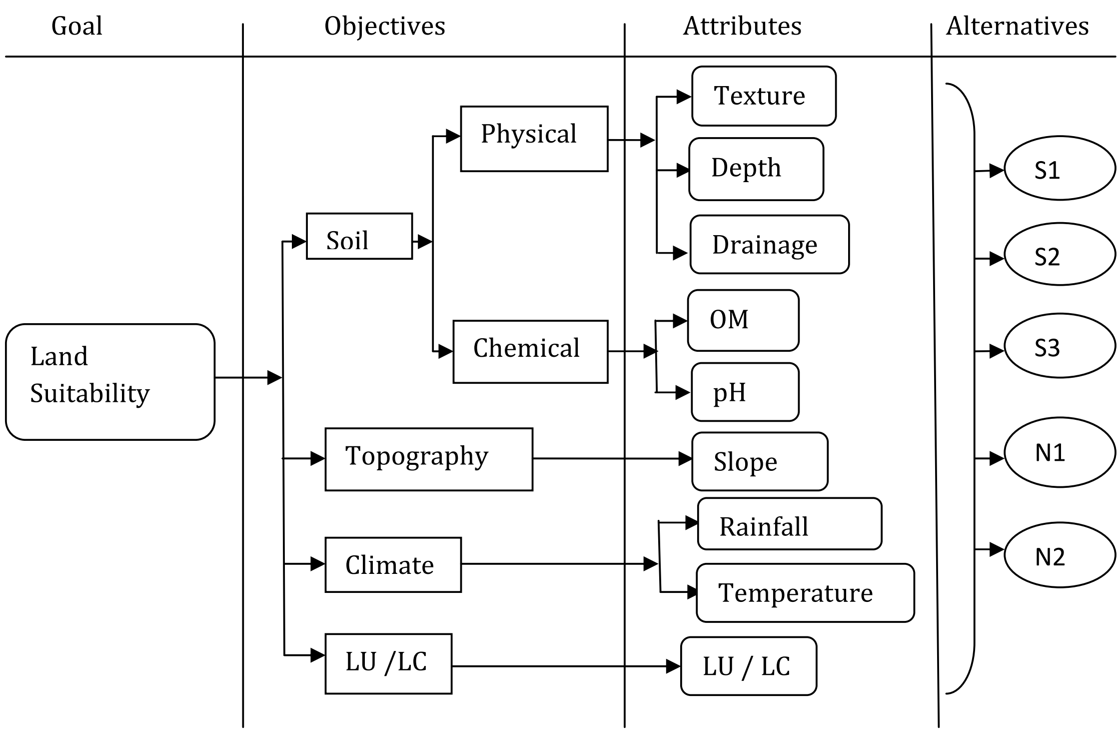


Fig. 7. Hierarchical organization of the criteria.

3.2.6 Multi Criteria Evaluation

The actual process of applying the decision rule is called evaluation. To meet a specific objective, it is frequently the case that several criteria will need to be evaluated. Such procedures are called Multi-Criteria Evaluations (Eastman et al. 1995). Voogd (1983) presented the application of several multi-criteria evaluation techniques to land use planning, where the number of spatial units evaluated was limited. The integration of multi-criteria methods and GIS allow to overcome this limitation and provides a tool with great potential for obtaining land suitability maps or selecting sites for a particular activity (Eastman et al., 1995; Mendoza, 1997). While GIS provide an appropriate framework for the application of multi-criteria evaluation methods, which are not capable of managing spatial data, the multi-criteria evaluation procedures add to GIS the means of performing trade-offs on conflicting objectives, while taking into account multiple criteria and the knowledge of the decision maker (Carver, 1991).

3.3. Data Analysis

3.3.1 Satellite Image Processing

3.3.1.1 Image Classification

To convert image data to thematic data, image classification is necessary. The present study used supervised classification technique to categorize the image in to different land use/ land cover categories. Supervised classification can be used to cluster pixels in data set into classes corresponding to user defined training classes. This classification type requires selecting training areas for use as the basis for classification. The most common supervised classification techniques are the maximum Likelihood classifier for parametric input data and parallelpiped classifier for non-parametric data.

Supervised classifications require a prior knowledge of the scene area in order to provide the computer with unique training classes. It is the job of the user to define the original pixels that contain similar spectral classes representing certain land cover class.

Accordingly, representative points thought to represent the various land cover classes were marked using GARMIN GPS during the field visit for the accessible places. These points were used to sample representative signatures for the various land cover types identified during the field visit. Following this, supervised land use / land cover classification has been carried out using ERDAS Imagine software from Landsat satellite image of 2005. Accordingly, five (5) land use / land cover types were identified. These are built up area, bush shrubland, forest, cultivated land and water body (Table 7). Hence, the larger part of the study area is cultivated land (which accounts about 77.9%).

Bush shrubland, built up area, forest, and water body account for about 18.9%, 1.9%, 0.6% and 0.6%, respectively. Figure 8 below illustrates the land use/land cover map of the study area.

Table 7. Land use/land cover classes of the study area.

LU/LC Classes	Area (km2)	Area (%)
Built up area	30.7	1.9
Bush shrubland	299.1	18.9
Cultivated land	1230.0	77.9
Forest	9.2	0.6
Water body	9.8	0.6
Total	1578.8	100.0

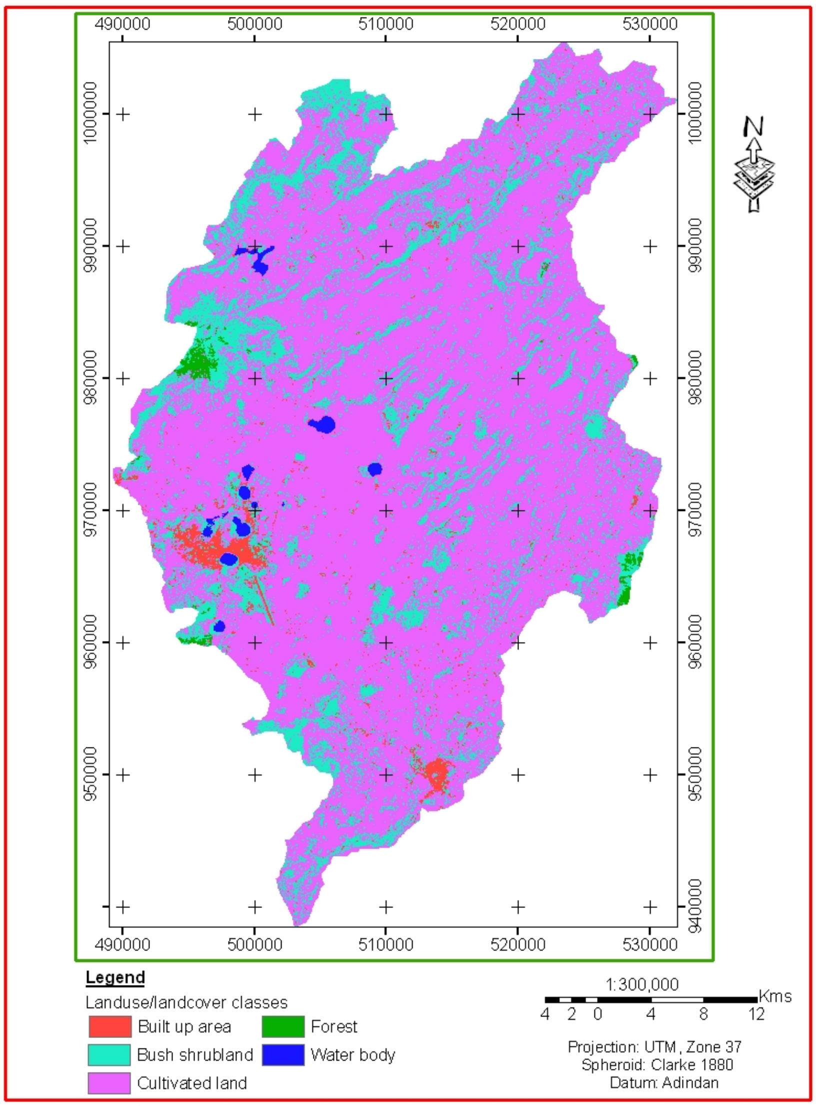


Fig. 8. Land use/ land cover map of the study area.

3.3.1.2 Accuracy Assessment

Since image classification without accuracy assessment is incomplete (Lillesand et al., 2004), the accuracy assessment for the images is done. This is due to the fact that, land cover maps derived from remote sensing imagery always contain some sort of errors due to several factors which range from classification technique to method of satellite data capture. Most assessments were conducted using the same data set as was used to train the classifier. The training and testing on the same data set result in overestimates of classification accuracy (Congalton, 1991). The present study, however, used a total of 415 randomly selected pixels for the 2005 land use / land cover map, which were checked with reference data (ground data) in the field to assess the accuracy of the classification.

The current study revealed an overall accuracy of 83.1% and a kappa index of agreement of 0.7923 (Table 8). The kappa coefficient 0.7923 implies that the classification process is avoiding 79% of the errors that a completely random classification generates. Individual class accuracies ranged from 38.9% to 94.9% for producers accuracy and 66.7% to 100% for user's accuracy.

Table 8. Accuracy assessment of the classified land use / land cover map.

C D	CL	BShL	F	BUA	WB	RT	CLT	NC	PA	UA	KC
C L	273	40	1	6	1	288	321	273	94.9%	84.8%	0.8027
BShL	13	61	1	4	0	102	79	61	59.8%	77.2%	0.6979
F	0	1	2	0	0	4	3	2	50.0%	66.7%	0.6634
BUA	2	0	0	8	0	18	10	8	38.9%	77.8%	0.7677
WB	0	0	0	0	2	3	2	2	66.7%	100.0%	1
CT	288	102	4	18	3	415	415	345			

Overall Classification Accuracy = 83.1%

Overall Kappa Statistics = 0.7923

Land cover categories: CL= Cultivated land, BShl= Bush shrubland, F= Forest, BUA= Built up area, WB= Water body

Accuracies: Overall classification accuracy= 83.1%, Overall kappa statistics= 0.7923, PA= Producer's Accuracy, UA= User's Accuracy, KC= Kappa coefficient

Totals: RT= Reference Total, CT= Column Total, NC= Number correct, CLT= Classified Total,

RT = CT

3.3.2 Land Suitability Analysis

3.3.2.1 Factors of suitability for Agricultural Crops

Land suitability analysis is an evaluation/decision problem involving several factors. The parameters considered for land use suitability analysis are: soil, climate, topography (slope), and land use/ land cover. The assessment of these parameters provides the information about the limitations of the land for agricultural development. The concept of limitation is derived from the quality of the land. All the above-mentioned parameters have been considered for analysis towards the identification of suitable areas for agricultural development and they are mapped separately. Each criteria map displays land suitability measured on the ordinal scale, that is, parcels of land were assigned values of high, medium or low suitability depending on land attributes. On the contrary, the study constrains or restricts built up areas, water body, and forest areas from the analysis.

The criteria maps are the input data to the GIS based decision making procedure. Given these maps, the next step is to combine the maps so that one can identify the suitable areas for crops. The combination procedure follows the conventional scheme for GIS-based MCDA (Malczewski, 1996). It involves three main steps. First, the criterion maps were standardized/ reclassified using Spatial Analyst's Reclassify tool. This step is necessary because the criterion maps contain the ordinal values (high, medium and low) that indicate the degree of land suitability with respect to a particular criterion (criteria standardization). Second, derivation of the of relative criterion importance using the pairwise comparison method. The criterion weights are automatically calculated once the pairwise comparison matrix is entered in IDRISI-AHP weight derivation module. Third, the criterion weights and the standardized criterion maps were combined / aggregated by means of weighted overlay technique and vector overlay analysis.

A. Soil

Soil is one of the most important and determinant factor for land suitability evaluation of agricultural crops. For this specific study, the soil mapping unit of this area is used for analysis. The physical and chemical properties of soils (obtained from OWWDSE, 2009 at scale of 1:50,000) are used for interpretation and analysis. The top soil surface, i.e.

the plough depth is considered for interpretation, hence the organic matter and pH indicated in (Table 9) is those of the plough depth of the respective soil mapping unit. GIS provide an advantage of mapping these properties of soils separately and make ready them for further overlay analysis to identify which soil mapping unit is best or worst suitable for the selected crop types. Table 9 below indicates the attributes of the soil mapping units of the study area; and Figure 9 indicates the map of the soil mapping units of the study area. The detail of soil properties with their area coverage in the study area is shown in Table 10 below.

The soil parameters considered for this land suitability analysis purpose are mapped separately as follows. The effective soil depth is the thickness of the loose soil above a limiting layer, which is impermeable for roots and/or percolating water. Deep well drained soil shows a root penetration until below 150 cm for most crops, however, root penetration might be stopped at shallower depth because of root restricting physical or chemical soil properties (presence of cemented, toxic, compacted or indurated layers, hard rock or gravel layers). The soil depth categories of the study area are classified as follows:

<25cm……………..Very shallow
25-50cm…………...Shallow
50-100cm…………Moderately deep
100-150cm ……….Deep
>150cm……………Very deep

Table 9. Major soils, Soil Mapping units and their properties of the study area.

Major Soils	SMU	Soil Type	Depth	Texture	Drainage	pH	OM
Chromic Luvisols	SMU1	Chromic Vertisols	200	SiCL	P	6.8	1.9
	SMU2	Chromic Luvisols	100	SiCL	W	8.0	1.6
	SMU3	Chromic Luvisols	24	SL	W	8.2	1.2
	SMU4	Chromic Luvisols	35	SL	E	7.9	0.89
	SMU5	Chromic Luvisols	150	CL	W	8.1	1.78
	SMU6	Chromic Luvisols	95	CL	W	7.5	1.7
Lithosols	SMU7	Lithosols	22	SL	E	6.9	0.88
	SMU8	Lithosols	45	L	W	7.3	1.85
Luvic Phaeozems	SMU9	Luvic phaeozems	220	SiCL	I	7.1	2.1
	SMU10	Luvic phaeozems	250	SiCL	I	7.1	1.9
Pellic Vertisols	SMU11	Pellic Vertisols	200	CL	I	5.8	2.4
	SMU12	Pellic Vertisols	200	CL	I	5.8	2.3
	SMU13	Pellic Vertisols	300	C	I	6.88	1.43
	SMU14	Pellic Vertisols	300	C	MW	6.91	1.42
	SMU15	Chromic cambisols	85	L	W	7.0	1.5
Vertic Cambisols	SMU16	Vertic Cambisols	200	C	I	7.11	1.54
	SMU17	Eutric Cambisols	150	CL	W	7.4	1.8
	SMU18	Eutric Cambisols	100	L	W	7.3	1.2

Note: (Drainage: E= execively, I= imperfectely, MW=moderately well, P= poorly, W= well Texture: C= clay, CL= clay loam, L= loam, SL= sandy loam, SiCL= silty clay loam)

Table 10. Area coverage of soil drainage, texture, depth, organic matter, and pH of the study area.

Drainage Classes	Area (km2)	Area (%)		Texture Classes	Area (km2)	Area (%)
E	30.9	2.0		C	765.3	48.5
I	742.2	47.0		CL	663.4	42.0
MW	256.7	16.3		L	39.8	2.5
P	8.5	0.5		SL	39.0	2.5
WD	540.5	34.2		SiCL	71.4	4.5
Total	1578.8	100.0		Total	1578.8	100.0
Depth Classes (cm)	Area (km2)	Area (%)		OM Content	Area (km2)	Area (%)
>150	950.9	60.2		>3.0	177.0	11.2
100-150	516.5	32.7		2.5-3.0	40.8	2.6
50-100	59.9	3.8		1.75-2.5	496.8	31.5
25-50	32.2	2.0		1.0-1.75	833.2	52.8
<25	19.4	1.2		<1.0	30.9	2.0
Total	1578.8	100.0		Total	1578.8	100.0
pH classes	Area (km2)	Area (%)				
5.2-6.0	177.0	11.2				
6.0-8.0	1356.0	85.9				
8.0-8.3	45.8	2.9				
Total	1578.8	100.0				

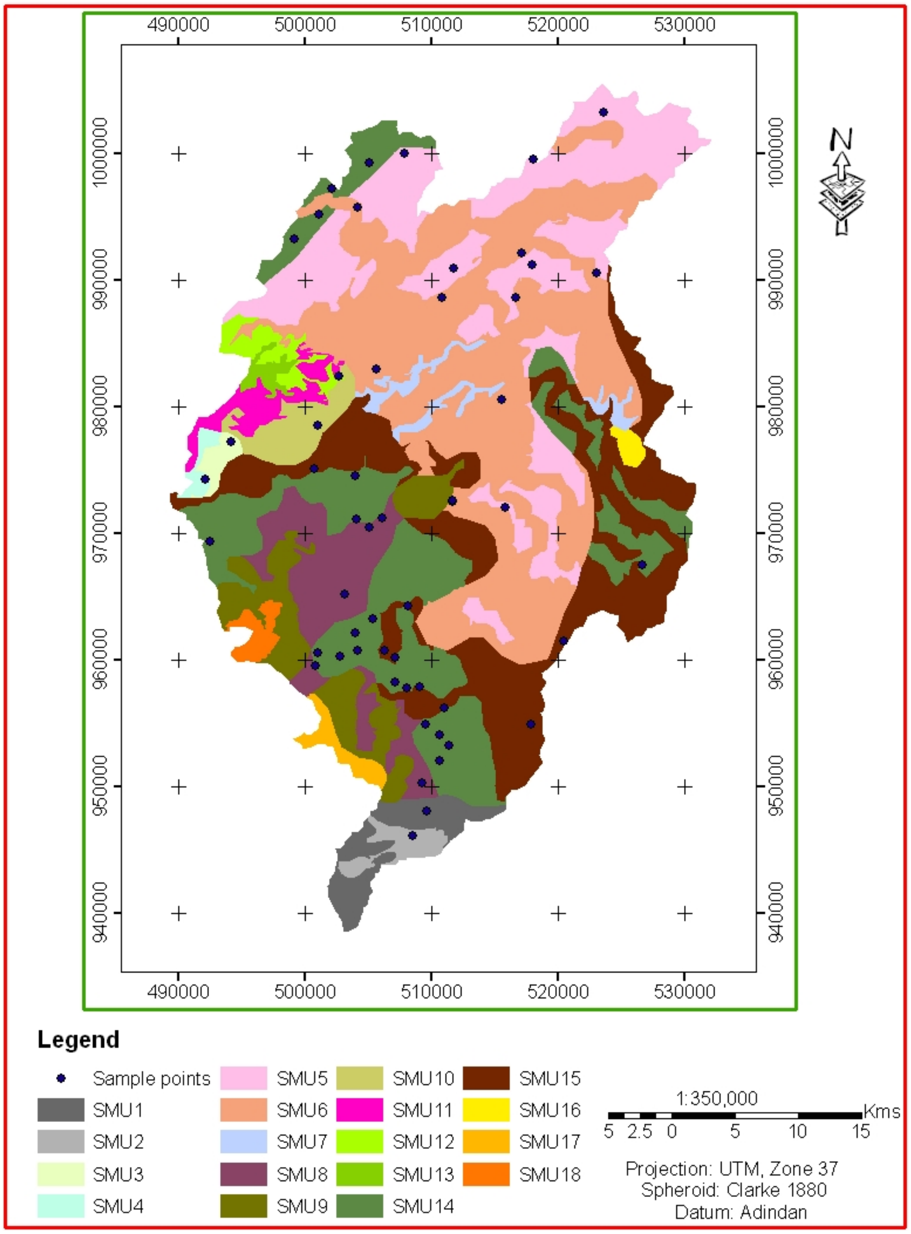


Fig. 9. Soil mapping units of the study area.

The p^H water tolerance limits for different plants vary generally, but for most commercial crops a neutral range is most suitable i.e. p^H water value b/n 6.6-7.3. Soils become acidic as crops remove cations or through leaching with climate being the dominant factor. Acidification is most rapid in soils derived from minerals low in cations and in coarse soils that can easily be leached. The soil p^H significantly affects the availability of most of the chemical elements important to plants and microbes; at low p^H (<5) there is a tendency for toxicity of elements such as iron, manganese and aluminium. The availability of nitrogen, sulfur and molybdenum are somewhat restricted at low p^H, whereas that of phosphorous is best at intermediate p^H level.

The role of organic matter in soils is very important. It is an ideal source of plant nutrients in soils. The measure of organic matter (OM %) is conducted to evaluate availability of plant nutrients and physical condition of the soil. Soil organic matter consists of plant, animal and microbial residues in various stage of decay. Organic matter contains about five present total nitrogen, so it serves as a store house for reserve nitrogen, but nitrogen in organic matter is in inorganic form and not immediately available for plant use, since decomposition usually occurs slowly. Organic matter gives dark color to many soils, holds water 20 times of its weight, provides aggregation, and has high cation exchange capacity. In general the depth, drainage classes, textural classes, organic matter content, and pH of soils of the soil mapping units of the study area is indicated as follows (Fig. 10).

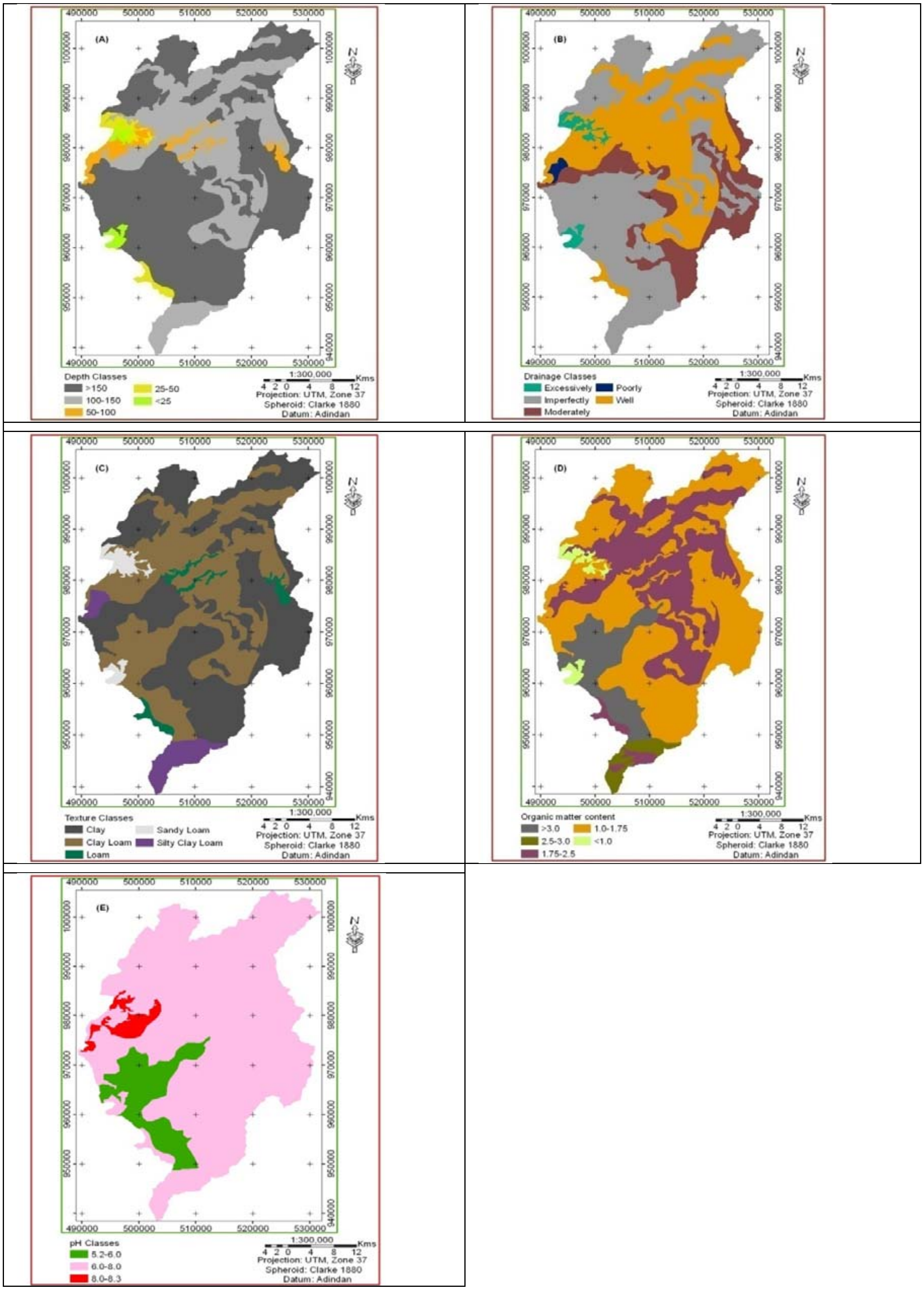


Fig. 10. Maps of soil properties considered for evaluation (A= depth, B= drainage, C= texture, D= OM, E= pH)

B. Climate

Agricultural activities and land use patterns are closely related to the temporal and spatial patterns of climatic elements; and success of land use strongly depends on climatic situation of an area. Rainfall and temperature are the major climatic factors that influence agricultural processes. It influences the spatial and temporal variations of agricultural activities and land use pattern. Therefore, in the land suitability evaluation climatic variables should be considered as a diagnostic land qualities/ or land characteristics.

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

Temperature regime influences temperature requirements of crops. A very low temperature (<6.5^{o}C) causes crop growth to cease, and hence a delay in growth seasons. The same is true in very high temperature conditions. Adverse effects of high temperatures only occur for most crops above 35 ^{0}c. Temperature regime can be assessed in various ways. In this study, it is assessed in terms of mean monthly temperature.

Thirteen stations (four inside and nine outside the study area) were taken into consideration for interpolation of rainfall and temperature. Temperature and rainfall data of these stations for 20 years was collected from NMSA of Ethiopia. The surface interpolation was carried out in the GIS environment using Spatial Analyst's Inverse Distance Weighted (IDW) technique. Figure 11 below indicate the temperature and rainfall maps of the study area.

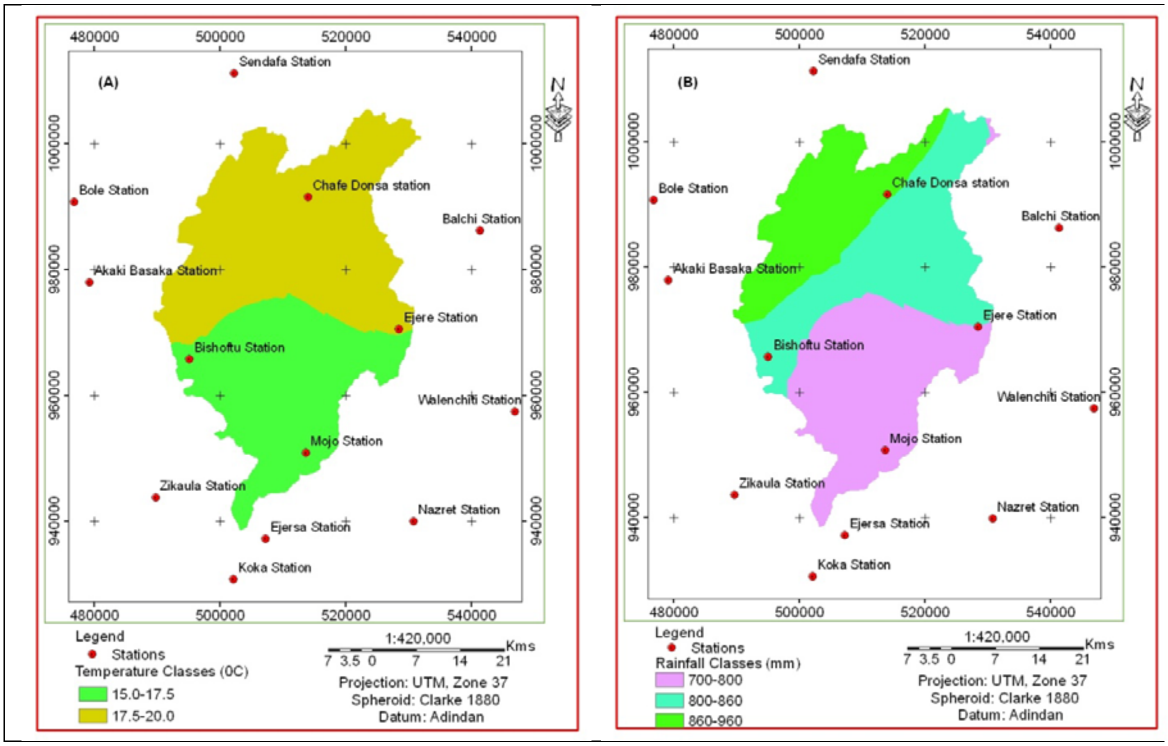


Fig. 11. Average monthly temperature and rainfall of the study area (A= mean monthly temperature, B= mean monthly rainfall).

C. Topography/ Slope

Slope of a given area plays an important role for agricultural activities in general, and specifically for crop production. Workability of the area, erosion hazard and potential for mechanization, especially for agricultural crops, depends on slope or topography of the area in one or the other way. Hence, this particular study considers slope as one factor for the land suitability analysis for agricultural crops. Slope of the study area was derived from the digital elevation model (DEM) which in turn was clipped from SRTM data of NASA satellite 30m resolution of Ethiopia by using a masking layer of the study area boundary. Accordingly, the topography of the watershed is characterized by undulating terrain constituting plains to steeply sloping hills. The slope percentage of the study area varies between 0-66%. On the basis of slope percentage, the study area has been classified into six slope classes: 0-2%, 2-8%, 8-16%, 16-30%, 30-60%, and >60% as depicted in the map below (Fig. 12). However, the majority of the study area falls under the slope class of 0-2%, which covers 46.5% of the total study area, and

40.5%, 8.8%, 3.4%, 0.8%, and 0.01% of the study area is covered by slope classes of 2-8%, 8-16%, 16-30%, 30-60% and greater than 60%, respectively.

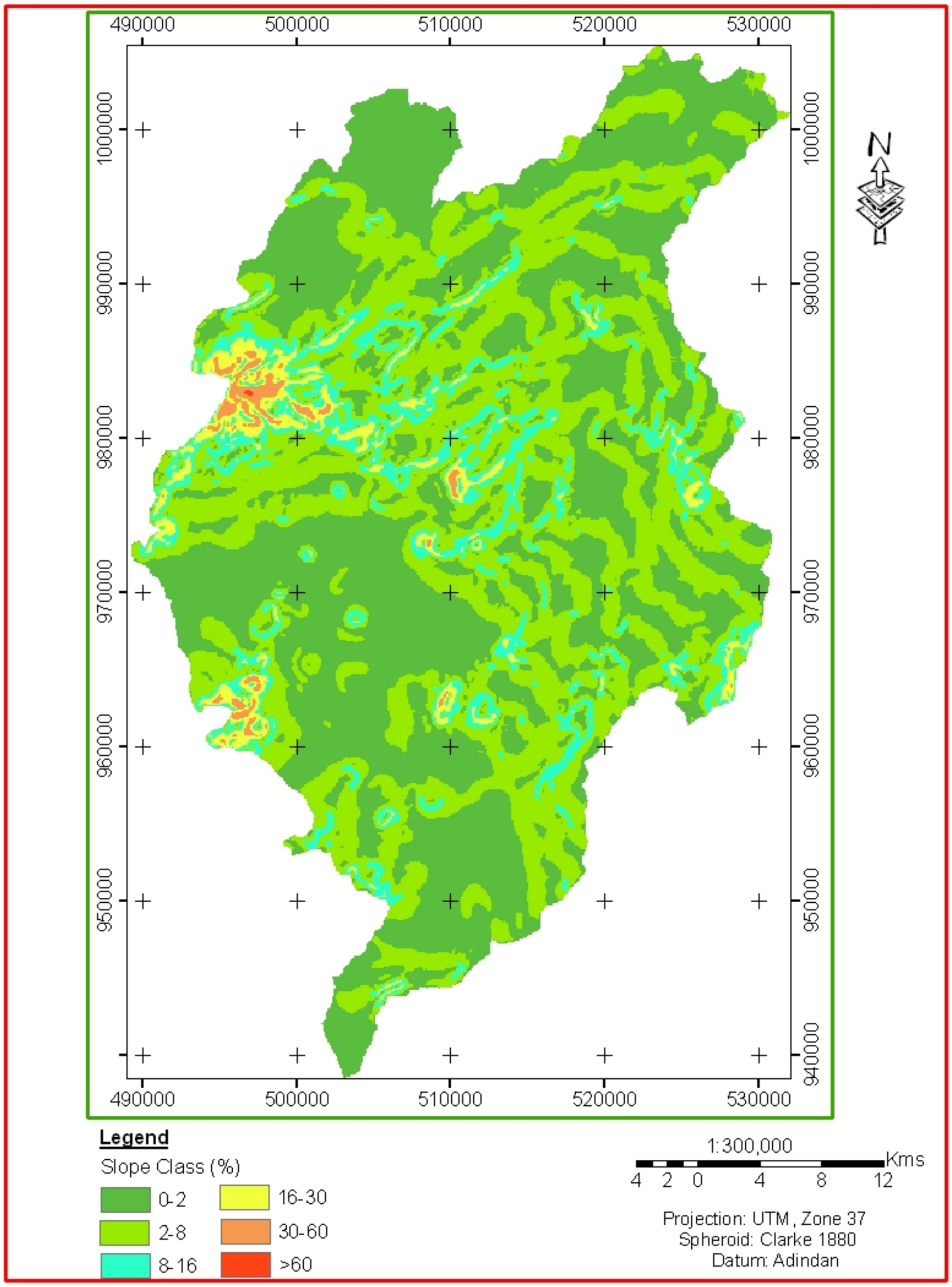


Fig. 12. Slope map of the study area.

D. Land use/ Land cover

As discussed in section 5.1 above, the land use/ land cover of the study area is classified as cultivated land, bush shrubland, forest, water body and built up area. These land use

/ land cover were reclassified or standardized to make it compatible with other parameters used for analysis.

3.3.2.2 Crop Requirement

Crops have specific bio-physical requirements for successful growth and production. Therefore, knowledge of crop requirements is the basis for a sound suitability assessment. The selection of the crop environmental requirements usually referred as land use requirements (LURs) of LUTs were based on four criteria: 1) importance for the use; (2) existence of critical value in the study area; (3) practicability of obtaining information; (4) availability of knowledge with which to evaluate the corresponding land quality (LQ). Accordingly, the following major crop requirements related to the following conditions are selected in the present crop environmental requirements characterization for evaluation:

1) Climate; that include amount of rainfall and thermal regime;
2) Rooting condition and workability; including effective soil depth and texture;
3) Wetness and Oxygen availability as expressed by drainage;
4) Natural fertility status based on soil pH and organic matter content; and
5) Mechanization potential and risk of erosion referring to slope;

Crop requirements, in this study, are established following the approach of FAO (1984), Landon (1991) and the guidelines of Sys et al., (1993). Adaptation has been made with respect to the grouping of requirements according to FAO (1984) guidelines. Requirements are expressed by defining optimal, marginal and unsuitable conditions for each land attributes that influence directly or indirectly plant growth, performance and biomass production. Requirement table was established through a review of experimental research findings and literature on parameters such as phenology and morphology of the crop, length of growth cycle and time of maturity, specific climatic and soil physical and chemical requirements. Reviews are consolidated through consultations with experienced agronomist, soil scientists, and agro-ecologists. The selected crops that were evaluated for this specific study include: teff, wheat, chickpea, and lentil. Table 11 below indicates the selected crops and their environmental requirements at different suitability classes.

Table 11. Environmental requirements rating for the selected crops in the study area.

Crops	Factor / Criterion	Range of Suitability				
		Highly Suitable (S1)	Moderately Suitable (S2)	Marginally Suitable (S3)	Currently Not Suitable (N1)	Permanently Not Suitable (N2)
Teff	Depth (cm)	>50	30-50	20-30	10-20	<10
	Texture (class)	Si, SiC, C	SiCL	SiL, CL,SC	L, SCL	S, LS,SL
	Drainage (class)	W, MW	I	SE, E	P	VP
	pH	5.5-7.5	5.2-5.5 and 7.5- 7.8	5.0-5.2 and 7.8-8.0	4.5-5.0 and 8.0- 8.5	<4.5 and >8.5
	OM (%)	>3.0	2.5-3.0	2.0-2.5	1.0-2.0	<1.0
	Slope (%)	0-13	13-25	25-40	40-55	>55
	Temperature (^{0}c)	15-21	14-15, 21-22	12-14, 22-23	11-12, 23-25	<11, >25
	Rainfall (mm)	400-550	250-400,550-800	200-250, 800-900	900-1000	<200, >1000
	LU /LC	CL	-	BShL	-	WB, BUA, F
Wheat	Depth (cm)	>100	75-100	50-75	25-50	<25
	Texture (class)	C, Si, SiC, SiL,SC	L, CL, SiCL	SCL	SL	LS, S
	Drainage (class)	W, SE, E	MW	I	P	VP
	pH	6.0-8.0	5.2-6.0 and 8.0-8.3	5.0-5.2 and 8.3-8.5	5.0-4.8	<4.8 and>8.5
	OM (%)	>3.0	2.5-3.0	2.0-2.5	1.0-2.0	<1.0
	Slope (%)	0-13	13-25	25-40	40-55	>55
	Temperature (0c)	14.9-18.4	14.4-14.9, 18.4-19.4	13.4-14.4,19.4-20.8	12.4-13.4, 20.8-21.3	<12.4, >21.3
	Rainfall (mm)	450-650	350-450,650-850	300-350, 850-1000	250-300, 1000-1200	<250, >1200
	LU/ LC	CL	-	BShL	-	WB, BUA, F

Lentil	Depth (cm)	>50	30-50	20-30	10-20	<10
	Texture (class)	SCL, L, SiL, CL	SiCL, SC, SiC,Si, C	SL	LS	S
	Drainage (class)	SE, E	W	MW	I	P, VP
	pH	5.5-7.3	5.3-5.5, 7.3-7.7	5.2-5.3, 7.7-8.0	5.0-5.2, 8.0-8.5	<5.0, >8.5
	OM (%)	>3.0	2.5-3.0	2.0-2.5	1.0-2.0	<1.0
	Slope (%)	0-20	20-35	35-40	40-50	>50
	Temperature (0c)	14.0-17.2	12.0-14.0, 17.2-17.9	11.0-12.0,17.9-19.1	10.0-11.0,19.1-19.6	<10.0, >19.6
	Rainfall (mm)	500-700	450-500, 700-800	350-400,800-900	900-1000	<350, >1000
	LU /LC	CL	-	BShL	-	WB, BUA, F
Chickpea	Depth (cm)	>50	30-50	20-30	10-20	<10
	Texture (class)	SCL, L, SiL, CL	SiCL, SC, SiC,Si, C	SL	LS	S
	Drainage (class)	SE, E	W	MW	I	P, VP
	pH	6.7-8.0	6.2-6.7, 8.0-8.2	5.7-6.2, 8.2-8.3	5.0-5.7, 8.3-8.5	<5.0, >8.5
	OM (%)	>3.0	2.5-3.0	2.0-2.5	1.0-2.0	<1.0
	Slope (%)	0-20	20-35	35-40	40-50	>50
	Temperature (0c)	16.2-19.6	14.9-16.2, 19.6-20.8	14.4-14.9, 20.8-21.9	13.7-14.4, 21.9-23.1	<13.7, >23.1
	Rainfall (mm)	350-650	300-350, 650-750	250-300, 750-850	850-900	<250, >900
	LU / LC	CL	-	BShL	-	WB,BUA, F

Source: FAO (1984); Landon (1991); Sys et al., (1993)

3.3.2.3 Factor / Criteria Rating

Land Suitability analysis for agricultural crops needs the consideration of different environmental factors/ criteria. In this particular land suitability analysis the criteria are mainly related to soil, topography (slope), climate, and land use/land cover. Soil data were assessed in terms of its depth, drainage, texture, organic matter and pH. Rainfall and temperature are taken as climatic factors. These are the most important requirements needed for all crops. A compilation of the crop requirements that were considered in the evaluation were made and factor rating for crops are decided. Factor ratings are sets of values which indicate how well each factor / criterion is satisfied by particular conditions of the corresponding land quality. Factor ratings are usually made in terms of five classes: highly suitable, moderately suitable, marginally suitable, currently not suitable, and permanently not suitable (FAO, 1985; 1993). In establishing the criterion rating (Table 11), references were made to: guidelines, research publications, and relevant literature. In addition experts from different disciplines like soil scientists, agronomists, agro-ecologists and agriculturalists from OWWDSE Land Use Planning and Natural Resource Study Division were consulted in arriving at a factor rating of a given land use type that can be used in the matching processes.

3.3.2.4 Criteria Standardization

The need for data standardization in GIS-based land suitability evaluation often arises as a consequence of the need to integrate into the evaluation process data measured not only in different units but also in different scales of measurement, such as nominal, ordinal, interval and ratio scales (Pereira and Duckstein, 1993). Because criteria are measured on different scales, it is necessary that factors be standardized before combination, and that they are transformed, if necessary, so that all factor maps are positively correlated with suitability. There are a number of approaches that can be used to make the attribute map layers comparable. Linear scale transformation is the most frequently used GIS-based approach for criteria standardization (Malczewski, 2003). The present study however used the module named reclass (in ArcGIS environment) for standardization of the factors. Thus, each factor will have an equivalent measurement basis before any weights are applied. Accordingly, all the factors used for this study are reclassified in to five classes (S1, S2, S3, N1 and N2) with the range of values 1 to 5, where the value of 1 takes the most suitable and 5 takes the least suitable for all factors considered. However, there are some factors that will not fulfil the whole range due to the crop requirements. Figure 13 below indicates the standardized factors for teff suitability analysis; whereas appendix 3 shows for wheat, chickpea and lentil.

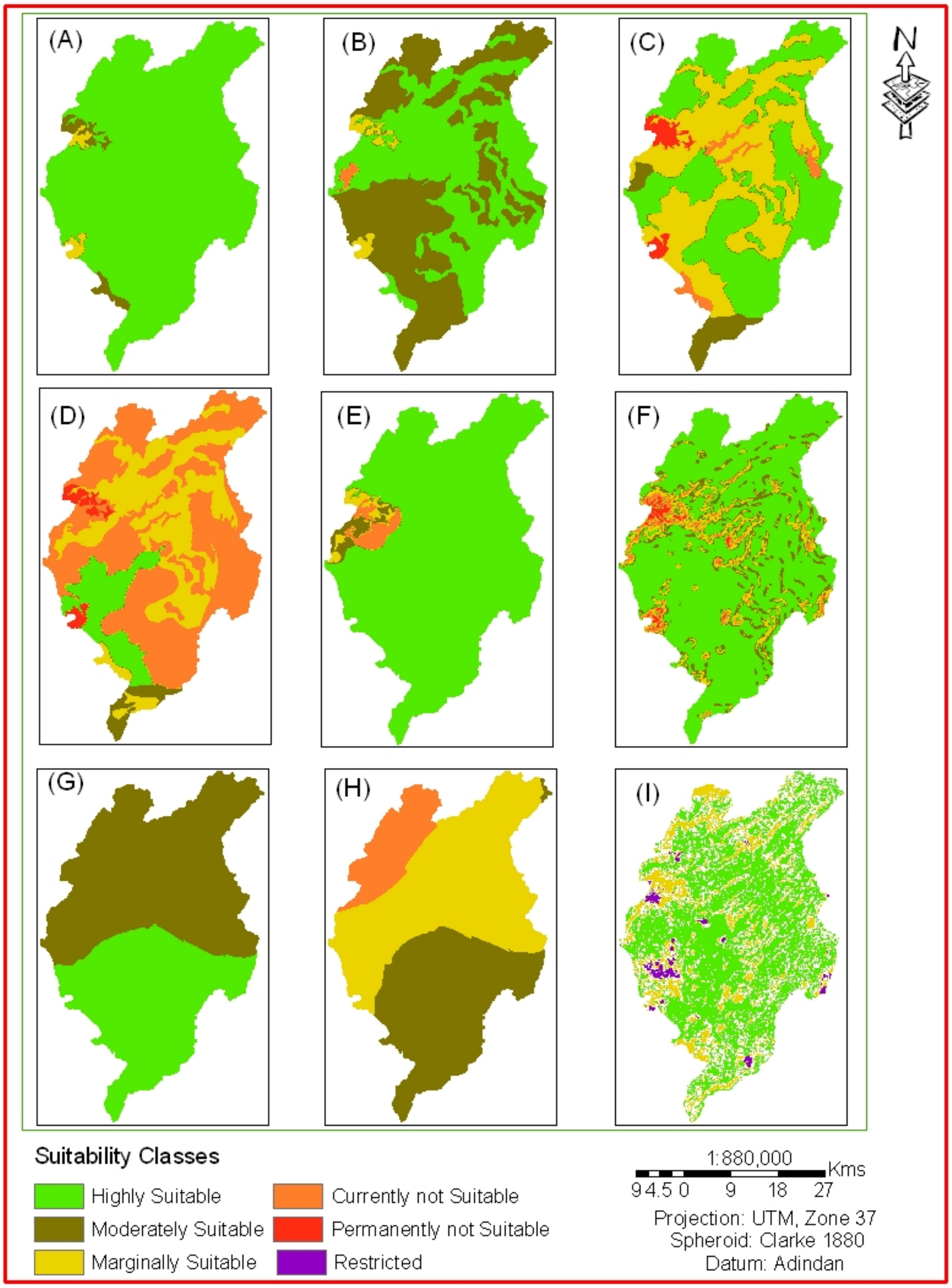


Fig. 13. Standardized factor maps for teff suitability analysis (A= Soil depth, B= Soil drainage, C= Soil texture, D= Soil OM, E= Soil pH, F= Slope, G= Temperature, H= Rainfall, I= Land use/land cover)

3.3.2.5 Assigning Criterion Weights

The purpose of weighting in land suitability analysis for agricultural crops is to express the importance or preference of each factor relative to other factor effects on crop yield and growth rate. In the procedure for MCE, it is necessary that the weights sum to 1. Accordingly, in IDIRISI, the weight module utilizes the pairwise comparison technique to help develop a set of factor weights that will sum to 1.0 (Table 12). In a pairwise comparison matrix, factors are compared two at a time in terms of their importance related to the stated objective.

In developing weights, an individual or group compares every possible pairing and enters the ratings into a pairwise comparison matrix or *ratio matrix* (Eastman, 2006). Since the matrix is symmetrical, only the lower triangle actually needs to be filled in. The remaining cells are then simply the reciprocals of the lower triangle. To this end, after discussion and careful analysis of the set of evaluation criteria with experts, all the pairwise comparisons for the set of the considered criteria were made. After all possible combinations of two factors are compared, the module calculates a set of weights and, importantly, a consistency ratio. This ratio indicates any inconsistencies that may have been arisen during the pairwise comparison process. The module allows repeated adjustments to the pairwise comparisons and reports the new weights and consistency ratio for each iteration. Figure 14 reveals the AHP weight derivation interface to derive the weights for the soil factors for teff production. Similarly Figure 15 shows the same method for the same crop for all factors (soil, rainfall, temperature, slope and LU/LC). Table 12 shows both factor weights as well as consistency ratio calculated for soil factors in IDRISI Andes AHP weight derivation module for all LUTs.

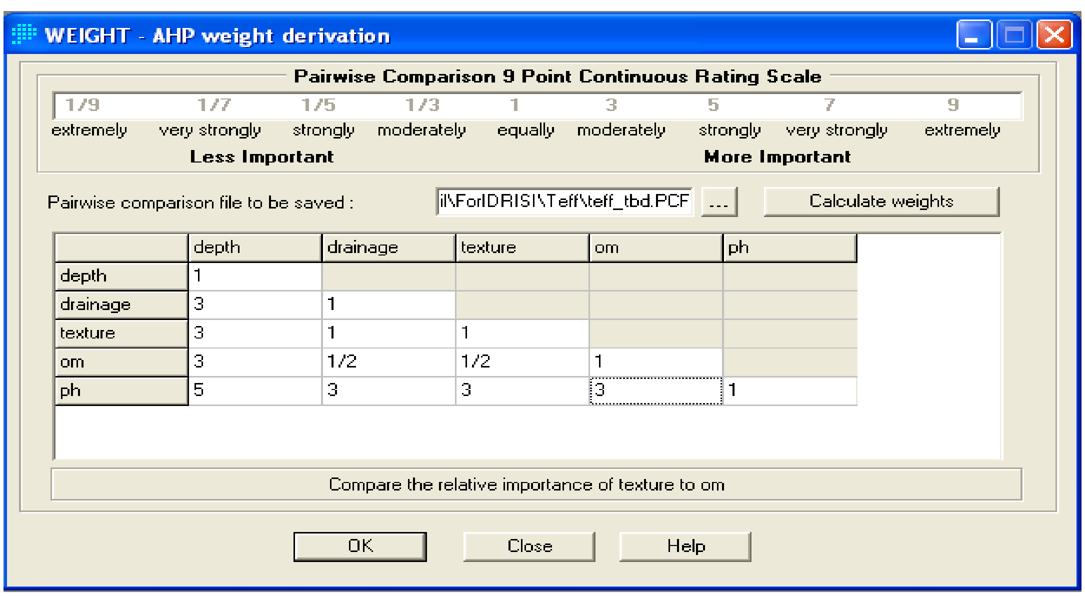


Fig. 14. AHP Weight derivation method for teff production.

With similar procedure and for the same factor, the weights for all selected crops for analysis are generated (Table 12).

Table 12. Criteria weights for crops regarding soil factor calculated by AHP weight derivation module.

	Teff		Wheat		Chickpea		Lentil	
Soil Factors	Weight	Weight (%)	Weight	Weight (%)	Weight	Weight (%)	Weight	Weight (%)
Depth	0.0617	6.17	0.0764	7.64	0.1082	10.82	0.0834	8.34
Drainage	0.1869	18.69	0.2100	21.00	0.2580	25.80	0.3554	35.54
Texture	0.1869	18.69	0.2580	25.80	0.3283	32.83	0.1533	15.33
OM	0.1258	12.58	0.0860	8.60	0.0571	5.71	0.0525	5.25
pH	0.4387	43.87	0.3696	36.96	0.2483	24.83	0.3554	35.54
Total	1.0000	100.00	1.0000	100.00	1.0000	100.00	1.0000	100.00
CR	0.03	3	0.03	3	0.03	3	0.05	5

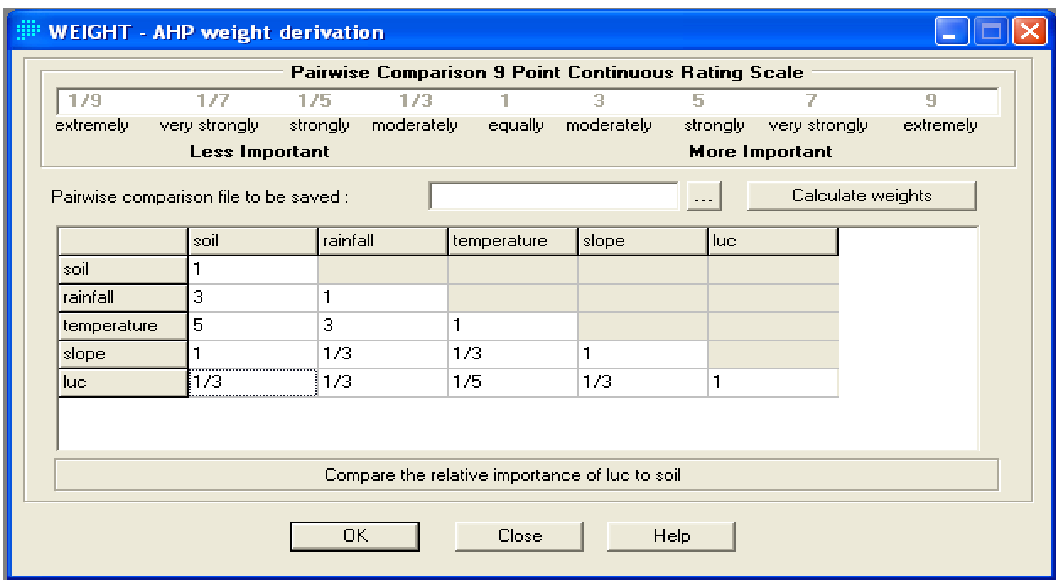


Fig. 15. AHP weight derivation method for teff considering all factors.

Based on this AHP weight derivation, the following eigenvectors of weights for factors considered for teff suitability analysis are generated. Table 13 below indicates eigenvector of weights for teff; while appendix 1 shows the eigenvector of weights for wheat, chickpea and lentil.

Table 13. Factors and their eigenvector weights for teff suitability analysis.

Factors	Weights	Weights (%)
Soil	0.1118	11.18
Rainfall	0.2442	24.42
Temperature	0.4611	46.11
Slope	0.1235	12.35
Land use/land cover	0.0593	5.93
Total	1.0000	100.00
Consistency Ratio (CR)	0.06	6

3.3.2.6 Aggregating the criterion weights and the standardized criterion maps

GIS can be used not only for automatically producing maps, but it is unique in its capacity for integration and spatial analysis of multisource datasets (Malczewski, 2003). These data are manipulated and analyzed to obtain information useful for a particular application such as land suitability analysis.

Once the criteria maps (factors and constraints) are developed, an evaluation (or aggregation) stage is undertaken to combine the information from the various factors and constraints. In the context of GIS, three decision rules i.e. Boolean overlay, weighted overlay and ordered weighted averaging are common for MCE (Jiang and Eastman, 2000; Malczewski, 2000; Malczewski, 2003). The simplest type of aggregation is the Boolean intersection or logical AND. This method is used only when factor maps have been strictly classified into Boolean suitable/unsuitable images with values 1 and 0. The evaluation is simply the multiplication of all the images. The present study, however, adopts the weighted overlay technique for developing the suitability maps for each LUTs and vector overlay analysis for deriving composite suitable land allocation map.

4. Results and Discussion

4.1 Soil Suitability Analysis for Agricultural crops

As described in chapter five (section 5.2.5), a weight is made for different soil properties considered for this specific study with respect to each other. These are depth, drainage, texture, organic matter, and pH. The weighted overlay analysis for these parameters of soil for the selected crops was made. The result indicates that 19.1%, 43.3%, and 31.3% are highly suitable for teff, wheat, and chickpea, respectively. However, there is no land that is classified as highly suitable for lentil. Similarly, 76.5%, 56.2%, 68.2%, and 65.3% are classified as moderately suitable whereas 2.7%, 0.5%, 0.5%, and 34.2% are marginally suitable for teff, wheat, chickpea and lentil, respectively. Although there is no land that is classified as currently not suitable for wheat and chickpea, 1.7% and 0.5% of the land is classified as currently not suitable for teff and lentil, respectively. Table 14 summarizes these findings.

Table 14. Suitability classes of soil with their respective area coverage.

Crops	Suitability Class	Area (km2)	Percent of total area
Teff	Highly Suitable	300.2	19.1
	Moderately Suitable	1208.3	76.5
	Marginally suitable	43.2	2.7
	Currently not Suitable	27.1	1.7
Wheat	Highly Suitable	684.5	43.3
	Moderately Suitable	885.5	56.2
	Marginally Suitable	8.8	0.5
Chickpea	Highly Suitable	495.5	31.3
	Moderately Suitable	1074.7	68.2
	Marginally Suitable	8.6	0.5
Lentil	Moderately Suitable	1031.0	65.3
	Marginally Suitable	538.9	34.2
	Currently not Suitable	8.9	0.5
Total		1578.8	100.0

Figure 16 below (A, B, C and D) indicate details of the soil suitability analysis map for teff, wheat, chickpea and lentil, respectively.

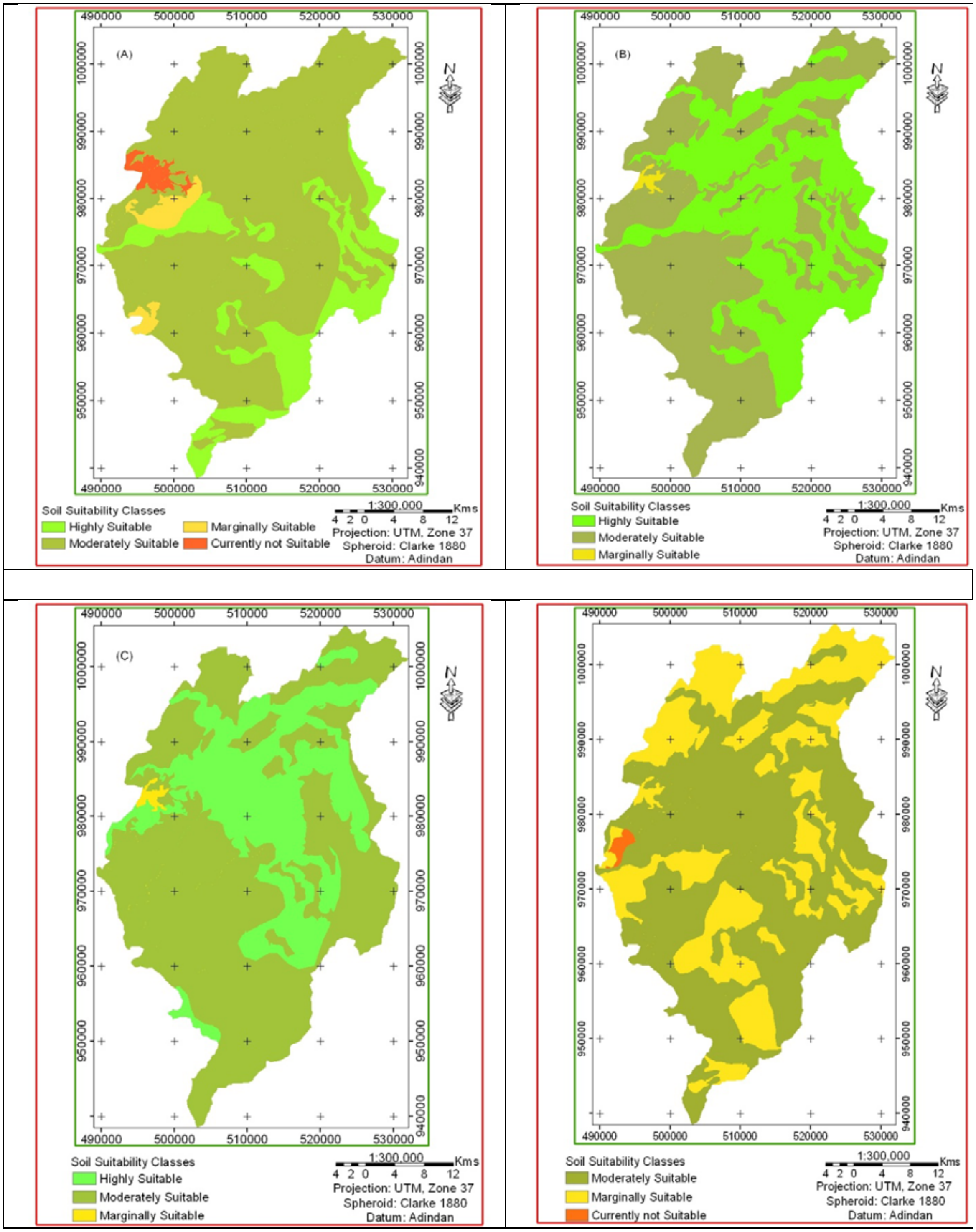


Fig. 16. Soil Suitability map for LUTs (A= teff, B= wheat, C= chickpea, D= lentil)

4.2 Land Suitability Analysis results for Agricultural crops

The land suitability analysis for the selected agricultural crops using the weighted overlay analysis results showed four classes of suitability. These are highly suitable, moderately suitable, marginally suitable and currently not suitable. However, there is no land that is classified as currently not suitable for wheat and highly suitable for lentil. The area coverage of each suitability class for each crop under the present study was calculated after converting the raster output of the weighted overlay analysis to a polygon feature in a GIS platform. Table 15 shows the output of the analysis.

Table 15 also demonstrates that 27.3%, 35.4%, and 15.7% of the study area are classified as highly suitable for teff, wheat, and chickpea production, respectively. This indicates that most of the study area is best suitable for wheat, although teff is considered as the dominant cereal crop produced in this study area. In addition, 65.2%, 60.9%, 77.9% and 80.2% were found to be moderately suitable while 4.1%, 0.6%, 3.3% and 16.5% is marginally suitable land for teff, wheat, chickpea and lentil, respectively. The result indicates that, there is no land that is classified as currently not suitable for wheat. However 0.3%, 0.03% and 0.04% of the study area is classified as currently not suitable for teff, chickpea and lentil, respectively. The result of the study showed that no part of the study area was recorded to be permanently unsuitable for the production of agricultural crops considered in this study.

Table 15. Land Suitability classes of crops with their respective area coverage.

Crops	Suitability class	Area (km2)	Percent of total area
Teff	Highly suitable	429.6	27.2
	Moderately Suitable	1028.3	65.1
	Marginally Suitable	66.7	4.2
	Currently not Suitable	6.4	0.4
Wheat	Highly Suitable	558.8	35.4
	Moderately suitable	962.4	61.0
	Marginally Suitable	9.8	0.6
Chickpea	Highly Suitable	247.9	15.7
	Moderately Suitable	1228.1	77.8
	Marginally Suitable	54.2	3.4
	Currently Suitable	0.8	0.1
Lentil	Moderately Suitable	1264.4	80.2
	Marginally Suitable	260.9	16.7
	Currently not Suitable	0.6	0.1
Restricted Area		47.8	3.0
Total Area		1578.8	100.0

The land suitability analysis maps for the selected agricultural crops were presented in Figure 17, Figure 18, Figure 19 and Figure 20 for teff, wheat, chickpea, and lentil, respectively.

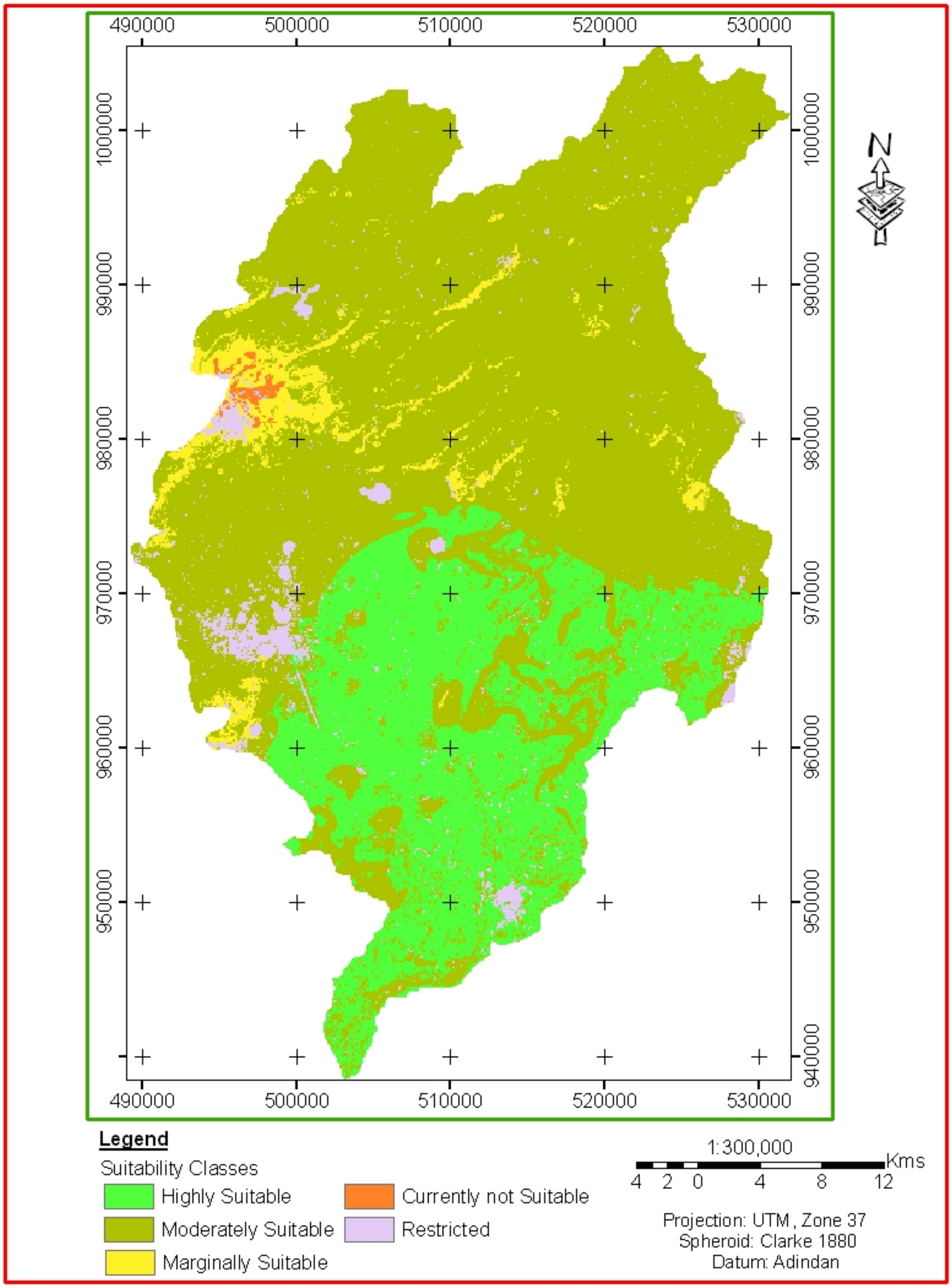


Fig. 17. Land suitability analysis result along with suitability classes for teff production.

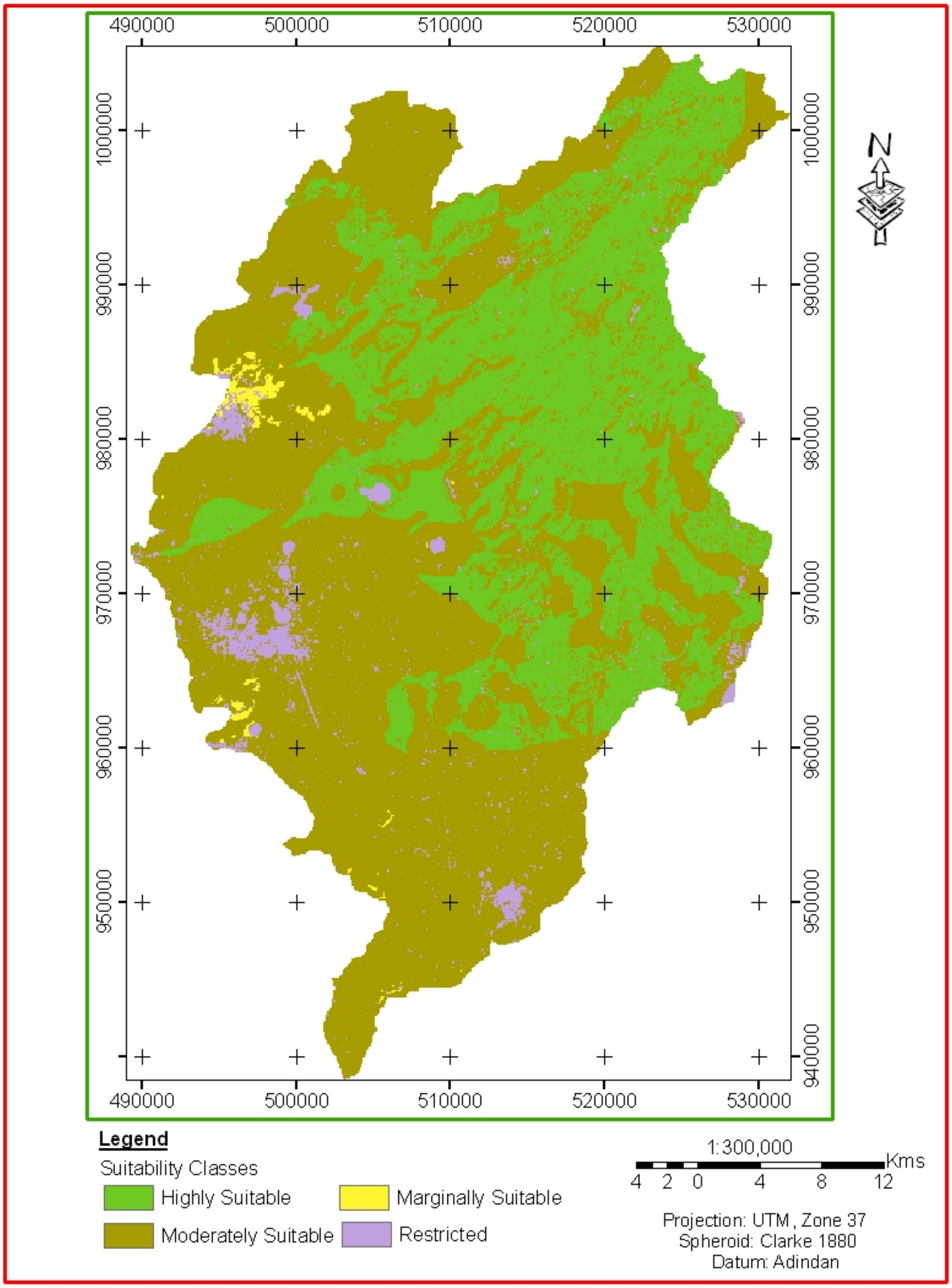


Fig. 18. Land suitability analysis result along with suitability classes for wheat production.

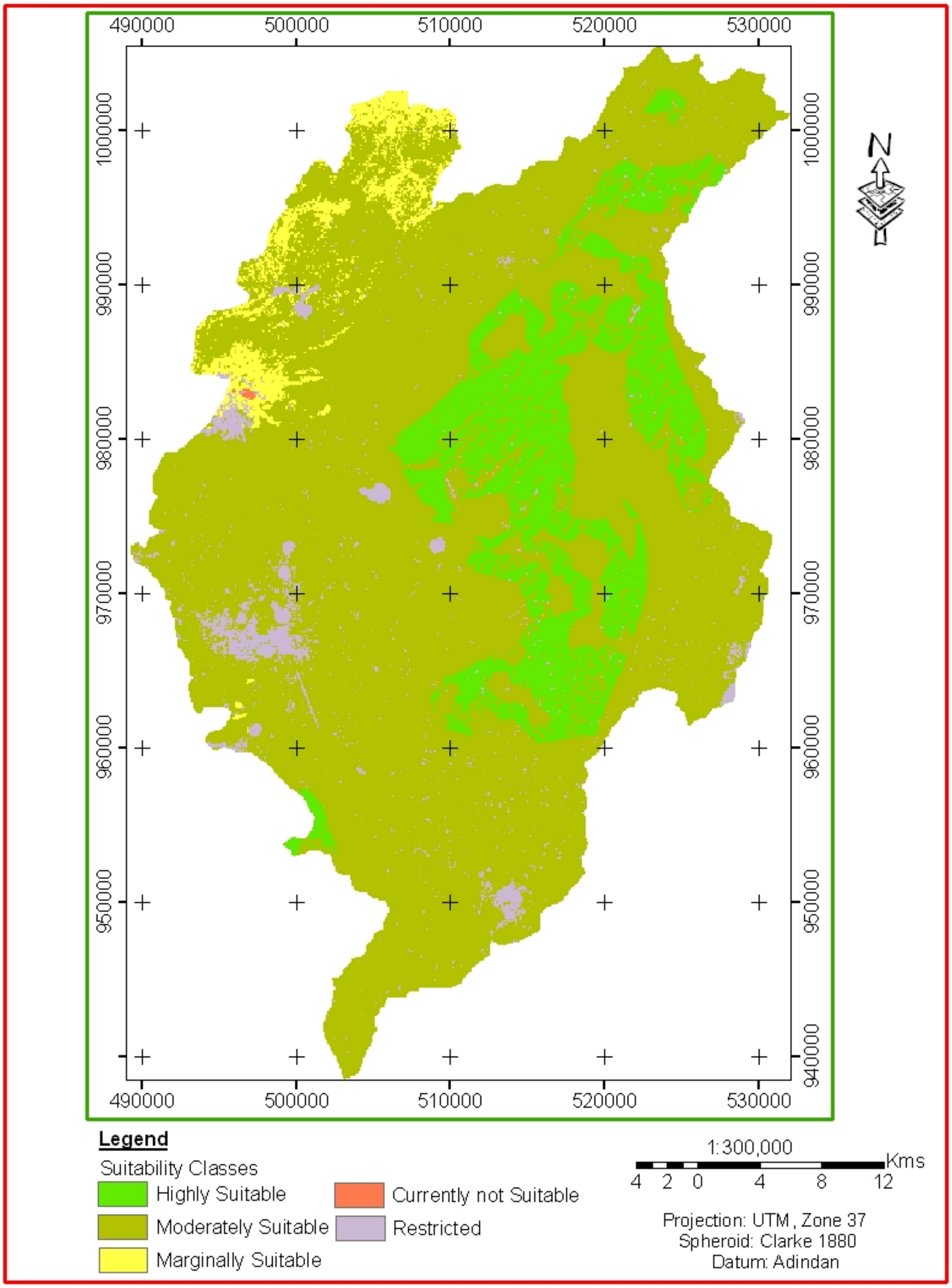


Fig. 19. Land suitability analysis result along with suitability classes for chickpea production.

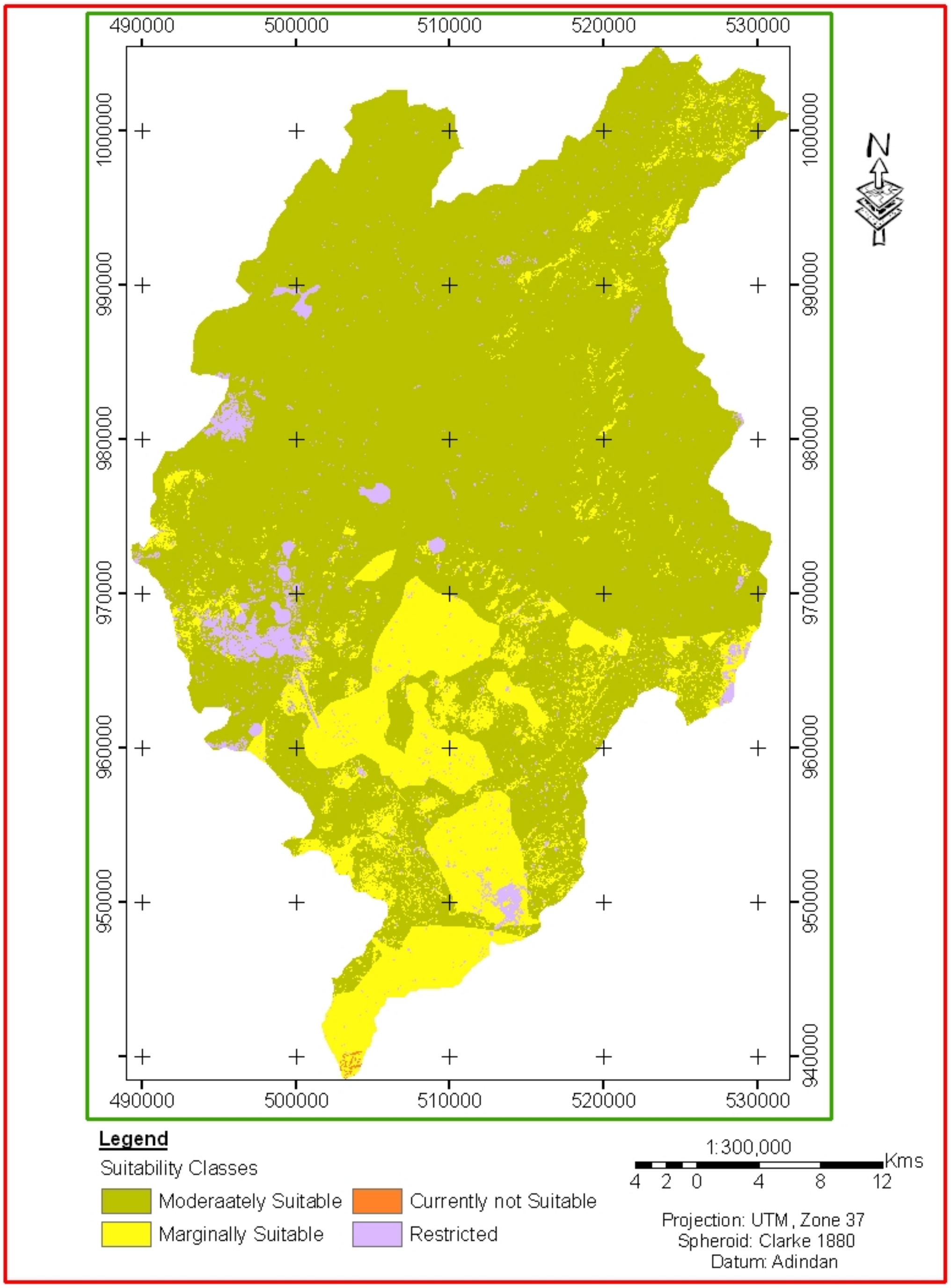


Fig. 20. Land suitability analysis result along with suitability classes for lentil production.

As indicated in section 3.1.3, most of the soils in the study area are suitable for crops. However, it is only 55.5%, 85.7%, 78.4% and 90.6% of chromic luvisols are moderately suitable for teff, wheat, chickpea and lentil, respectively. The larger part of lithosols (62.9%, 85.3%, 76.9% and 19.5%) is moderately suitable for teff, wheat, chickpea and lentil, respectively. Regarding Luvic phaeozems, 70.4% of the soil is highly suitable only for teff. Similarly, it is only 46.7%, 24.1%, and 1.4% of pellic vertisols are highly suitable for teff, wheat, and chickpea, respectively. Furthermore, 8.9%, 55.9% and 33.7% of vertic cambisols of the study area are highly suitable for teff, wheat, and chickpea, respectively. This is indicates that crop suitability is not only determined by soil but also other factors like climate and topography have their own role. Table below indicates the details of soil types versus crop suitability.

Table 16. Major soil types versus crop suitability.

		Teff		Wheat		Chickpea		Lentil	
Major Soils	Suitability Classes	Area (km^2)	Area (%)	Area (km^2)	Area (%)	Area (km^2)	Area (%)	Area (km^2)	Area (%)
Chromic Luvisols	S1	-	-	1.3	1.2	-	-	-	-
	S2	57.0	55.5	88.0	85.7	80.5	78.4	93.1	90.6
	S3	34.3	33.4	7.2	7.1	15.4	15.0	3.5	3.4
	N1	5.3	5.1		0.0	0.5	0.5		0.0
Total area of soil (Km^2)		102.7	100.0	102.7	100.0	102.7	100.0	102.7	100.0
Lithosols	S1	2.5	8.6	-	-	4.0	13.8	-	-
	S2	18.2	62.9	24.7	85.3	22.3	76.9	21.2	72.9
	S3	6.1	20.9	2.0	7.0	0.5	1.7	5.7	19.7
Total area of soil (km^2)		29.0	100.0	29.0	100.0	29.0	100.0	29.0	100.0
Luvic Phaeozems	S1	39.3	70.4	-	-	-	-	-	-
	S2	15.3	27.4	54.5	97.6	54.6	97.9	10.9	19.5
	S3		0.0	0.2	0.3		0.0	43.4	77.8
	N1	-	-	-	-	-	-	0.6	1.0
Total area of soil (Km^2)		55.8	100.0	55.8	100.0	55.8	100.0	55.8	100.0
Pellic Vertisols	S1	326.3	46.7	168.7	24.1	9.7	1.4	-	-
	S2	332.0	47.5	493.8	70.6	635.9	91.0	493.7	70.6
	S3	4.4	0.6	0.2	0.0	17.3	2.5	168.5	24.1
Total area of soil (Km^2)		699.1	100.0	699.1	100.0	699.1	100.0	699.1	100.0
Vertic Cambisols	S1	61.3	8.9	386.6	55.9	233.1	33.7	-	-
	S2	603.9	87.2	298.4	43.1	433.1	62.6	645.4	93.2
	S3	20.4	2.9	0.0	0.0	18.9	2.7	39.8	5.7
Total area of soil (Km^2)		692.2	100.0	692.2	100.0	692.2	100.0	692.2	100.0

4.3 Suitable Land allocation for the selected crops

The land suitability result obtained for specific LUT only indicates the different suitability classes for that LUT in the study area. When different LUTs are involved in the evaluation, it seems good to indicate the appropriate parcels of land best suitable for the LUTs and which LUTs compete for the same parcel of land at its best suitability class. Overall land suitability analysis indicates the overall suitability of the land for each LUTs. It also indicates which LUTs compete for a parcel of land at the same level of suitability class. Overall land suitability analysis is an indicative of appropriate land allocation. Hence, the overall land suitability analysis is performed for the LUTs considered in the study area.

The overall suitability analysis result is obtained after conversion of the raster data to vector data format for all land utilization types. The analysis is performed in a vector overlay analysis in a GIS environment using Analysis Tool. Table 16 demonstrates the result of appropriate land allocation for the selected LUTs along with their best suitability classes. The result demonstrates the condition where a plot of land is suitable for one or more than one LUTs at the same level of suitability class. This indicates competing nature of LUTs for the same parcel of land. Fore instance, 4.03% of a single plot of land is highly suitable for both teff and wheat. Similarly, 11.23% is highly suitable for wheat and chickpea. In the same manner, 26.79% of the study area is moderately suitable for teff, wheat, chickpea and lentil at the same geographical area. The detail of the result was presented on Table 16. Figure 21 shows the map of suitable land allocation for the evaluated crops. The white section in the map reveals places which are restricted, marginally suitable, and currently not suitable for all evaluated LUTs.

Table 17. Suitable land allocation for the selected agricultural crops along with their area coverage.

Overall Suitability Analysis		
Code	Area (km2)	Area (%)
S1_CP	30.97	2.0
S1_Tf	324.42	21.1
S1_Tf, CP	2.68	0.2
S1_Tf, Wt	62.03	4.0
S1_Tf, Wt, CP	40.42	2.6
S1_Wt	281.57	18.3
S1_Wt, CP	172.79	11.2
S2_CP	0.44	0.03
S2_CP, Lt	2.15	0.2
S2_Lt	14.97	1.0
S2_Tf	1.21	0.1
S2_Tf, CP	0.87	0.1
S2_Tf, CP, Lt	0.62	0.1
S2_Tf, Lt	1.28	0.1
S2_Tf, Wt	0.34	0.02
S2_Tf, Wt, CP	91.79	6.0
S2_Tf, Wt, CP, Lt	412.35	26.8
S2_Tf, Wt, Lt	34.69	2.3
S2_Wt	0.41	0.03
S2_Wt, CP	4.79	0.3
S2_Wt, CP, Lt	47.44	3.1
S2_Wt, Lt	11.05	0.7

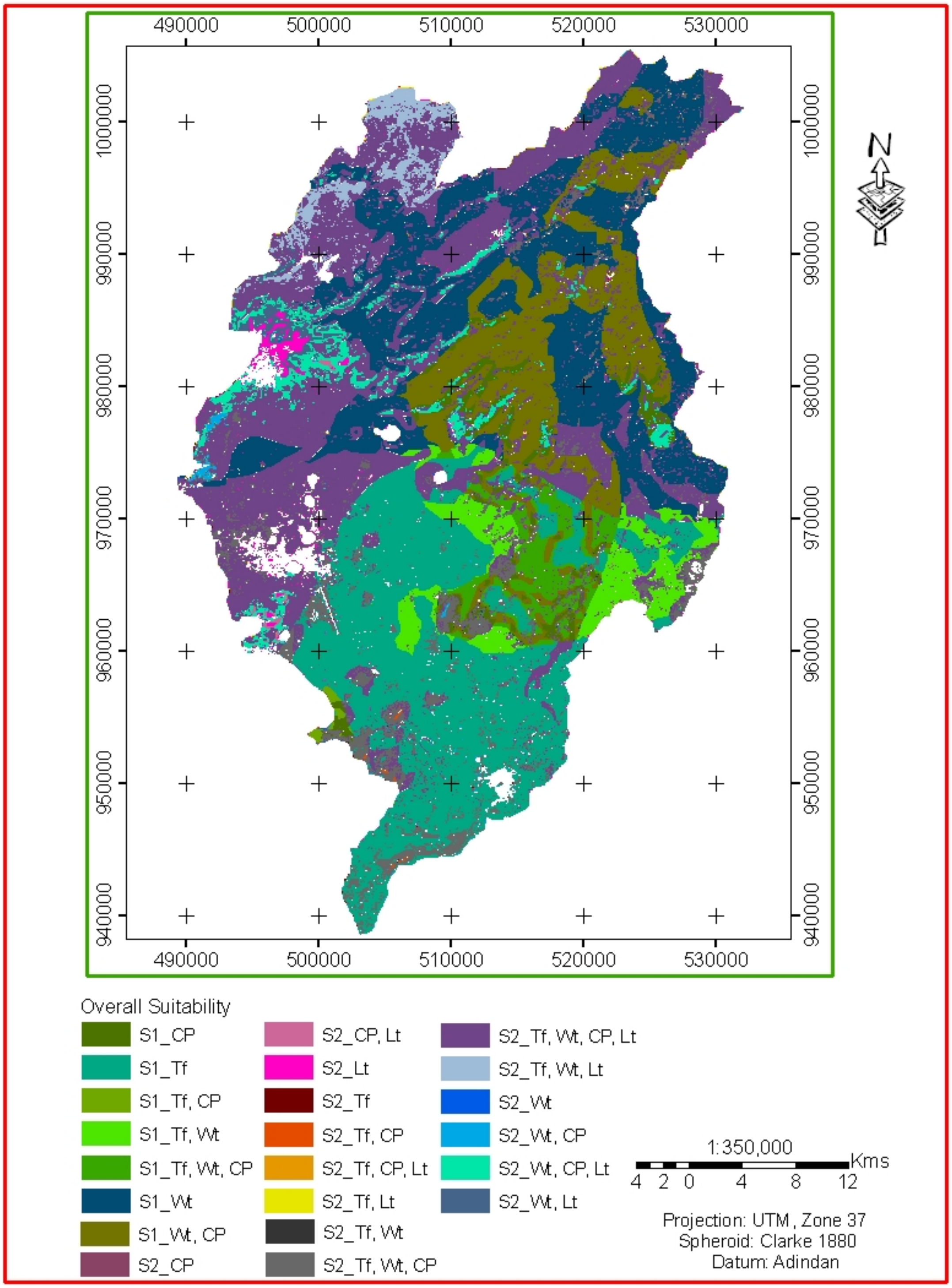


Fig. 21. Appropriate land allocation map with their respective degree of suitability. (Note: S1 = highly suitable, S2 = moderately suitable, Tf = teff, Wt = wheat, CP = chickpea, Lt = lentil)

5. Conclusion and Recommendations

5.1 Conclusion

The main aim of the study was to identify the suitable land parcels for agricultural crops in Mojo watershed. Integrating MCE with GIS for spatial decision making process is a worthwhile technique. The parameters used for the evaluation of land suitability for agricultural crops are soil (depth, drainage, texture, organic matter and pH), rainfall, temperature, slope and land use/ land cover. The larger portion of the soils of the study area is very deep and deep, which accounts for 60.2% and 32.7%, respectively. Clay and clay loam soils are dominant textural classes in the study area with area coverage of 48.5% and 42.0%, respectively. Furthermore, well and moderately well drained drainage classes account for about 34.2% and 16.3%, respectively. The study discloses that, the larger portion of the study area fell under the slope classes class 0-2% and 2-8%, which covers 46.5% and 40.5% of the total area, respectively. Supervised image classification is used to categorize image data in to different land use /land cover classes. Hence, the larger part of the study area (77.9%) is cultivated land.

These parameters are rated according to the specific crop requirements from highly suitable to permanently not suitable. They are standardised and weight is made using pairwise comparison technique before they are aggregated to produce land suitability maps for the evaluated LUTs.

The study used weighted overlay technique of MCE in a GIS platform to arrive at the final land suitability for agricultural crops. The weighted overlay analysis result for soil factors indicate that 19.1%, 43.3%, and 31.3% of soils of the study area are highly suitable for teff, wheat and chick pea, respectively. Similarly, the larger portion of the study area is classified as moderately suitable for all crops in terms of soil which accounts a value of 76.5%, 56.2%, 68.2% and 65.3% for teff, wheat, chickpea and lentil, respectively. In contrary to this, there is no parcel of land that is highly suitable for lentil.

As per the land suitability analysis result for crops, 27.3%, 35.4%, and 15.7% of the study area is highly suitable for the production of teff, wheat, and chickpea, respectively. Furthermore, with regard to the output of the suitability analysis, it should be noted that the large portion of the study area (65.2%, 61.0%, 77.9% and 80.2%) for all selected LUTs fell under the suitability class called moderately suitable for teff, wheat, chickpea and lentil, respectively. Similarly, 4.1%, 0.6%, 3.3% and 16.5% of the total area is marginally suitable land for teff, wheat, chickpea and lentil, respectively. Insignificant portion of the study area (0.3% and 0.03%) is currently not suitable for teff and lentil, respectively. The result indicated that there is no land that is permanently suitable for the evaluated LUTs.

The overlay analysis (union) is done for land suitability results to indicate the best suitable land and identify places for which LUTs compete at the same level of suitability class. The result indicated that 11.2% for wheat and chick pea, 4.3% for teff and wheat, 2.6% for teff, wheat, and chickpea, and 0.2% for teff and chickpea is highly suitable. The output revealed that only 21.1%, 18.3%, and 2.0% of the study area is highly suitable for teff, wheat, and chickpea, respectively.

5.2 Recommendations

- ❖ A parcel of land has to be studied to provide its maximum yield. Hence, land suitability analysis for agricultural crops using multi-criteria evaluation in a GIS environment is one of the appropriate ways to increase food production and to feed the highly increasing population of the country in general, and the study area in particular.
- ❖ The parameters used for land suitability analysis in this study focused on the physical factors like soil, temperature, rainfall, land use/land cover and slope. There are additional variables that can influence land suitability analysis. Hence, further study that incorporates socio-economic variables (like income, preference, market, and yield) and road for land suitability analysis for agricultural crops for this study area is necessary.
- ❖ The LUTs considered in this study are limited to four selected crops. This study focused on creals (teff and wheat) and pulses (chickpea and lentil). To increase the choice for the decision makers as well as for the stake holders, further analysis for different LUTs is necessary. Therefore, further research has to be conducted for different LUTs which include cereals, pulses, oilseeds, cash crops, livestock, etc to identify the best alternative use for a specific parcel of land.

References

Bandyopadhyay, S., Jaiswal, R. K., Hegde, V. S. and Jayaraman, V. (2009). Assessment of land suitability potentials for agriculture using a remote sensing and GIS based approach. International Journal of Remote Sensing **30**: 879- 895.

Carver, S.J. (1991). Integrating multi-criteria evaluation with geographical information systems. International Journal of Geographical Information Systems **5**: 321-339.

Chakhar, S. and Mousseau, V. (2008). GIS-based multi-criteria spatial modeling generic framework. International Journal of Geographical Information Science **22**:1159 - 1196.

Congalton, R.G. (1991). A Review of Assessing the Accuracy of Classification of Remotely Sensed Data. Remote Sensing of Environment **37**: 35-46.

Davidson, D.A. (1992). The Evaluation of Land Resources, Second edition, Longman Series, United Kingdom.

Drobne, S. and Lisec, A. (2009). Multi-attribute Decision Analysis in GIS: Weighted Linear Combination and Ordered Weighted Averaging. Informatica **33**: 459-474, Slovenia.

Eastman, J. R., Weigen J., Peter A. K., and James, T. (1995). Raster Procedure for Multi-Criteria/Multi-0biective Decisions: Photogrammetric Engineering & Remote Sensing **61**: 539-547. American Society for Photogrammetry and Remote Sensing.

Eastman, J.R. (2006). IDRISI Andes guide to GIS and Image processing. Manual version 15.00, Clark University.

FAO (1976). A framework for Land Evaluation. FAO Soils Bulletin No.32, ILRI Publication No.22, International Institute for Land Reclamation and Improvement, Wageningen, The Netherlands.

FAO (1983). Guidelines: land evaluation for rainfed agriculture. Soils Bulletin 52. FAO, Rome, Italy.

FAO (1984). Land evaluation: Technical report 5, Part III. Crop environmental requirements; Report prepared for the Government of Ethiopia by FAO acting as executing agency for the UNDP, Rome, Italy.

FAO (1985). Guidelines: Land Evaluation for Irrigated Agriculture. FAO Soils Bulletin No.55, Rome, Italy.

FAO (1988). Irrigation and water resources potential for Africa. FAO report AGL/MISC/11/87. Rome, Italy.

FAO (1993). Guidelines for land-use planning. FAO Development Series 1, Food and Agricultural Organization of the United Nations, Rome, Italy.

FAO (2006). World reference base for soil resources: A framework for international classification, correlation and communication. Rome, Italy.

FAO (2007). LAND EVALUATION: Towards a revised framework, Land and water discussion paper. Food and Agricultural Organization of the United Nations, Rome, Italy.

Florent, J., Marius, T., and Andre, M. (2001). Using GIS and outranking multi-criteria analysis for land-use suitability assessment. International Journal of Geographical Information science **15** : 153-174, Taylor and Francis.

Hailu Beyene (2008). Adoption of improved teff and wheat production technologies in crop livestock mixed systems in Northern and Western Shewa Zones of Ethiopia. University of Pretoria, Pretoria.

Ignas, D. (2004). Information and knowledge based system for land suitability analysis in Cambodia. A paper prepared for the land resource assessment forum (14-17 Sep 2004).

James, C.A., Harriet, D.R., Dana, L.H., Gregory, S.M., Bruce C.V., Marvin, J.S., Mark, A.W., and Lajpat, R.A. (2002). Multi-criteria Spatial Decision Support Systems: Overview, Applications, and Future Research Directions. Colorado State University, Colorado.

Jankowski, P. (1995). Integrating geographical information systems and multiple criteria decision-making methods. International Journal of Geographical Information Science **9**: 251-273.

Jiang, H. and Eastman, J.R. (2000). Application of fuzzy measures in multi-criteria evaluation in GIS. International Journal of Geographic Information Systems **14**:173-184.

Landon, J.R. (1991). Booker Tropical Soil Manual, a hand book for soil survey and Agricultural Land Evaluation in the tropics and subtropics. Longman, Booker. 474p.

Lillesand, T.M., Kiefer, R.W. and Chipman, J.W. (2004). Remote Sensing and Image Interpretation. 5th ed. John Wiley and Sons Inc: Hoboken, NJ, USA.

Lo, C.P. and Yeng, A.K.W. (2002). Concepts and Techniques of Geographic Information Systems. New Delhi, India.

Malczewski, J. (1996). A GIS-based approach to multiple criteria group decision-making. International Journal of Geographical Information Science, **10**: 955 - 971.

Malczewski, J. (2000). Review article on the use of weighted linear combination method in GIS: common and best practice approaches. *Transactions in GIS,* **4**:5-22.

Malczewski, J. (2003). GIS-based land-use suitability analysis: a critical Overview, Progress in Planning **62**: 3 – 65

Malczewski, J. (2006). GIS-based multi-criteria decision analysis: a survey of the literature. International Journal of Geographical Information Science **20:** 703 -726.

Martin, D. and Saha, S.K. (2009). Land evaluation by integrating remote sensing and GIS for cropping system analysis in a watershed. National Bureau of Soil Survey and Land Use Planning, Regional Centre, IARI Campus, Indian Institute of Remote Sensing, New Delhi, India. Current Science, **96**:4.

Mendoza, G.A. (1997). A GIS-based multi-criteria approach to land use suitability assessment and allocation. In: Seventh Symposium on systems analysis in forest resources, Traverse City, USDA Forest Service. [http://www.ncrs.fs.fed.us/pubs/gtr/other/gtr-nc205/landuse.htm).

Ministry of Finance and Ecomonic Development (2009). Annual Report on Macroeconomic Development in Ethiopian.

Owusu, K.A. (2007). Identification of land use/cover transfer hotspots in the Ejisu-Juabeng District, Ghana. MSc thesis, ITC, The Netherlands.

Pereira, J.M.C. and Duckstein, L. (1993). A multiple criteria decision-making approach to GIS-based land suitability evaluation. International Journal of Geographical Information Science **7**: 407 – 424.

Prakash, T.N. (2003). Land Suitability Analysis for Agricultural Crops: A Fuzzy Multi criteria Decision Making Approach. MSc thesis, ITC, The Netherlands.

Rossiter, D.G. (1996). A theoretical framework for land evaluation. A Discussion Paper. *Geoderma*, **72** : 165-202.

Senes, G. and Toccolini, A. (1998). Sustainable land-use planning in protected rural areas in Italy. Landscape and Urban Planning **41**: 107 - 117.

Sys, C. (1985). Land Evaluation (Algemeen Bestuur van de Ontwikkelingss, Ghent, Belgium: International Training Centre for Post-Graduate Soil Scientists, State University of Ghent).

Sys, C., Van Ranst, E., Debaveye, J., and Beerneart, F. (1993). Land Evaluation: Part III. Crop Requirements, Agricultural Publication No 7, International Training Center for Post Graduate Soil Scientists, University GHENT, Brussels, Belgium.

Voogd, H. (1983). Multi-criteria Evaluation for Urban and Regional Planning, London, Pion.

World Bank (2006). Sustainable Land Management: Challenges, Opportunities and Trade-offs; the World Bank, Washington DC.

Appendixes

1. Factor weights calculated by AHP weight derivation module in IDRISI Andes for LUTs.

1.1 Factor Weights for Wheat

Factors	Soil	Rainfall	Temperature	Slope	LU/LC	Weights	Weights (%)
Soil	1					0.1686	16.90
Rainfall	3	1				0.3223	32.10
Temperature	3	1	1			0.3479	34.87
Slope	1/3	1/3	1/5	1		0.0761	7.62
LU/LC	1/3	1/3	1/3	1	1	0.0851	8.52
Total						1.0000	100.00
CR						0.04	4

1.2 Factor Weights for Chickpea

Factors	Soil	Rainfall	Temperature	Slope	LU/LC	Weights	Weights (%)
Soil	1					0.1192	11.92
Rainfall	1	1				0.1048	10.48
Temperature	5	3	1			0.4759	47.59
Slope	1	3	1/3	1		0.2075	20.75
LU/LC	1	1	1/5	1/3	1	0.0926	9.26
Total						1.0000	100.00
CR						0.04	4

1.3 Factor Weights for Lentil

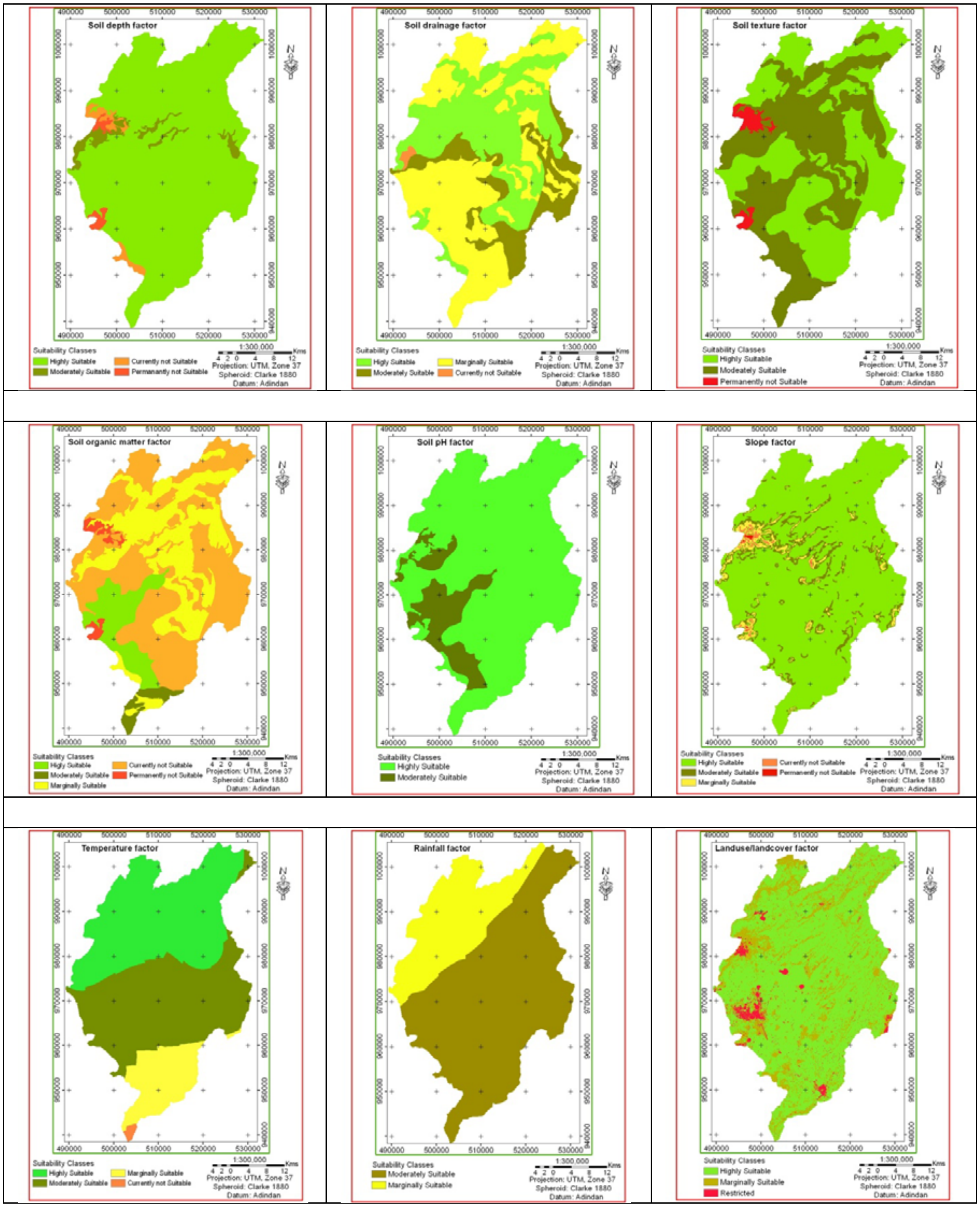
Factors	Soil	Rainfall	Temperature	Slope	LU/LC	Weights	Weights (%)
Soil	1					0.1346	13.46
Rainfall	3	1				0.2519	25.19
Temperature	3	3	1			0.4368	43.68
Slope	1/3	1/3	1/3	1		0.0854	8.54
LU/LC	1	1/3	1/5	1	1	0.0913	9.13
Total						1.0000	100.00
CR						0.06	6

2. GPS readings recorded for representative land use/land cover categories.

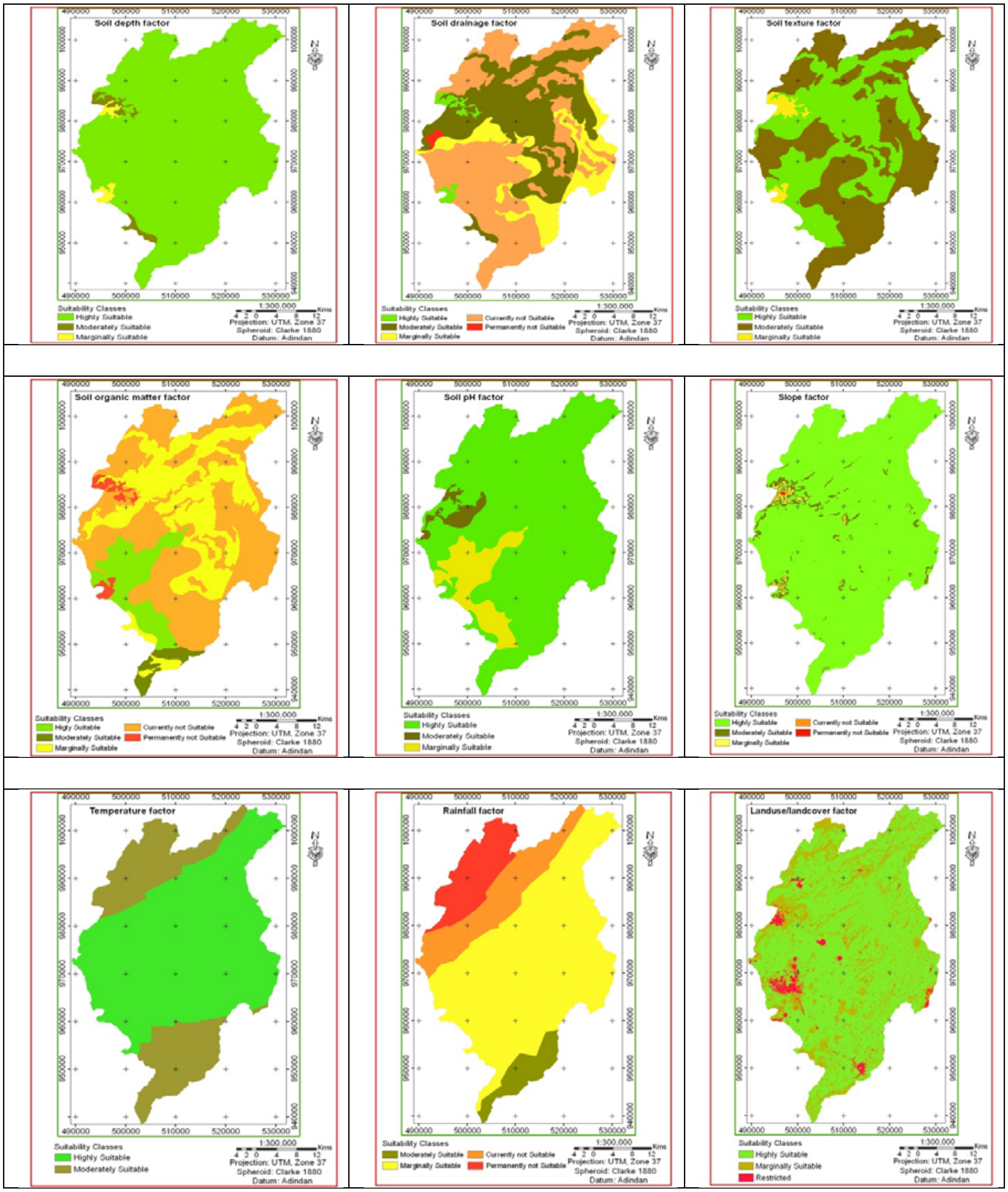
Waypoints	UTM Coordinate		Land use/land cover category
	Easting (X)	Northing (Y)	
279	514412	949605	Built up area
269	513558	991363	Built up area
303	505133	965278	Built up area
304	503972	958798	Built up area
307	496975	968717	Built up area
268	518736	953697	Bush shrubland
293	504567	980803	Bush shrubland
294	503074	979571	Bush shrubland
297	501286	976723	Bush shrubland
305	5081 59	956465	Bush shrubland
271	495235	980633	Bush shrubland
272	503239	957754	Bush shrubland
276	510362	945041	Bush shrubland
277	509994	953057	Bush shrubland
278	500610	972556	Bush shrubland
296	501168	976786	Cultivated land
281	524610	966641	Cultivated land
282	524611	966641	Cultivated land
283	527836	969548	Cultivated land
284	527402	968444	Cultivated land
285	523185	965733	Cultivated land
286	521101	962115	Cultivated land
287	517637	957392	Cultivated land
288	516651	949837	Cultivated land
290	506848	984875	Cultivated land
291	504105	982508	Cultivated land
292	503568	982189	Cultivated land
295	501386	977094	Cultivated land
273	508738	965586	Cultivated land
274	506507	966261	Cultivated land
275	496578	975044	Cultivated land
289	511347	990732	Forest
270	511230	989889	Forest
308	494716	980295	Forest

3. Standardized / Reclassified factor maps for the selected LUTs.

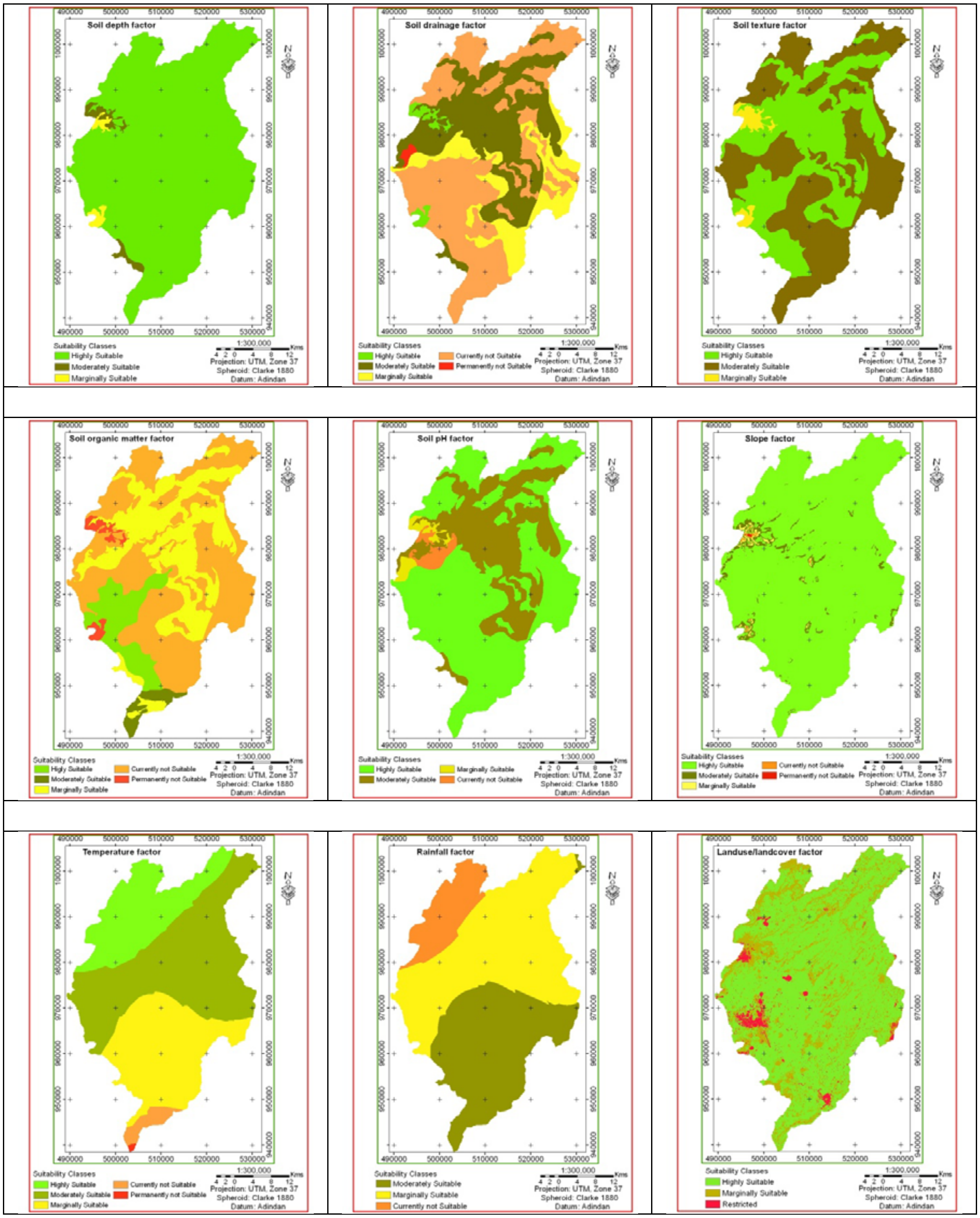
3.1. Standardized / reclassified factor maps for wheat production.



3.2. Standardized / reclassified factor maps for chickpea production.



3.3. Standardized/ reclassified factor maps for lentil production.



4. Partial view of the study area (Photographs taken during field work)

DECLARATION

I hereby declare that the thesis entitled "GIS and Remote Sensing based Land Suitability Analysis for Agricultural Crops in Mojo Watershed" has been carried out by me under the supervision of Dr. Dagnachew Legesse, Department of Earth Science, Addis Ababa University, Addis Ababa during the year 2010 as part of Masters of Science program in Remote Sensing and GIS. I further declare that this work has not been submitted to any University or Institution for the award of any degree or diploma.

Dula Wakassa

Signature ___________________

Addis Ababa University

Addis Ababa

Date: June, 2010

CERTIFICATE

This is certified that the thesis entitled "GIS and Remote Sensing based Land Suitability Analysis for Agricultural Crops in Mojo Watershed" is a bonafied work carried out by Dula Wakassa under my guidance and supervision. This is the actual work done by Dula Wakassa for the partial fulfillment of the award of the Degree of Masters of Science in Remote Sensing and GIS from Addis Ababa University, Addis Ababa, Ethiopia.

Dr. Dagnachew Legesse

Signature ____________________

Department of Earth Science

Addis Ababa University

Addis Ababa