AGRICULTURAL LAND SUITABILITY ANALYSIS FOR MAJOR CROPS USING GEOSPATIAL TECHNOLOGY : A CASE STUDY OF DIGA DISTRICT, EAST WOLLEGA ZONE, OROMIA, ETHIOPIA

Obsa Aga Guyo

A Thesis Submitted to

The department of Geomatics Engineering

School of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Geoinformatics

Office of Graduate Studies

Adama Science and Technology University

August, 2021

Adama, Ethiopia

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APPROVAL PAGE OF M.Sc. THESIS

We, the advisors of the thesis entitled "Agricultural Land Suitability Analysis for Major Crops Using Geospatial Technology : A Case Study of Diga District, East Wollega Zone, Oromia, Ethiopia" and developed by Obsa Aga, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

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DECLARATION

I hereby declare that this Master Thesis entitled “Agricultural Land Suitability Analysis for Major Crops Using Geospatial Technology : A Case Study of Diga District, East Wollega Zone, Oromia, Ethiopia” is my original work. : A Case Study of Diga District, East Wollega Zone, Oromia, Ethiopia” is my original work. That is, it has not been submitted for the award of any academic degree, diploma, or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

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Name of the Student	Signature	Date

RECOMMENDATION

We, the advisors of this thesis, hereby certify that we have read the revised version of the thesis entitled “Agricultural Land Suitability Analysis for Major Crops Using Geospatial Technology: A Case Study of Diga District, East Wollega Zone, Oromia, Ethiopia” prepared under our guidance by Obsa Aga Guyo submitted in partial fulfillment of the requirements for the degree of Master’s of Science in Geo-informatics. Therefore, we recommend the submission of a revised version of the thesis to the department following the applicable procedures.

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LIST OF ACRONYMS

CSA	Central Statistical Agency
ERDAS	Earth Resources Data Analysis System
ESRI	Environmental Systems Research Institute
FAO	Food and Agricultural Organization
LE	Land Evaluation
LULC	Land use / Land cover
GIS	Geographic Information System
MCA	Multi-Criteria Analysis
MCDM	Multi-Criteria Decision Making
MCE	Multi-Criteria Evaluation
OWWDSE	Oromia Water Works Design and Supervision Enterprise
RS	Remote Sensing
USGS	United States Geological Survey
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. However, land suitability analysis, by its nature is a complex process and involves considerations of multi-criteria evaluation which considers not only physical conditions but also environmental, social, and economic factors. Hence, this study aimed to analyze land suitability analysis for some selected crops productions (teff, wheat, and barley) in Diga District, East Wollega Zone, Western Oromia, Ethiopia, using geospatial techniques and multi-criteria evaluation. Ten factors namely: land-use land-covers, road, soil (depth, texture, drainage, and pH), climate (rainfall and temperature), and topography (elevation and slope) were evaluated and prioritized as per the judgment of agronomist experts. Factors were weighted in a hierarchical order using the analytical hierarchy process approach to produce their weights of importance to the land suitability for an agricultural area. The weighted overlay was used to incorporate all layers of factors to produce a composite factor map. Weighted overlay analysis was adopted to integrate all weighted factors to produce the final suitability map. The final suitability map classified the whole Diga District area into five suitability classes. Accordingly, 6.73% highly suitable for teff, 4.41% highly suitable for wheat, 4.14%, for barley, 6.45%, 12.93%, and 11.19% were found to be moderately suitable for teff wheat and barley respectively and 14.51%, 9.44%, and 9.45% were found to be marginally suitable for teff, wheat and barley, while 5.22%, 6.77 % and 8.77% were currently not suitable for teff, wheat, and barley. Therefore, the final suitability map provides a useful guide for future agricultural land use. Thus, the study implies the effectiveness of geospatial technology and MCE to handle land suitability analysis aimed at identifying environmentally safe and economically feasible sites for future agricultural areas. The study would support the planning experts to increase crop production to improve farmer's life hood, and also supports the government in formulating effective agricultural policies to increase agricultural production.

Keywords: *Analytic Hierarchy Process, Multi-criteria Evaluation, Agricultural Land suitability, Geospatial technology, and Major Crops.*

CHAPTER I: INTRODUCTION

1.1 Background of the Study

The rapidly growing world population places considerable pressure on increasingly scarce natural resources, spurring the need to develop more efficient and sustainable agricultural production systems to feed these growing populations (Kamkar et al., 2014). On the other hand, continuous utilization of the agricultural land in past decades regardless of land suitability has caused much more destruction than provide the resources (FAO, 2007). Hence, proper evaluation based on agricultural land use planning is essential to solving this problem (Elsheik et al., 2010).

According to World Bank, (2006), 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 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.

According to Hailu B. (2008), as cited in Dula W. (2010), 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 the population has risen at a rate of over 3% per year. 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 B. 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 labor force. 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 labor pool. Despite this potential, however, Ethiopian agriculture has remained underdeveloped because of drought, a poor economic base, and a low level of technologies on agricultural application (MoFED, 2009).

Cropland suitability analysis is a prerequisite to achieving optimum utilization of the available land resources for sustainable agricultural production (Perveen et al., 2007). Land evaluation is a process of predicting land performance over time according to the specific types of use (Martin and Saha, 2009). Agriculture land suitability analysis is defined as the process of analyzing land performance when used for alternative kinds of agriculture (He et al., 2011). The principle purpose of agriculture land suitability evaluation is to predict the potential and limitation of the land for crop production (Pan and Pan, 2012). 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).

Land-use suitability mapping and analysis are one of the most useful applications of Geographic information systems (GIS) for spatial planning and management (Malczewski, (Malczewski, 2004). Land Suitability analysis is a multi-criteria evaluation, which aims at identifying the most appropriate spatial pattern for future land uses according to specific requirements, preferences, or predictors of some activity. GIS serve the multi-criteria evaluation function of suitability assessment well, providing the attribute values for each location and both the arithmetic and logical operators for combining attributes (Sailesh et al., 2011).

Remote sensing technology is capable of providing up-to-date geographic information and is the main source of input data for assessing and monitoring the environment in a GIS environment. For example, the current land use/land cover information of the study area will be extracted and mapped from satellite images and used as input data for the study. Thus, remote sensing serves as a tool for environmental resource assessment and monitoring. In addition, it has some fundamental advantages that make it a veritable tool in environmental monitoring and management and impact studies (Idowu and Ukoje, 2009). Furthermore, remote sensing techniques make it possible to increase the speed and frequency with which one can analyze a landscape. Therefore, remote sensing can aid in making quick and focused decisions (Steininger and Horning, 2007).

Although the application of GIS is widely spread in resource inventory and mapping, the potential of GIS for planning and decision-making is not utilized fully due to its limited ability to represent judgments, values, arguments, and options of the decision-makers. On the other hand, multi-criteria decision analysis (MCDA) is a fruitful approach to solve such limitations. Moreover, MCDA solves the complexity and conflicting criteria for solid waste landfill site selection and helps us to consider multiple alternative solutions and evaluation criteria (Cheng et al., 2002). Hence, Spatial Multi-Criteria Decision Making (SMCDM) methods can overcome these limitations (Laskar, 2003). The accuracy of complexity and intractable decision-making in environmental projects can be improved by using multi-criteria decision-making analysis with GIS. In this particular study, GIS and Remote Sensing were used to generate, manipulate, and analyses geospatial data that were used as land suitability analysis site selection criteria. Moreover, SMCDA was integrated to select potential Land suitability sites efficiently with better accuracy.

Analysis of land suitability is very needed to contribute to the world's food production in general and in particular in Ethiopia, to improve food security. The process of land suitability analysis is the categorization and grouping of specific areas of land in terms of their suitability defined usage (FAO, 1976). Land needs careful and appropriate use to achieve optimum productivity and to ensure environmental sustainability for the future generation. This requires effective and operative management of land information on which such decisions should be based because the land is one of the non-renewable natural resources. Decision on appropriate use includes the past and present human activities and the status of physical and chemical properties of the land. Land evaluation is concerned with the assessment and valuation of land when used for specified purposes Dula W. (2010).

Hence, the present study employs geospatial techniques augmented with Multi-Criteria Evaluation (MCE) approach and analytical hierarchy process (AHP) for appropriate land suitability analysis for agriculture land allocation for Diga District.

1.2 Statement of the Problem

According to (Pirbalouti *et al.*, 2011), the problem of selecting the correct land for the cultivation of a certain agricultural product is a long-standing and mainly empirical issue. Even though the issue of agricultural productivity and food security is widely studied in different parts of the world, the impact of unwise use of land resources and absence of utilization of the land according to its potential suitability is still a serious problem, particularly in developing countries.

Currently, Ethiopia faces many problems resulted from the unwise useof land resources while the degree of the problem is not identified. As a result, still there is a lack of information on the status and classification of land use suitability in Ethiopia (Ahmed, 2012). It is suspected that much agricultural land used currently is below its optimal capacity in a different part of the world. Also, many researchers and institutions have tried to provide a framework for optimal land suitability analysis for agricultural crop production.

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

Agriculture is the main source of income and form of survival for peoples of this area and cereals 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. In the study area, there is no study about the resource potential mapping of the area that could match with crop requirements. Hence, undertaking suitability analysis of the land for the major crop will help to invest the scarce resource of smallholders on the best alternative agricultural commodity.

Diga is one of the districts in which agriculture is the dominant activity for the livelihood of the community. But this agricultural activity is not based on land suitability analysis. The farmers cultivate what crops they need rather than what crop the land prefers for the maximum yield. Therefore, there is an urgent need to develop land suitability analysis for land and crops production. GIS and remote sensing technologies offer a dynamic tool for multidimensional land use management and analysis. This study integrates multi-criteria evaluation with GIS to identify the suitable areas for the crop's productions using the relevant variables of soil, climate, land use land cover, market, road, and topographic factors to improve crop production and livelihood status of particularly small holder's farmer.

1.3 Objectives of the Study

1.3.1 General objectives

The general objective of this study is to conduct land suitability analysis for future Agricultural land using Geospatial techniques augmented with multi-criteria evaluation and AHP approach in Diga District, Oromia, Ethiopia.

1.3.2 Specific objectives

The Specific Objectives of this research are:

- To determine criteria that influence the suitability of agricultural land for major crop production.
- To identify the land suitability area for agricultural crop production and
- To develop a thematic map of land suitability area for the study area.

1.4 Research Question

To realize the stated objectives, the following research questions were designed:

1. What are the underlying parameters that influence the surface land suitable use in Diga District?
2. How many area of land is suitable for Agricultural crop Production in Diga District?
3. Which part of the land is more suitable for future agricultural production?

1.5. Significance of the Research

The findings of this research identified the suitability indexes of the entire land suitability analysis of Diga District for future use of agricultural crop production areas. Moreover, the study focused on mapping suitable sites for future agricultural production practices. These can create awareness of agricultural production practices land use sustainable development. This scientific classification in line with the final suitability map can be used as a guide map to the future land use plan for agriculture of the study area. As a result, the study may support spatial decision-making to satisfy the crop demand of the highly increased population of the area. Hence, the paper is useful for planners, policy-makers, developers, and land managers. Moreover, it helps Diga District agricultural experts and developers to recognize that where is optimal land suitable for future agricultural activities to keep land sustainable development while utilizing the land properly.

1.6 Scope of the Study

This study focused on land suitability analysis for future agricultural land use in Diga District. While thematically, related kinds of literature, reports, and land suitability analysis for agriculture have been reviewed to acquire background information, strong theoretical bases, selection of appropriate methodology, identification of gaps in the literature, and to compare the findings in the existing body of knowledge. Based on this, the review was focused on the following themes; definition and concept of a land suitability analysis, land-use planning, controls and regulations, compatibility of land uses, land-use suitability analysis and influencing factors, Suitability of agricultural land and development, determination of criteria for land-use suitability analysis, geospatial technologies in land-use suitability analysis, multi-criteria evaluation, analytical hierarchy process, and weighted overlay analysis.

1.7 Organization of the Thesis

This thesis includes four chapters and the conclusions and recommendations section. The first chapter presents the introductory part, which describes the background of the study, statement of the problem, the objectives of this research, research question, the significance of the study, the scope of the study, and organization of the paper. The second chapter discusses the literature related to the study, reviews related papers to find the scientific support and the theories behind the methodology. The third chapter includes a description of the study area, data sources, and data collection methods, software, and facilities used to analyze the data. The fourth chapter presents results and discussions that focus on developing spatial data analysis using geospatial techniques with MCE and AHP methods. In this chapter, the determination of criteria (factors) and weight computation are key parts of the study. At the last, conclusions are drawn from the findings, and recommendations are provided to improve the analysis of land suitability analysis for an agricultural production area for future decisions.

CHAPTER II: LITERATURE REVIEW

2.1 Definition and Concepts of Land Suitability

Land suitability is the way of dividing land into different suitability classes for the production of crops in a sustainable manner. The suitability analysis enables identifying the main factors of particular crop production and allows decision-makers to develop a crop management system for increasing land productivity. To achieve the optimum utilization of the available land resource for agricultural production sustainably, the cropland suitability analysis is a prerequisite (Mohammed, 2004). Land suitability evaluation is a classification of lands in terms of their suitability for specific land use. Land evaluation can be carried out based on biophysical factors and socioeconomic conditions of the area. Physical land evaluation is a prerequisite for land use planning because it guided decisions on optimal use of land resources (Elaalem, 2012).

Land suitability analysis is a fundamental system to identify the natural resource potentialsand limitations of a given area that could help to provide decisions on farming (Endalkachew & Negese, 2020). The process of land capability classification is the evaluation and grouping of specific areas of land in the terms of their suitability for a defined use (Henok 2010).

2.2 Suitability of Agricultural Land and Influencing Factors

2.2.1 Some parameters used in the land suitability analysis for agriculture

For the determination of the suitability of land in the study area that is suitable for agriculture, different parameters are used. Some of the parameters that are used to determine the suitability of land for agriculture are slope, land use land cover (LULC), soil character (depth, texture, drainage, and pH), elevation, and climate data (temperature, precipitation), and road.

2.2.2 Rainfall and temperature

Quoting IPCC Ericson (2008) cited in Getnet (2010) wrote that annual rainfall is likely to decrease throughout most of the African region, except for Eastern Africa, where annual rainfall is projected to increase. Trend analysis of annual rainfalls in Ethiopia has shown that rainfalls remained more or less constant when averaged over the whole country, while a declining trend has been observed over the Northern half of the country and Southwestern Ethiopia. On the other hand, recent climate trends have based on United nations development program climate data indicate a change in temperature and rainfall.

2.2.3 Topography

The most important elements in topography are relief/slope and elevation. The relief is related to land management and erosion hazard and elevation is related to temperature and solar radiation and thus closely linked to plant requirements. Topography can influence the type of land use. For example, gentle land is suitable for agriculture than steep slopes.

2.2.4 Climate

Climate has a great effect on land characteristics; its crucial influence on land suitability analysis is the range and type of crops permitted by the climate in a specific area. Rainfall and temperature are the major climatic factors influencing the physical and agricultural processes (Dula, 2010).

2.2.5 Soil

Soils are natural unconsolidated materials on the surface of the earth and are composed of solid, liquid, and gas. They have organic as well as inorganic matter, which is intimately mixed by natural processes. By this mixing and transforming, they are aggregated into a porous body. The pores accommodate air and water (Khan. O 2013).

Soil classification is the orderly arrangement of soils according to some known or inferred characteristics. Soils are classified to organize information regarding their properties and behavior so that they can be used for different purposes with the maximum benefit under sustainable management. The evaluation of soil properties to pretend the performance for specific crops is a necessary part of land use planning activity applied to agriculture. Soil depth indicates the depth to which the roots of cultivated plants can reach and use the available water and nutrients. It is the most important soil property affecting the hydrologic properties of soil and its behaviors against erosion. The soil layer is the root zone and source of water and nutrients to plants (Akinci et al., 2013). Maximum Water Holding Capacity (MWHC), level of moisture (Bhagat, 2014), amount of soil nutrients and growth of plants as well as agricultural productivity vary according to soil depth. Availability of nutrients and MWHC have a significant positive relationship with soil depth. Rocky, barren and scrub land are included in the soil class ‘thin and shallow’. Agriculture lands, fallow lands, and dense forests are classified into soil classes viz. deep, moderately deep, and marginally deep soils, respectively (Yu *et al*., 2011).

2.2.6 Soil texture

According to the Ministry of Agriculture, about 19 soil types are identified throughout Ethiopia. Complexes of soil-forming factors have primarily influenced the distribution of the soil types (MoA, 2000).

2.2. 7 Land use/land cover

Land use refers to man's activities and the varied uses which are carried on overland and it includes agricultural land, built-up land, recreation area, wildlife management area etc.. Land cover refers to natural vegetation, water bodies, rock/soil, artificial cover, and others noticed on the land (NRSA, 1989).

2.2.8 Normalized difference vegetation index

Change in the biophysical parameter of vegetation canopy implies a climate change, accordingly, vegetation is used as the most key inputs into climate change models (Ogunbadewa, 2013). Consequently, climate variability is one of the most important factors affecting vegetation conditions. In this regard, remote sensing plays a crucial role to detect and characterize vegetation dynamics that suffering from climate variability. The Normalized Difference Vegetation Index (NDVI) is related to the amount of photosynthetically absorbed radiation. It is a measure of the quantity and vigor of vegetation on the land surface.

NDVI is an integrated function of photosynthesis, leaf area, and evapotranspiration. It is a symbol of vegetation biomass, and it's a ratio between near-IR and red refection. The total amount of biomass has an indirect and direct relation with surface energy balance; the surface temperature is consistent with the interference of sunlight, canopy cover ratio, and evapotranspiration cooling effect (Kanwal, 2019).

2.3 Land Suitability Analysis

Land-use suitability is the capacity or level of land suitable for prescribed uses (Steiner et al., 2000; Collins et al.,2001; Marull et al., 2007), and involves collective physical, socioeconomic, environmental, and ecological perspectives which are quantified through set criteria (Collins et al.,2001). Malczewski, (2004) stated that suitability analysis or assessment should be made according to specific requirements, preferences, or predictors of certain activities. Accordingly, local expert knowledge, the preferences of decision-makers, and community participation are represented in land suitability analysis by scientific integration of existing real-world criteria.

According to McSherry et al. (2000) land-use suitability analysis is the process of determining the fitness of a given tract of land for a defined specific use. It is also a process to evaluate the advantages of possible locations in which a predetermined use can be developed (Opadeyi, & Nizeyimana, 2005). It helps to locate the most desirable direction for future urban growth; the suitability of various land uses should be carefully analyzed and interpreted as appropriately as possible. Hence, land suitability analysis aimed to identify the suitable spatial patterns of land for future uses as predetermined specific requirements, preferences (Collins et al., 2001). Generally, the main purposes of land suitability analysis are also to identify and locate the suitable areas for a possible land use development activity, such as residential, industrial, tourism development, agricultural land use, potential areas for forestry, and other such land-use activities.

The process of site suitability requires the identification of the appropriate locations for a particular land use activity by considering physical resources (Laurin & Ongaro, 2006). There are various criteria to be considered in land suitability analysis some of the relevant parameters include: topographic factors (elevation, slope, aspect), natural resources (soils, geology, hydrology, flora and fauna habitat, and environmentally sensitive areas), and existing land use and development (man-made facilities such as transportation systems, existing urban areas, and utility networks) (Pareta, 2013). These different types of information constitute the “criteria” based on which the area under consideration (Keeney & Raiffa, 1993). These criteria are individually considered to identify areas of opportunity for areas suitable to the land use under consideration and constraints than (areas not suitable to the land use under consideration (Pareta, 2013).

In the land-use planning process, land suitability analysis is a mandatory component of the local land-use plan. It is a process for determining a planning area's supply of land that is suitable for development (Division et al., 2005). The analysis includes consideration of several factors such as natural system constraints, compatibility with existing land uses and development patterns, existing land-use policies, and the availability of community facilities. A key output of the analysis is a land suitability map that shows vacant or under-utilized land that is suited for the development (Division et al., 2005). In general, different factors considered in a land suitability analysis fall into one of three categories: (1) physical constraints, such as slope, soil, groundwater aquifers, and flood plains; (2) access, such as distance to roads, surface waters, sewer lines, or water lines; and (3) costs and benefits of the development. New developments could impact the physical environment or human society, such as an aquifer, a wildlife habitat, or historical sites.

Land suitability analysis is a systematic procedure for examining combined effects of a related set of factors that an analyst assumes to be the important determinants of locational suitability (Kaiser et al., 1995). Specifically, a land suitability analysis examines selected land characteristics to determine the level of suitability and ranks available land accordingly. The optimal land will be used for the intended purpose first. The selection of land characteristics is normally a judgment of the person in charge of the study. Those characteristics are represented by a set of factors. According to (Wang & Hofe, 2007)the process follows the following eight steps: Select a land-use type for analysis; Select factors to be considered and attribute values of each factor; Determine a score for each factor attribute; Weigh the factors; Calculate a composite score from the attribute values and weigh it for each factor; Rank the combined scores to establish suitability levels; Identify available land-based on existing land uses; Compare with comprehensive other land use controls that further remove unavailable land

2.4 Multi-Criteria Decision Making (MCDM) for Land Suitability Analysis

Decision analysis can be defined as a set of systematic procedures for analyzing complex decision problems. Differences between the desired and the actual state of the real-world geographical system are spatial decision problems, which can be approached systematically using multi-criteria decision-making. Many real-world spatially related problems give rise to geographical information system-based multi-criteria decision-making. Geographical information systems and multi-criteria decision-making have developed largely independently, but a trend towards the exploration of their synergies is now emerging (Samo and Anka, 2009). Multi-criteria analysis is a set of mathematical tools and methods allowing the comparison of different alternatives according to many criteria, often conflicting, to guide the decision-maker towards a judicious choice (Chakhar and Mousseau, 2008). There are many criteria upon which land suitability depends. Earlier, the multi-criteria land suitability was assessed more non-spatially, assuming the spatial homogeneity over the area under consideration. Agricultural crop suitability involves the integration of information from various streams of science. The suitability analysis evaluates many alternative land use types under the light of various criteria from various streams. Alternatives here are competing with one another; criteria are both qualitative and quantitative. Decisions have to be taken at various levels starting from selecting the LUTs to the allocation of the LUTs for an area that suits best. So, the suitability analysis is a multiple criteria decision-making process. This, however, is unrealistic in cases like land suitability studies, where decisions are made using criteria that vary across space (Malczewski 1999).

2.4.1 Spatial multi-criteria decision making for land suitability analysis

The application of GIS is widely spreading in resource inventory and mapping. However, the potential of GIS for planning and decision-making couldn't be utilized fully due to its limited ability to represent judgments, values, arguments, and options of the decision-makers (Laskar, 2003). GIS-based Multi-Criteria Decision Analysis (GIS-MCDA) is a process of decision making in which geographical data and value judgments are brought together to obtain more information for the decision-makers. GIS and MCDA can benefit from each other. GIS techniques and procedures have an important role to play in analyzing MCDM problems through automating, managing, and analyzing a variety of spatial data for decision making. Although an increasing number of GIS are described as systems for supporting spatial decision problems, most GISs lack the kind of spatial analysis required by decision-makers. On the other hand, MCDM methodologies provide a rich collection of techniques and procedures to reveal decision maker's preferences and to incorporate them into GIS-based decision-making (Jankowski, 2006).

MCDM problems involve criteria of varying importance to decision-makers and information about the relative importance of the criteria is required. 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).

2.4.2 Analytic hierarchy process approach

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

The Analytic Hierarchy Process (AHP) is a Multi-Criteria Decision Making approach originally introduced by Prof. Thomas L. Saaty in 1960. It is applied to determine the influential factors in the hierarchy of selected dissimilar inputs to Weighted Overlay Analysis. One of the most widely known and used Multi-Criteria Analysis approaches, the AHP method enables users to determine the weights of the parameters in the solution of a multi-criteria problem. In the AHP method, a hierarchical model consisting of objectives, criteria, sub-criteria, and alternatives is used for every problem (Saaty, 1994). AHP technique used for LSA can be outlined into five steps i.e. (1) determination of ranks,(2) preparing pairwise comparison,(3) calculation of weights, (4) determination of score and

(5) Weighted overlay analysis.

The hierarchical structure of AHP is useful for complex spatial decisions with a higher confidence level (Saaty, 1980). Several researchers are attracted to AHP for its effective mathematical properties i.e., weight determination through pairwise comparisons of criterion and score for sub-criterions. Therefore, it minimizes the judging errors within its mechanism (Cengiz and Akbulak, 2009). It is the more flexible technique with higher precision in LSA (Malczewski, 2006).

2.4.3 Determination of criteria weights in the land suitability analysis

AHP method is a powerful and popular technique that can be applied in a GIS environment and provides a means for analyzing multiple complicated problems that allow subjective as well as objective factors to be considered in a multicriteria decision-making process (Haile and Suryabhagavan 2019; Kou et al. 2016; Jablonsky 2015; Vaidya and Kumar 2006).

For valuation of the criteria features, various methods such as logistic regression, the AHP method, the weight of evidence, ratio estimation, and the Delphi process could be chosen (Adewumi et al. 2019). Several researchers have used the AHP method of pair-wise comparison matrix, to assign the weights to each of the considered factors (Haile and Suryabhagavan 2019; Rajasekhar et al. 2019; Ramík 2017; Mandal and Mondal 2016; Ataei et al. 2008; Vaidya and Kumar 2006).

Mayunga (2018) showed that the essence of pair-wise comparison is that two criteria are evaluated at a time to determine their relative importance. In this research, the AHP method was adopted to give value to the criteria and select the best appropriate site. After the hierarchy has been established, a pair-wise comparison matrix of each element within each level is constructed. This pair-wise comparison permits for an independent rating of each factor's contribution, which therefore simplifies the decision-making process (Adewumi et al. 2019).

Local expertise can weigh each element against each other within each level by adapting a comparison scale (Table 2), which is related to the levels above and below it and mathematically tie the entire scheme together. The consistency of the weight for various factors was checked through, a single numerical value, the consistency ratio (CR), which measures the level of the inconsistency of the pair-wise comparison matrix (i.e., the likelihood of whether factor weights were randomly assigned). The consistency ratio (CR) can be defined by the mathematical relation equation (Vaidya 2006). The weight of each factor is computed using the Principal Eigen Value of squire reciprocal matrix using Analytical AHP in IDRISI software (Eastman, 1999). The Eigen value in AHP lies between 1 and 9; Where, class 1 = represents equal preference between two factors and class 9 stands for a factor extremely preferred over the other (Eastman, 2012.).

Table 2.1: Example scale for comparisons

Intensity of importance	Description
1	Equal to Moderate importance
3	The strong or essential importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2,4,6,8	Intermediate values Reciprocals Values for inverse comparison

Source: Adapted from (Saaty, 1980)

This can be done based on the relative importance of each criterion mentioned in the literature related to the study and judgment of planning experts familiar with the environment of the study area (Eastman,2012), (Ebistu &Minale, 2016). This requires the determination of factor weights in the following three steps:

(1) Filling the eigenvector value of the reciprocal matrix by comparing the priority importance of every two factors concerning the problem. Either the upper or the lower triangle filling is sufficien.t

(2) Adding every value of the column

(3) Dividing values corresponding to every factor by the column total to determine the relative weight of the factors.

Computation of consistency ratios (CR) was done after calculating consistency index (CI) and obtaining random index (RI), corresponding to the number of parameters considered, from the table. Based on the above techniques, the criteria weights for the seven parameters are determined using the ArcGIS software after they get prioritized and the consistency ratio is found to be acceptable.

Moreover, the Consistency Ratio (CR) has been estimated to check the degree of consistency in the aggregate group judgments made by experts (Forman & Selly, 2001) and CI which is the consistency index; RI is the random index - the average result of consistency index depending on the order of the matrix. Moreover, the Consistency Index

(CI) is simplified as where, λ max is the largest or principal Eigen value of the matrix, and n stands for the order of the matrix. Accordingly, the CR does not exceed1. i.e., CR of ≤0. 1 is considered as reasonable to accept (Saaty, 1997).

2.5 Overlay Computation in the Land Suitability Analysis

In raster overlay, the grid or pixel cell values of each raster data are combined using arithmetic and Boolean operators to drive a new value in a composite map. This method is often expressed as map algebra. The raster GIS provides the functional ability to perform map layers mathematically. This is particularly important for the multi-criteria overlay analysis in which various maps are combined using various mathematical functions. In this case Conditional operators such as: “and”, “or” and “if” are the base of mathematical functions that are supported in GIS.

Overlay analysis is one of the most methodologies applied in suitability analysis and optimum site selection. ESRI (2020) demonstrates Overlay analysis as a technique for applying a common scale of values to diverse and dissimilar inputs to create an integrated analysis. Suitability analysis identifies the best or most preferred locations for a specific phenomenon. Overlay analysis always requires many different criteria of a common reference system for analysis. For example, selecting a suitable site for a new residential housing development needs analyzing of such parameters as land value, proximity to existing utilities, proximity to existing social services slope, and flood frequency.

It is impossible to add a raster of land value (dollars) to a raster of proximity to utilities (Kilometers) and obtain a meaningful value. In addition, the parameters under investigation may not be equally important. It may be that the cost of land is more important in choosing a site than the distance to utility lines ((ESRI), 2020). Some values in a particular raster may be ideal for your purposes (for example, slopes of 0 to 5 degrees), while others may be good, others bad, and still others unacceptable. According to ESRI (2005), the following lists are the general steps to perform overlay analysis: Define the problem, Break the problem into sub-models, Determine significant layers, Reclassify the data within a layer, Weight the input layers, Add or combine the layers, and Analyze the results.

The three main overlay approaches available are Fuzzy Overlay, Weighted Overlay, and Weighted Sum, and each approach has different basic premises and assumptions((ESRI), 2015).

2.5.1 Weighted overlay in the land suitability analysis

In Weighted Overlay analysis, a series of tools can complement the Weighted Overlay tool to follow the general overlay analysis steps described above ((ESRI), 2015). The Weighted Overlay tool scales the input data on a defined scale (the default being 1 to 9), weights the input roasters, and adds them together. The more favorable locations for each input criterion will be re-classed to the higher values such as 9.

In the Weighted Overlay tool, the weights assigned to the input raster must equal 100 percent. The layers are multiplied by the appropriate multiplier, and for each cell, the resulting values are added together and weighted Overlay assumes that more favorable factors result in higher values in the output raster, therefore identifying these locations as being the best(Baidya et al., 2014).

The weighted overlay is a technique for applying a common measurement scale of values to diverse and dissimilar inputs to create an integrated analysis. Weighted overlay only accepts integer raster as input, such as a raster of land use or soil types. Continuous (floating point) raster must be reclassified to integer before they can be used. Generally, the values of the continuous raster are grouped into ranges, such as for slope, or Euclidean distance outputs. Each range must be assigned a single value before it can be used in the weighted overlay tool. One can either not worry about the value assigned to each range (but note the range of values the new value corresponds to), and assign weights to the cell values in the weighted overlay dialog box later, or we can assign weights at the time of reclassifying, then with the correct evaluation scale chosen, simply add the raster to the weighted overlay dialog box. The cells in the raster will already be set according to suitability (or preference, or risk, or some similarly unifying scale). The output raster can be weighed by importance and added to produce an output raster ((ESRI), 2015).

2.6 Geospatial Technologies in the Land Suitability Analysis

Geospatial technology is a multidisciplinary field that includes disciplines such as surveying, photogrammetry, remote sensing, mapping, geographic information systems (GIS), geodesy, and global navigation satellite system (GNSS) (PunCheng, 2001). As the U.S. Department of labor defined, the geospatial industry can be considered as "an information technology of practical fieldwork that acquires, manages, interprets, integrates, displays analyzes, or otherwise use data focusing on the geographic, temporal, and spatial context" (Klinkenberg, 2007). Ethnological progress relates to geospatial software and analyzes of geospatial data are some of them. The integrated approach of geospatial technologies such as GPS data, remote sensing imagery, aerial photographs, Google Earth and GIS are valuable in the development of modern Geo-information.

2.6.1 Application of GIS for land suitability analysis

According to Burroughs (1994), Geographic Information Systems (GIS) is a powerful tool for collecting, storing, retrieving, transforming, and displaying spatial data from the real world. It is the most useful technique to investigate multiple geospatial data with precision and higher flexibility in land suitability analysis (Mokarram & Aminzadeh, 2010). According to Foote and Lynch (1996), the ultimate aim of GIS is to provide support for the spatial decisions making process. Suitability analysis in a GIS context is geographic and the GIS-based analysis process is important to determine the appropriateness of a given area for a particular use.

Geographic information systems (GIS) have emerged as useful computer-based tools for spatial analysis, description, and manipulation. it is now accepted widely as a valuable tool for managing, manipulating, measuring and analyzing, and displaying large volumes of diverse data pertinent to many local and regional planning activities and its use in environmental planning is rapidly increasing (Bualhamam, 2009).

Recently, Use of GIS in agriculture has increased because of misuse of resources like land, water, etc. GIS is the principal technology used to integrate spatial data coming from various sources in a computer. GIS techniques deal with the management of spatial information of soil properties, cropping systems, pest infestations, and weather conditions. This is primarily an intermediate step because it combines the data collected at different times based on sampling regimes, to develop the subsequent decision technologies such as process models and expert systems (Robert *et al.*, 2009). GIS functionality can play a major role in spatial decision-making GIS is the tool for input, storage and retrieval, manipulation and analysis, and output of spatial data (Marble et al. 1984). GIS functionality can play a major role in spatial decision-making. The necessary effort is involved in information collection for the suitability analysis for crop production.

2.6.2 Application of remote sensing in land suitability analysis

Remote sensing renders the information about the various spatial factors under consideration. According to Lillisand et al. (2004), remote sensing is a technique used to derive information about the physical, chemical, and biological properties of objects without direct physical contact. 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). Land use /land cover mapping from satellite imagery of remotely sensed data is one of the advantages of remote sensing.

According to Lillisand et al., (2004), as Cited in Gemechu (2018), Image classification serves a specific goal, i.e., converting image data into thematic data. The resulting classified satellite image is comprised of a mosaic of pixels, each of which belongs to a particular theme which is essentially a thematic map of the original image. In the application context, one is reasonably interested in the 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. As far as classification of the image is considered, there are two common classification types: unsupervised and supervised classifications.

CHAPTER THREE III: MATERIALS AND METHODS

3.1 Description of the Study Area

3.1.1 Geographic location

Diga District is located in East Wollega Zone, western parts of Ethiopia in Oromia Regional State, and is about 340 km far from the national capital, Addis Ababa. Its average altitude approximately 2503 m.a.s.l. geographically, it is located between 9º 4’ 30” N latitude and 36º 18’ 00” E longitude. It covers a total area of about 58633 hectares. The administration of the woreda is divided into 22 kebeles

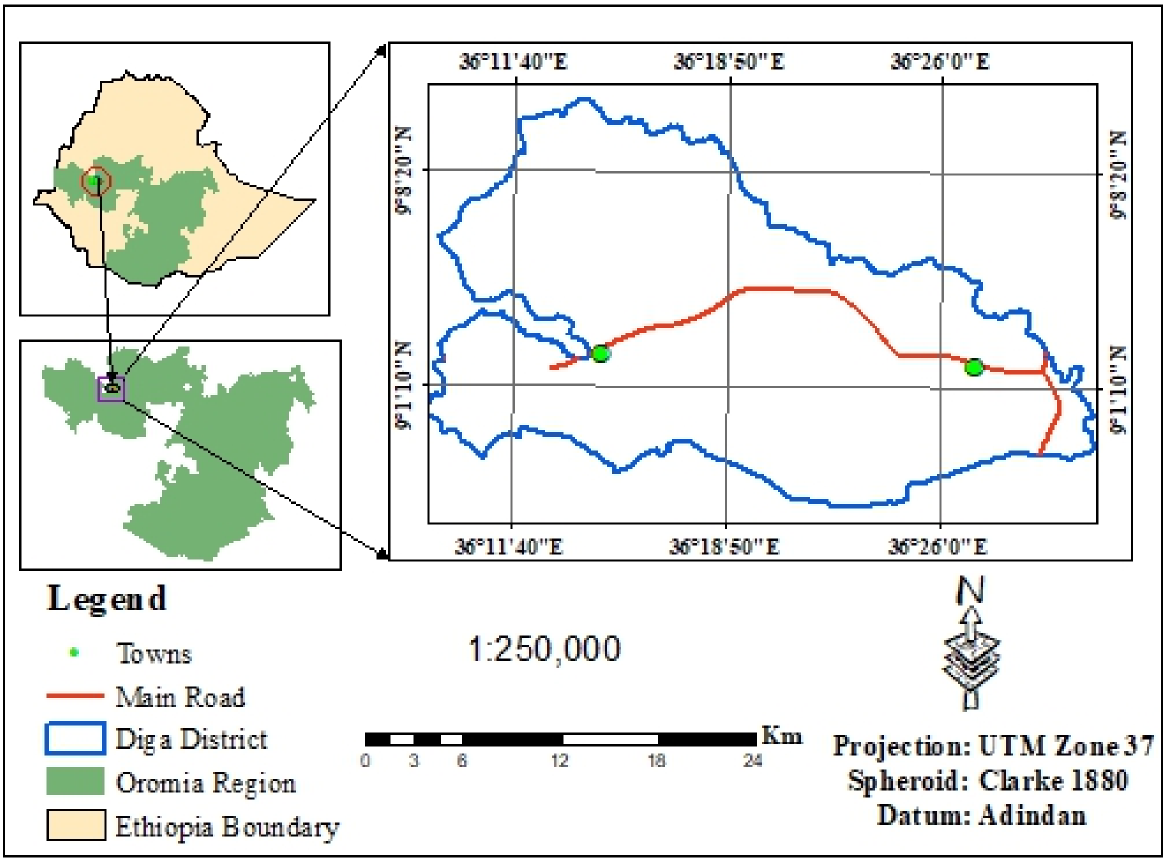

Figure 3.1: Location map of the study area

3.1.2. Physiography and drainage

The general elevation of the study area ranges between 1124 to 2342 meters above sea level. Diga District is found in the lower part of the Didessa basin.

The topography is undulating from a plateau in the western, south western, and north western parts of the area. However, western parts of the study area are characterized by gentle and flat land areas.

3.1.3 Slope

The slope of the study area was calculated from DEM (30*30m resolution) used in the ArcGIS environment as a thematic map. Finally, slopes were reclassified and calculated in the GIS environment. Finally, slopes were reclassified and calculated in the GIS environment. Accordingly, the District was classified in to five slope classes: 0 - 8%, 8 - 15%, 15 - 30%, 30 - 50% and > 50%

3.1.4 Climate

Agricultural activities and land use patterns are closely related to the temporal and spatial patterns of climatic elements, and the success of land use strongly depends on the 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 patterns. Therefore, in the land suitability evaluation climatic variables should be considered as a diagnostic land quality/ or land characteristic (Dula 2010).

According to the study area maximum and minimum annual temperature, and mean monthly rainfall of the study area was extracted from average of the three stations (Nekemte, Gimbi and Arjo) using the interpolation method from the spatial analysis tool of the arc toolbox since the area is located between the three stations shown in (figure 3.2), and 3.3 below. The average rainfall of Diga District is about 337.36ml per year (Figure. 3.2). The minimum mean monthly temperature of the woreda ranges between 12.7°C to 13.4°C, while the maximum mean monthly temperature varies between 24.0°C to 25.1°C, throughout the year in the last ten years ago.

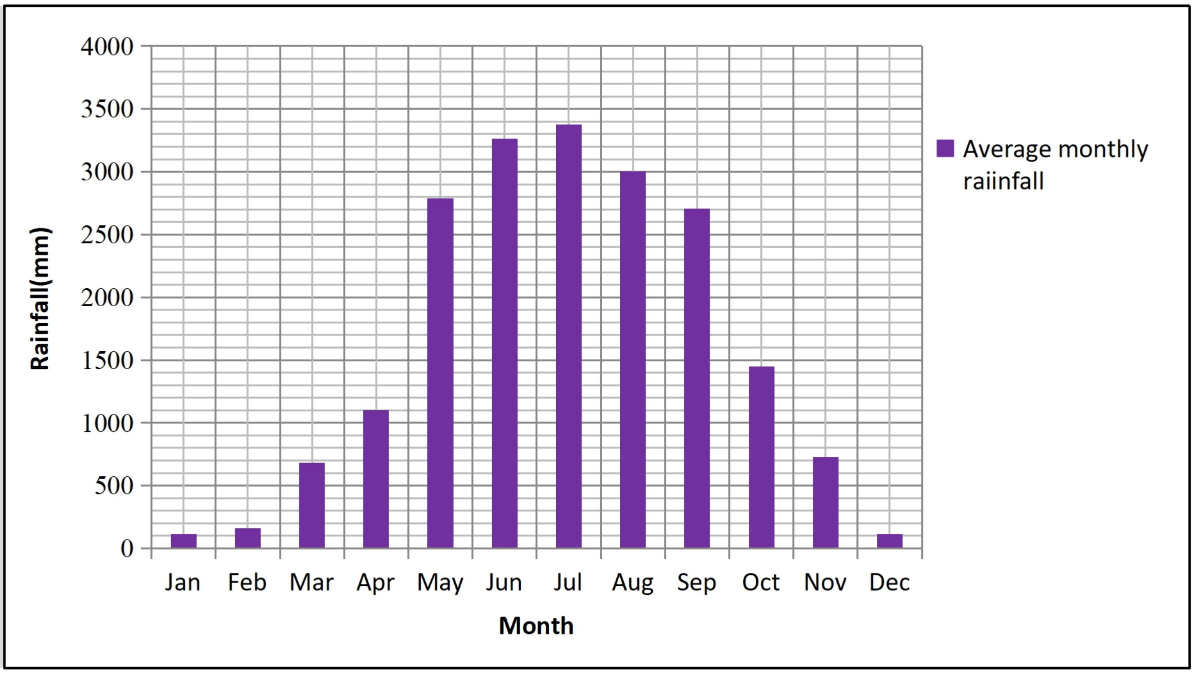

Figure 3.2: Mean Monthly Rainfall (mm) of the study area (2009–2018)

(Source: National Meteorological Agency)

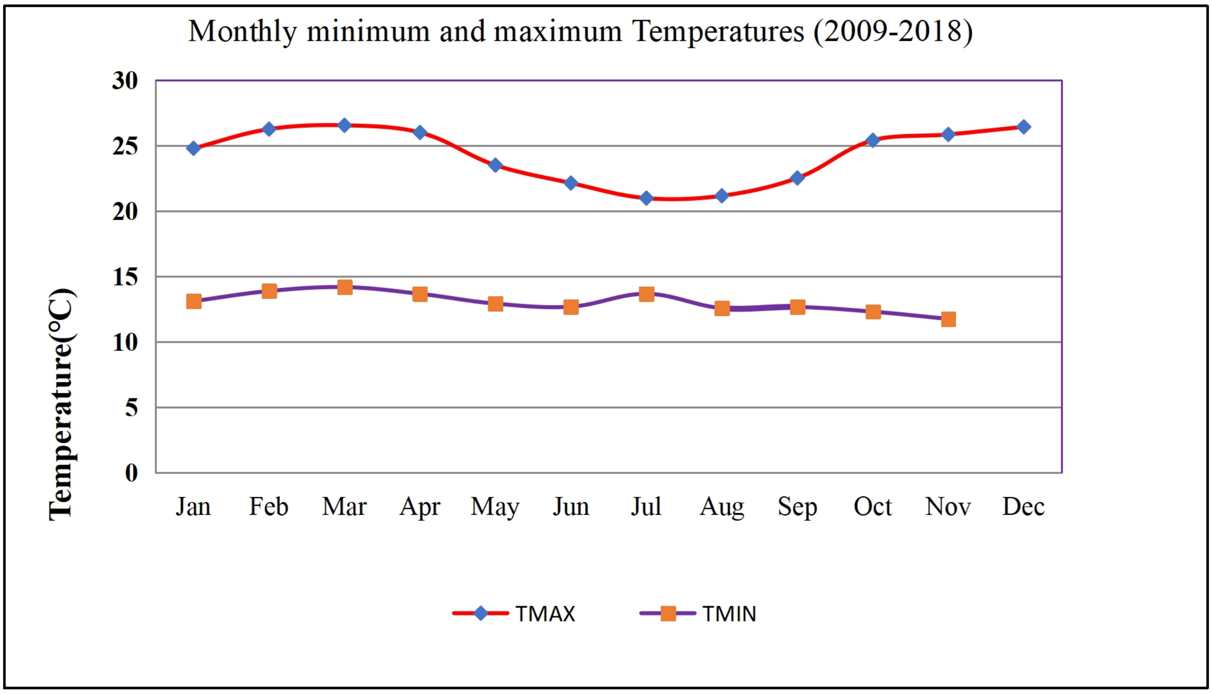

Figure 3.3: Monthly minimum and maximum temperatures (°C) of (2009 – 2018)

(Source: National Meteorological Agency)

3.1.5 Prop production of the study area

The study area is covered with a variety of crops and natural vegetation. The major crops cultivated in the study area are Teff, Wheat, and Barley. These major crops are mainly produced for consumption and market purposes.

Table 3.1: Major Crop production of four years hectare/quintal in the study area.

	Cropping Years							
	2016/2017		2017/2018		2018/2019		2019/2020	
Major crops	Land (ha)	Yield (Q/Ha)	Land (ha)	Yield (Q/Ha)	Land (ha)	Yield (Q/Ha)	Land (ha)	Yield(Q/Ha)
Teff	1867	22652	1682	18572	1753	17853	1740	21230
Wheat	938	1740	794	15248	1066	21778	950	21778
Barley	290.5	6972	329	7567	328	6944	320	6818
Total	3100.5	31539	2815	41740	3164	46956	3080	51848

Source: Diga District Agricultural and Natural Resource Office, (2020)

3.1.6 Soil

The five soilforming factors are namely topography; parent materials, climate(temperature and rainfall), biological activities (flora and fauna), and time determine the types of soil that are formed in a particular area. As a result, soil can vary from place to place. Accordingly, the types of major soil found in the study area were classified into five major soil types namely Acrisols, Cambisols, Lixisols, Nitisols, and Vertisols (OWWDE, 2014).

3.2 Data Collection

Collecting accurate and reliable data is the most determinant factor for any research as it determines the quality of the research. In this particular research, the first steps were to identify the environmental factors to be considered for siting land suitability followed by a setting criteria based on the international rules. Accordingly, the necessary data were collected from different respective sources. Primary data collection emphasis had been placed on field surveys using open-ended questionnaires, and interviews with local expertise. Whereas secondary data collections included reviewed literature and policy analysis on agricultural land suitability analysis for crop production and gathered spatial data from different institutes which were existed in a different format**.**

3.2.1 Delineation of Factors for Land Suitability from Different Sources

The factors in this study include; explained, Soil depth, soil texture, drainage, pH, LULC, elevation, slope, rainfall, temperature, and roads are factors to were delineated and restrict an area. These factors are explained as follows.

Soil depth: In this study, soil texture was acquired from Oromia water work design and supervisionenterprise shapefile of the study area. Depth of soil profile from parent material to layer obstacles for roots. It is one of the basic criteria used in classification.

Soil texture: In this study, soil texture was acquired from Oromia water work design and supervision enterprise shapefile of the study area. Soil texture is an important soil characteristic that influences storm water infiltration rates. The textural class of soil is determined by the percentage of sand, silt, and clay. Soil texture determines the rate at which water drains through saturated soil; water moves more freely through sandy soils than it does through clay soils, and also influences how much water is available to the plant; clay soils have a greater water holding capacity than sandy soils.

Soil drainage: In this study, soil texture was acquired from Oromia water work design and supervision enterprise shapefile of the study area. Is important for plant health at least as important as pruning, mulching, and fertilizing.

Soil pH: In this study, soil texture was acquired from Oromia water work design and supervision enterprise shapefile of the study area.

Land Use/Land Cover: Land use land cover of the study area was acquired from USGS sentinel-2 of 2020 and it has its own influence on land suitability analysis for agricultural crop production.

Elevation: is one of agricultural land suitability analysis influencing factor for crop production and it is acquired for this study from DEM (Digital Elevation Model) of 15m spatial resolution and plays an important role for agricultural activities in general, and specifically for crop production.

Slope: Slope of a given area plays a crucial role for agricultural process in general, and specifically for selected crop production.

Climate: Rainfall and temperature are the major climatic factors that influence agricultural processes and they were obtained from Ethiopia National Meteorology Agency which is located in Addis Ababa for this research work.

Road: Accessibility of road to agricultural land is important for raw material transportation as well as to get good market for crops produced and this road shapefile data was extracted from oromia road infrastructure.

3.2.2 Data types and sources

Table 3 shows the list of data and their sources along with their resolution and year of acquisition and the format of the data in detail (Table 3).

Table 3.2: List of Data sets and data source

Data Required	Format	Data Source	Resolution	year
Sentinel-2	Raster(.tiff)	USGS	10*10m	2020
Digital Elevation Model (DEM)	Raster(.tiff)	Geospatial information institute (GII)	20m*20m	-
Road		Google Earth pro		
Soil data	Shape file	Oromia Water Work Enterprise and Supervision		2014
Climate data	text	National Meteorology Agency Addis Ababa		2009-2018
Woredas	Shape file	CSA		

3.2.3 Software's and materials used

ArcGIS Desktop is a widely used software for this study. The three components of ArcGIS desktop-like Arc Map, Arc Catalog, and Arc Toolbox have been used to create the geodatabase, editing, data management and storage, geo-referencing data from different sources, performing spatial multi-criteria analysis, generating criteria maps, and assigning weight for each criterion, overlaying, analysis and visualization of output data (Asefa & Mindahun, 2020).

In this study, ERDAS imagine 2015 was also the software used to process Sentinel-2 and prepare land use land cover of the study area which then became the input for analysis in the GIS environment. Furthermore, IDRISI is a comprehensive geographic analysis and image processing system that has been developed by Clark Labs for Cartographic Technology and Geographic Analysis at Clark University, South Carolina, USA. This software has been used to perform multicriteria decision analysis using the built-in decision support module.

Table 3.3: Lists of software and instrument used

No	Software and materials used	Version	Purpose
2	ERDAS Imagine	15	For processing and analyzing satellite image
3	IDRISI Selva	32	To assign a weight for each factor for analysis
4	Google Earth Pro	-	Used for digitization, visual image, and interpretation.
5	Microsoft Word and Excel	2016	Integrate attribute data and composite final thesis
6	GERMIN handheld GPS	60	To collect coordinate data from field
7	IBM SPSS statistics	22	For tabulations and graphical representations

3.3 Data Preparation for Analysis

3.3.1 Creating geodatabase

A geodatabase is the physical storage of geographic information (spatial, aspatial, metadata, and relationship) inside a relational database management system. It contains layers vector data representing features and raster data representing images and grid surfaces. The purpose of geodatabase is to make the features in GIS datasets and define a relationship among features that were displayed on maps as layers. Each layer represents particular types of features that have been used for spatial analysis. In this study, a common personal geodatabase was built using Universal Transverse Mercator projection system world geodetic system 1984 to store, query, and manage both spatial and non-spatial data that could be used for the final analysis to achieve the proposed objectives.

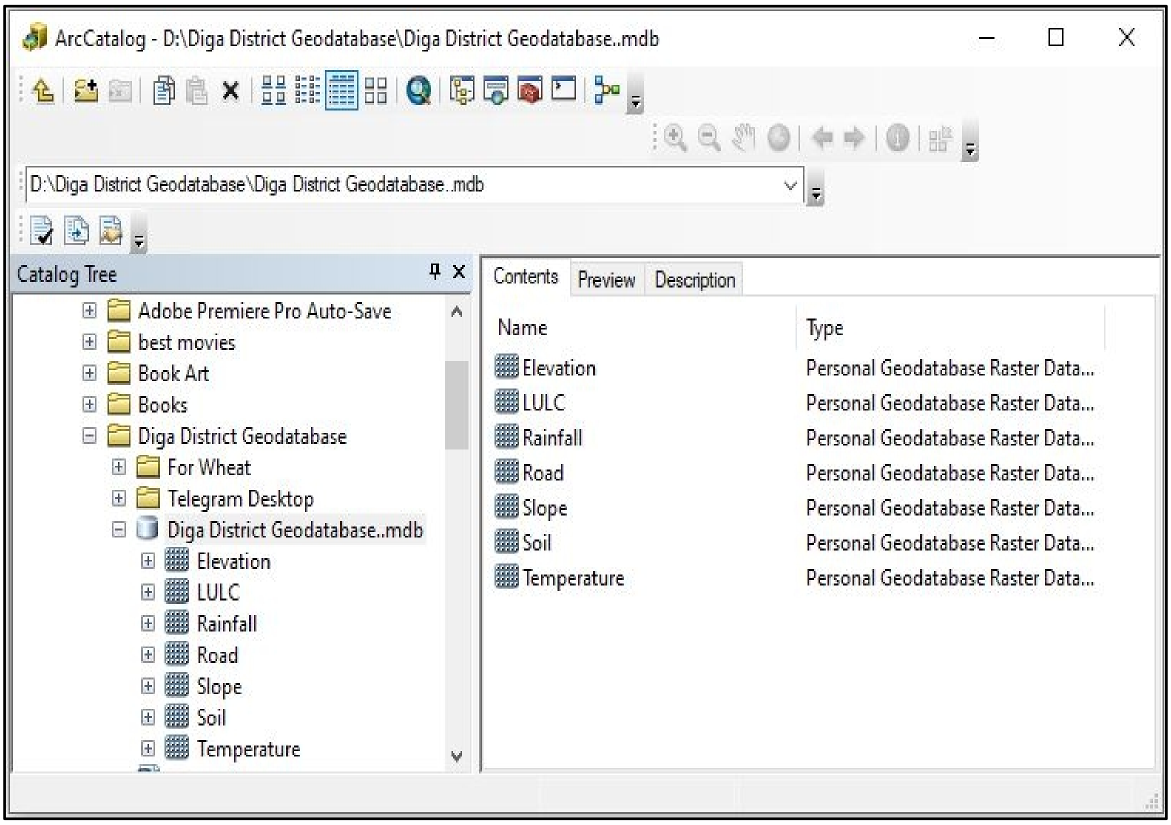

Figure 3.4: Created Geo-database for the study area for the analysis.

3.3.2 Layer extraction (digitization)

Digitization is the process where features on a map or image are converted into digital format for use by a GIS. This can be done by either manual or automation techniques. In this study, onscreen digitization was performed to extract layers that represent criteria for decision making.

3.4 Methods of Data Analysis

The data analysis process of the land suitability analysis for agricultural areas involves numerous factors with complicated correlations. Therefore, the Geospatial technique with multi-criteria spatial analysis techniques and The Analytic Hierarchy Process (AHP) approach has been used to address the proposed study. The methodological procedure of land suitability analysis identification of optimum sites for agricultural areas was well presented in the following Figure 6.

3.4.1 Reclassifying (re-scaling values of a set of rasters)

The Reclass tools are used to allow the researcher to reclassify or change input cell values to alternative values. In this study, all thematic layers were converted to raster, and then raster reclassification using reclass tool from Arc Toolbox of ArcGIS 10.8 was adopted to reclassify the old value to the new one. The reason behind reclassifying raster data is to replace new values with the old ones based on new information, group certain values and reclassify values to a common scale of measurement. After the data were collected from various sources, the data were analyzed by using different software like ArcGIS, IDRISI Selva, and ERDAS IMAGINE.

3.5 Crop Requirements

Crops have specific 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 to as land use requirements of land use type 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. Accordingly, the following major crop requirements related to the following conditions are selected in the present crop environmental requirements characterization for evaluation:

- Climate (rainfall and temperature).
- Rooting condition (soil depth and texture).
- Wetness and Oxygen availability (as expressed by drainage).
- Natural fertility status (soil pH).
- Slope (risk of erosion referring).

Following the approach of FAO (1984), Landon (1991), and the guidelines of Syset et al., (1993), Crop requirements in this study, are established Adaptation has been made to the grouping of requirements according to FAO (1984) guidelines. Reviews are consolidated through consultations with an experienced agronomist, and soil science expert. The selected crops that were evaluated for this specific study include teff, wheat, and barley.

Table 3.4: Major crop environmental requirements at different suitability class

Crops	Factor	Range of Suitability			
		Highly suitable (S1)	Moderately Suitable (S2)	Marginally Suitable (S3)	Not Suitable (N1)
Teff	Soil depth(cm)	>50	30-50	20-30	<10
	Soil Textures(class)	Si,SiC,C	SiC	SiL,CL,SC	L,SCL,S,LS,S
	Drainage	M	P,W	VP	SE
	pH	5.5-7.5	5.2-5.5 and 7.5-7.8	5.0-5.2 and 7.5-8.0	
	LULU	FL	-	Bshl	F, Res, and SW
	Elevation	1600-2200	1000-1600 or 2200-2400	2400-2800	<1000
	Slope	0-7	7-15	15-25	>25
	Rainfall	450-550	300-450or550-800	800-1200	<2000
	Temperature	15-21	14-15OR21-22	12-14OR22-23	<11
	Road (Km)	0-2	2-4	4-7	7-10
Source	Dula, 2010. Kasa, 2012. Ibrahim,2016, Gemechu 2018, Hamere Yohannes & Teshome Soromessa 2018Agricultural Experts				
Wheat	Soil depth(cm)	>100	75-100	50-75	<50
	Soil Textures(class)	C,Si,SiC,Si L,C	L,CL,SiCL	SCL	LS,S
	Drainage	W, SE	MW	I	VP
	pH	6.0-8.0	5.2-6.0/8.0-8.3	5.0-5.2 and 8.3-8.5	<5
	LULU	FL	-	Bshl	F, Res, and SW
	Elevation	1600-2200	1000-1600,2200-2400	2400-2800	<100
	Slope	0-13	13-25	25-40	>40
	Rainfall	450-650	350-450,650-850	300-350,850-1000	<300
	Temperature	14.9-18.4	14.4-14.9,18.4-19.4	13.4-14.4,19.4-20.8	<13,
	Road (Km)	0-2	2-4	4-7	7-10
Source	Dula, 2010. Kasa, 2012. Ibrahim,2016, Gemechu 2018, Hamere Yohannes & Teshome Soromessa,2018 Agricultural Experts				
Bearly	Soil depth(cm)	>50	30-50	20-30	10-20
	Soil Textures(class)	Si,,SiC,C	SiC	SiL,CL,SC	L,SCL,S,LS,SL
	Drainage	W, MW	I	E	VP
	pH	5.5-7.5	5.2-5.5 and7.5-7.8	5.0-5.2 and 7.8-8.0	<4.5 and >8.5
	LULU	FL	-	Bshl	F, Res, and Sw
	Elevation	2200-2323	2000-2200	1800-2000	<1800
	Slope	0-7	7-15	15-25	>25
	Rainfall	900-1100	1100-1300	1300-1500	>1500
	Temperature	12-18	18-24	24-28	>28
	Road (Km)	0-2	2-4	4-7	7-10
Source	Dula, 2010. Kasa, 2012. Ibrahim,2016, Gemechu 2018, Hamere Yohannes & Teshome Soromessa,2018Agricultural Experts				

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

3.6 MultiCriteria Decision Making (MCDM)

Analytic Hierarchy Process (AHP) is a widely used method in MCDM and was introduced by Saaty (1980). AHP is a decision support tool, which can be used to solve complex decision problems. It uses a multilevel hierarchical structure of objectives, criteria, sub-criteria, and alternatives use the fundamental scale of absolute numbers to express individual preferences or judgment below this scale consists of nine points (Table 6).

In general, nine objects are the most, which an individual can simultaneously compare and consistently rank. The score of differential scoring assumes that the row criterion is of equal or greater importance than the column criterion. The reciprocal values (1/3, 1/5, 1/7, 1/9) have been used where the row criterion is less important than the column criterion. To ensure the credibility of the relative significance used, AHP also provides measures to determine the inconsistency of judgments mathematically. Based on the properties of reciprocal matrices, the consistency ratio (CR) can be calculated. CR< 0.1indicates that level of consistency in the pair-wise comparison is acceptable. Saaty (1980), Suggested that if CR is smaller than 0.1, then the degree of consistency is fairly acceptable (Table 3.5). But if it is larger than 0.1, then there are inconsistencies in the evaluation process, and the AHP method may not yield meaningful results (Chu & Liu, 2002)).

Table 3.5: The preference scale for pairwise comparison

Intensity of importance	Definition
1	Equal importance: two activities contribute equally to the objective.
3	Moderate importance: Experience and judgment slightly favoring one activity over another.
5	Essential or strong importance: Experience and judgments strongly favor one activity over another
7	Very strong / demonstrated importance: An activity is strongly favored and its dominance is demonstrated in practice
9	Extreme importance: The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	intermediate values between the two adjacent judgments when the above numbers compromise are needed
1/3,1/5,1/7,1/9	Reciprocal values of the previous appreciation

Source: Adopted from Saaty (1980)

3.6.1 Criterion rating

According to FAO, (1985; 1993), as cited in Gemechu (2018), Land Suitability analysis for crops needs the consideration of different environmental factors/ criteria. In this particular land suitability analysis for selected major crops production, the criteria are mainly related to topography (altitude and slope), climate (rainfall and temperature), soil (soil depth, soil pH, soil texture, and soil drainage), land use/land cover and road. These are the most important requirements needed for all crops. A compilation of the crop requirements that were considered in the evaluation was made and factor ratings for crops are decided. Factor ratings are sets of values that indicate how well each factor 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.

3.6.2 Criterion standardization

The evaluation choices could be expressed according to different scales.The large value of the multi-criteria method needs that all criteria are expressed on the same scale. Standardization of criteria allows the re-scaling of evaluation dimensions between 0 and 1 where 0 indicates not suitable and value 1 indicates suitable. Following the processing and preparation of data, the factors were organized in the class of fit to their weight of importance. In the AHP approach, the criteria are standardized, by using pair-wise comparison methods. The standardization of factors or criteria brought about in ratings is based on literature and agricultural experts.

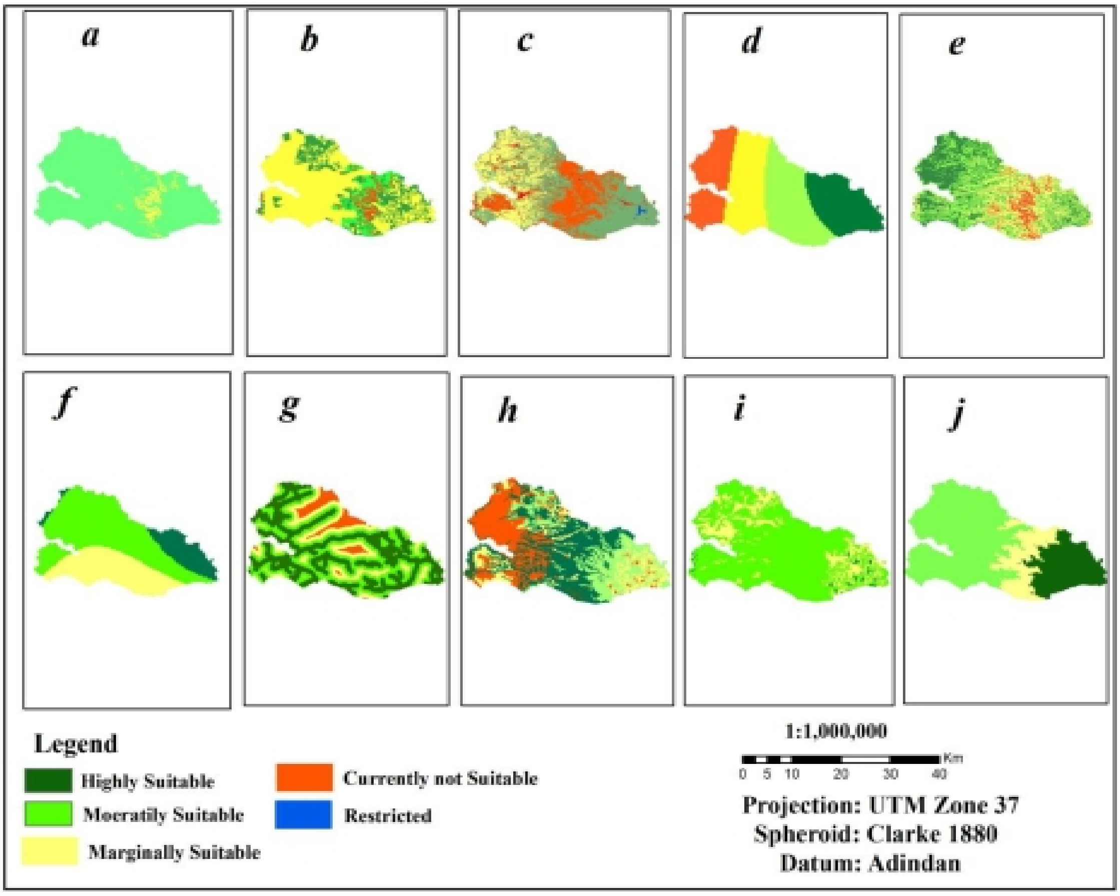

Figure 3.5: Standardized factors map for teff suitability analysis

(a= depth b= texture c= lulc d= temperature e= slope f= rainfall g= road h= pH i= drainage j= elevation

3.6.3 Assigning criterion weights for each factor

One of the components of GISbased MCE methodology is assigning criteria weights for each factor map. The purpose of weighting in land suitability analysis for the agricultural process is to express the importance or preference of each factor relative to another factor's effect on land suitability analysis. Several criterion-weighting procedures based on the judgments of decision-makers have been proposed in the multi-criteria decision literature. Accordingly, one of the most promising is pair-wise comparisons developed in the context of a decision-making process is known as the AHP. In MCE using a weighted linear combination, it is necessary that the sum of the weights to 1. In developing a pairwise comparison matrix, all the factors are compared of their standing related to the declared objective. In developing weights, an individual or group compares every possible pairing and enters the evaluation into a pair-wise comparison matrix (Eastman, 2006). Since the matrix is symmetric, only the lower triangle is necessary to be filled in. The remaining cells are then simply the reciprocals of the lower triangle.

3.6.4 Aggregating the criterion weights and standardized criterion maps

According to Malczewski, (2003), 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 data sets. These data are manipulated and analyzed to obtain useful information for a particular application such as land suitability analysis. Once the criteria maps are developed, the aggregation stage is undertaken to combine the information from the various factors. In the context of GIS, three decision rules i.e., Boolean overlay, weighted overlay and ordered weighted averaging are common for MCE (Malczewski, 2000; Jiang and Eastman, 2000; Malczewski, 2003). The type of aggregation used is a weighted overlay. 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 land-use type and vector overlay analysis for deriving a composite suitable land allocation map.

3.6.5 Weighted overlay analysis

The Weighted overlay approach is the most commonly used GISbased decision rules technique ((ESRI), 2015). One of its most common applications is to solve landuse suitability analysis and site selection, the decisionmaker determines and assigns the weights of relative importance directly to each attribute map layer Tesfaye (2017). The total score for each alternative under consideration is the product of the importance weight assigned to each attribute multiplied by the scaled value given for that attribute to the alternative and then summing the product's overall attributes. The scores are calculated for all of the alternatives. The one chosen is that with the highest overall score. The method can be executed using any GIS system with overlay capabilities.

The use of this method allows the evaluation criterion map layers to be combined to determine the resulting composite map layer. Using the weighted linear combination, factors are combined by first applying a weight to each factor, followed by a summation of the results to yield a suitability map. The GIS overlay process can be used to combine the factors in the form of a Weighting Overlay process and the result is then summed up producing a suitability map as shown by the formula (Al-shalabi et al., 2006).

3.7 Conceptual Framework and Flowchart of the Analysis

In this study, there were four important steps to analyze land suitability maps for agricultural production. These are: (1) determining influencing parameters to be used in the analysis for decision making, (2) assigning factor priority, weight, and class weight (ranking) to the parameters involved, (3) Developing weighted overlay analysis and determine overall suitability of the entire study area and (4) Validate the suitability by comparing with the existing land use of the study area to further restrict the suitability. The details of the conceptual framework and each processing step are shown in Figure 6 below.

MCDA technique is applied to incorporate decision maker's judgment and preferences using the AHP method. This method includes the selection of the criteria for the spatial Multi-Criteria Evaluation (SMCE) technique for the land suitability analysis for agricultural production. The final step involved in AHP is the aggregation of the relative weights obtained at each level of the hierarchy to calculate the suitability index. ArcGIS is used to combine the spatial data with the suitability index so that a continuous land suitability map is generated. The output is a land suitability map for agricultural production.

In general, Figure 3.6 summarizes the overall methods, techniques, and approaches used to carry out this thesis, to analyze agricultural land and identify suitable areas for future agricultural activities in Diga District.

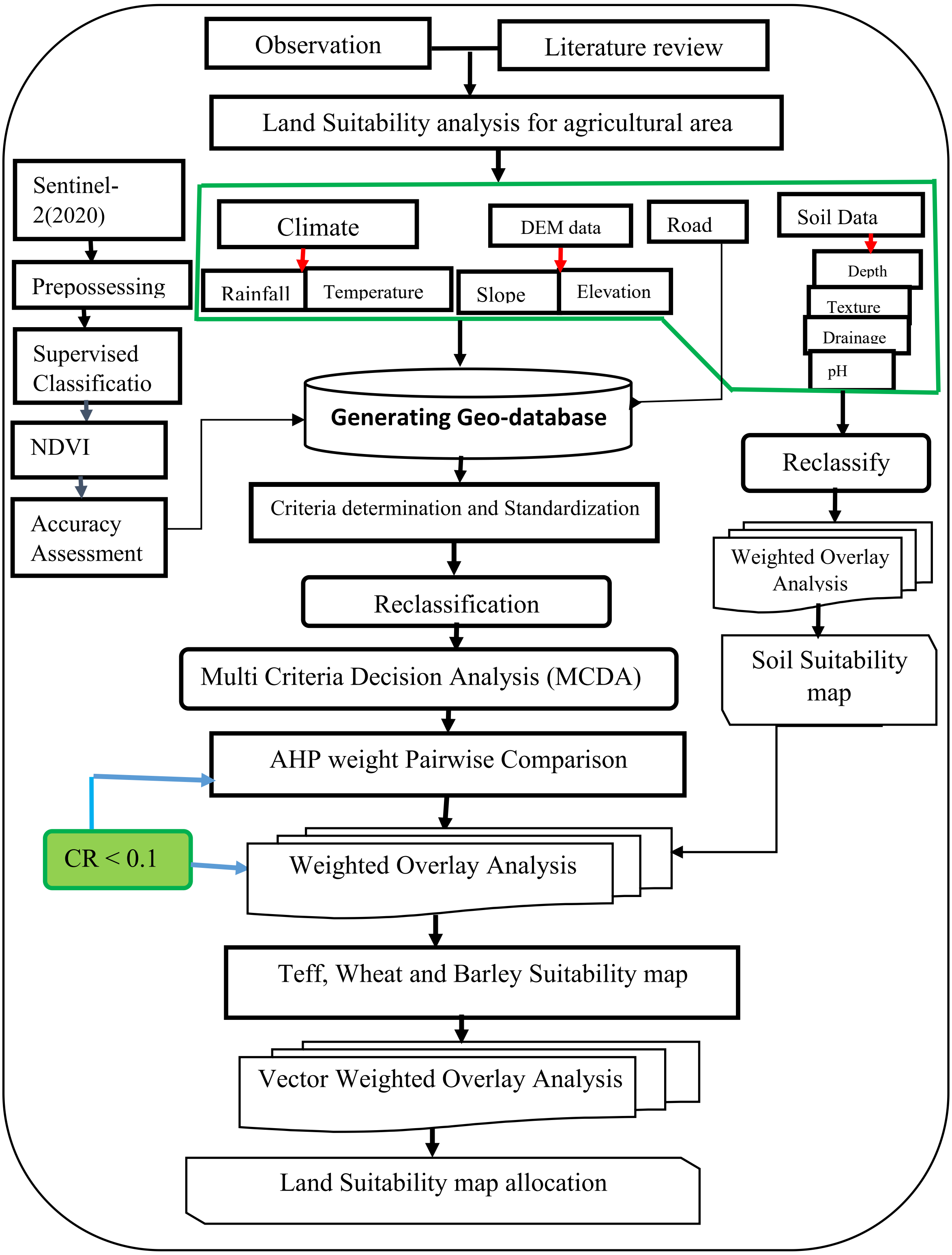

Figure 3.6: Technological Scheme

CHAPTER FOUR FOUR: RESULTS AND DISCUSSIONS

4.1. Influencing Criteria for Suitability of Crops Production Analysis

By synthesizing literature reviews, expert opinions, and available data, a wide variety of criteria (factors) have been selected to achieve the objectives of this study.

According to FAO (1987) as cited by Henok (2010), Physical and chemical factors of the land as well as climate are the major factors that determine crop suitability of a given land. However, in this paper, only physical land properties were evaluated to analyze the land suitability of the study area for agricultural crop production. The physical land properties of the study area, which were evaluated, include soil depth, soil texture, drainage, pH, slope, elevation, land use land cover, and road. The climate (Temperature and Rainfall) of the study area was also used for cropland suitability analysis. The factors were selected to evaluate and identify the most suitable areas for future agricultural crop production activities to satisfy the demand for farmers' livelihood.

4.1.1. Determined weight values for influencing criteria in the AHP method

The prioritization of the suitability criteria and the computation of influencing weights were the necessary steps in site suitability analysis. Therefore, the influencing weight of all criteria was generated using 9 class values applied in each factor based on their relative importance (Satty, 1980). The attributes of all factors were standardized by transforming the original values to a suitability value using a suitability scale from 1 - 9 (Saaty T., 1997). The eigenvector weights of ten factors are computed using decision support wizard IDRISI 32 software (Eastman,1995) with the supports of expert judgments (Chandio et al, 2014). Figure 7 and Table 7 show the input value of pair-wise comparison using a nine-point continuous rating scale and the derived eigenvector of all criteria.

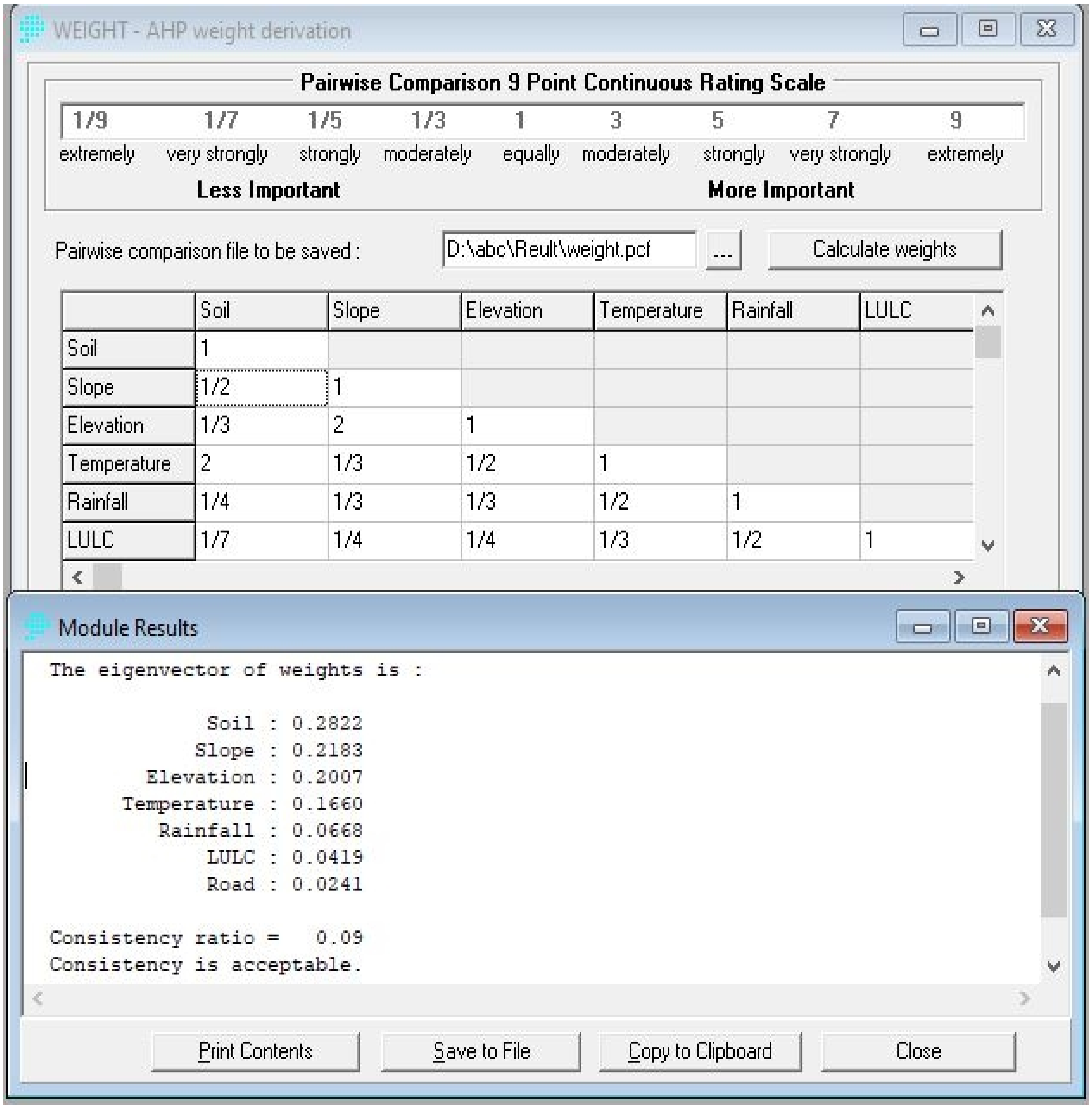

Figure 4.1: AHP Weight derivation method map for teff crop production for the study area

Based on this AHP weight derivation module, the following eigenvectors of weights for all factors considered for agricultural land site selection are generated (Table 4.1).

Table 4.1: Factors and their eigenvectors weights for agricultural land sitting in Idrisi software.

Factor	Soil	Slope	Elevation	Temperature	Rainfall	LULU	Road
Soil	1						
Slope	1/2	1					
Elevation	1/3	2	1				
Temperature	2	1/3	1/2	1			
Rainfall	1/5	1/3	1/3	1/2	1		
LULC	1/7	1/4	1/5	1/5	1/2	1	
Road	1/9	1/7	1/7	1/7	1/5	1/3	1

Consistency ratio (Cr) = 0.09

Consistency is acceptable.

With the above similar procedure and methods, also the same all factor, the weights for all selected major crops for analysis are generated as bellow in Table: 4.2

Table 4.2: the weighted result of major crops obtained from AHP weight derivation.

	Teff		Wheat		Barley	
Factors	Weight	Weight (%)	Weight	Weight (%)	Weight	Weight (%)
Soil	0.2822	28.22	0.3274	32.74	0.3158	31.58
Slope	0.2183	21.83	0.2341	23.41	0.2591	25.91
Elevation	0.2007	20.07	0.1777	17.77	0.1840	18.40
Temperature	0.1660	16.60	0.1166	11.66	0.1214	12.14
Rainfall	0.0668	6.68	0.0768	7.68	0.0615	6.15
LULC	0.0419	4.19	0.0419	4.19	0.0361	3.61
Road	0.0241	2.41	0.0235	2.35	0.0220	2.20
Total	1.00	100.00	1.00	100.00	1.00	100.00
CR	0.09	9	0.08	8	0.07	7

4.1.2 Ranking the suitability of influencing criteria

The FAO classification model for suitability is widely used in the studies of land suitability analysis (Qiang and Ping, 2000; Zhang, 2003; Aburas et al., 2017). So, this study classifies suitability levels into five classes as permanently suitable, not suitable, marginally suitable, moderately suitable, and highly suitable. According to established criteria and ranked on a simple five-point scale from 0 to 4. Criteria Ranking Scores 0 = unacceptable (undesirable/least-cost-effective), 1= poor, 2 = fair,3 = good,4 = excellent (most desirable/most cost-effective) (ICEFP, 2004)

4.2 Suitability Evaluations for Agricultural Crop Production in Diga District

4.2.1 Soil type

In the FAO World Reference Base for Soil Resources, Cambisol is a soil with a beginning of soil formation. The horizon differentiation is weak. This is evident from weak, mostly brownish discoloration and/or structure formation in the soil profile. Cambisols are developed in medium and fine-textured materials derived from a wide range of rocks, mostly in alluvial, colluvial, and aeolian deposits. Most of these soils make good agricultural land and are intensively used. The soil characteristics were categorized according to FAO; (1976) land suitability structured into land suitability order, land suitability class, land suitability subclass, and land suitability units. Deep and 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 (Henok, 2010).

A soil characteristic is one of the most important factors in agricultural land use assessment. In this study soil depth, texture, drainage, and PH are taken as indicators to assess the general soil suitability for agriculture. The physical and chemical properties of soils are obtained from (OWWDSE, 2014) at the scale of 1:50,000 are used for interpretation and analysis.

Table 4.3: Reclassified major soil of the study area

Major Soil groups	Area in (ha)	Area in (%)
Acrisols	25941.64	44.24
Lixisols	7523.68	12.83
Nitisols	3923.74	6.69
Cambisols	17494.38	29.84
Vertisols	3749.81	6.40
Total	58633.00	100.00

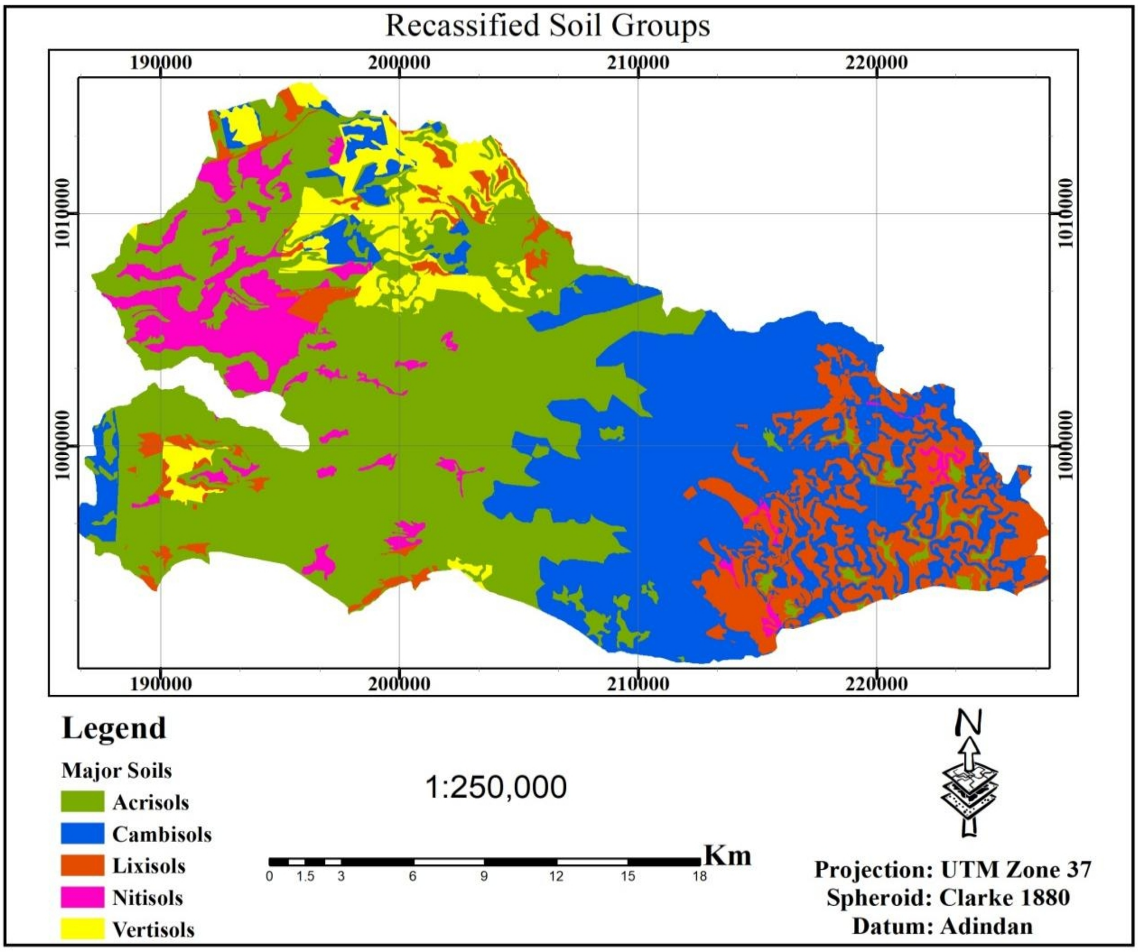

Figure 4.2: Reclassified major soil group map of the study area

4.2.2 Suitability analysis for soil of the study area

A soil depth variation from place to place determines the growth of plants and also affects the growth of plant roots. The thickness of the soil materials, which give structural support, nutrients, and water for crops, is referred to as soil depth (Henok, 2010). The soil depth of the study area was classified into four classes. Soil series were bedrock between 10 and 50 centimeters from the surface were described as shallow. Bedrock between 50 and 100 centimeters was described as moderately deep. 100 - 150 were deep and if it is greater than 150 cm it was very deep.

Soil texture is related to other physical properties and chemical properties of soil; generally, influences physical soil fertility. The soil texture of the study area was evaluated and classified into loam, clay, clay loam, and silt clay loam whereas loam and clay texture is the dominating in area coverage.

Evaluation of the soil drainage requirement is a critical element in selecting land for crop production because it permits normal plant growth. Adequate soil drainage is essential to ensure sustained productivity and to allow efficiency in farming operations. Soil permeability properties of the study area were classified as well-drained, moderately well-drained, poorly drained, very poorly drained, and imperfectly drained.

Tadesse, (2010) stated that the pH is a measure of soil acidity or alkalinity that indicates the activity of the hydrogen ion (H^+) and hydroxyl ion (OH) in a water solution. Both these ions have high chemical activity. Their chemical activity is lowest when the solution or soil is close to a neutral pH of 7.0. The pH characterizes the chemical environment of the soil and may be used as a guide to the suitability of soils for various pasture and crop species. Acidification is most rapid in soils derived from minerals low in cations and in coarse soils that can easily be leached. The soil pH significantly affects the availability of most of the chemical elements important to plants and microbes; at low pH (<5) there is a tendency for toxicity of elements. The availability of nitrogen, sulfur, and molybdenum is somewhat restricted at low pH, whereas that of phosphorous is best at intermediate pH level that is from 5 to 8.5 of pH level. In this study, the two levels of soil pH were generated and classified as follows.

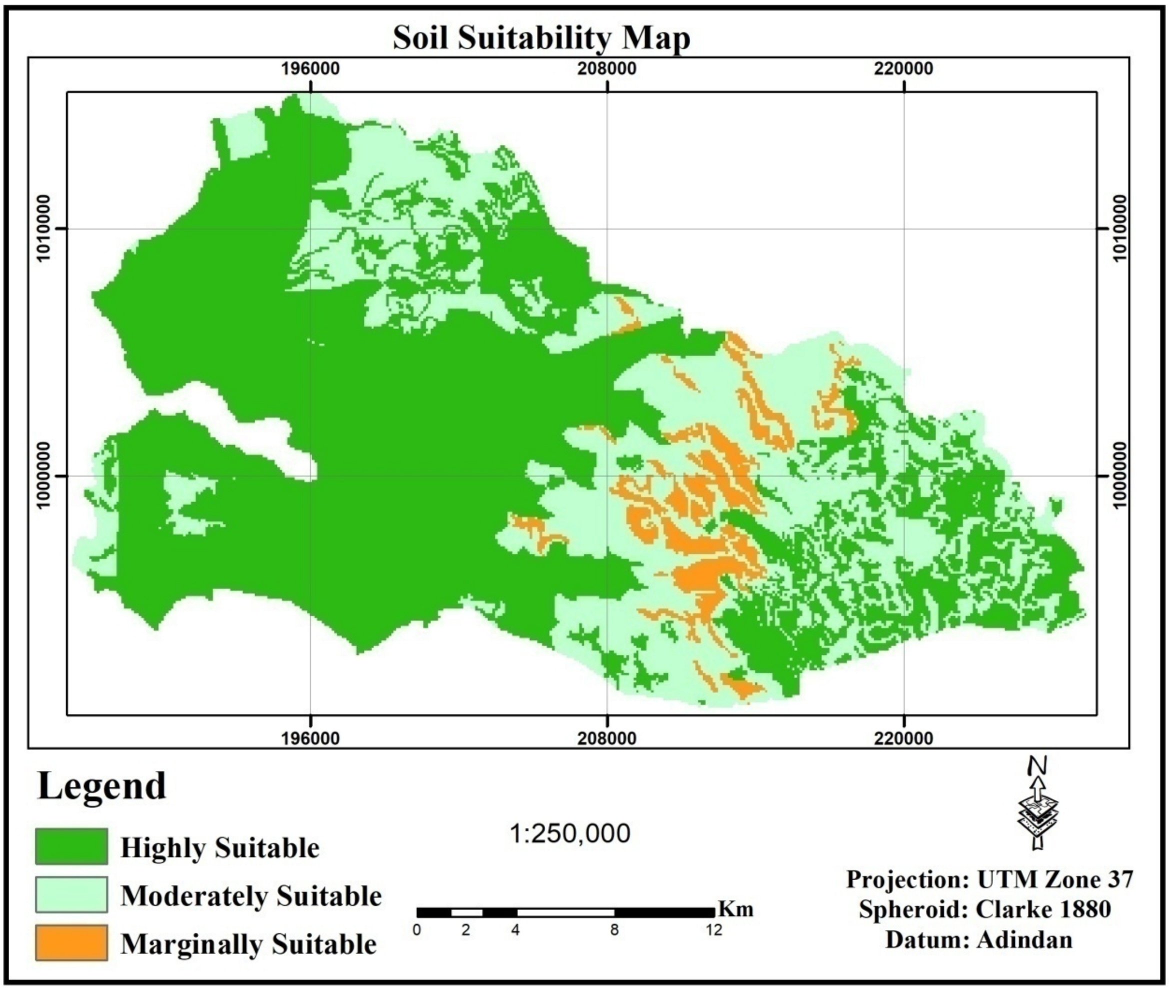

Figure 4.3: Soil suitability map of the study area

4.2.3 Suitability Analysis for Slope

The slope of the study area was calculated from DEM (30*30m resolution) and used in the ArcGIS8 environment as a thematic map. For slope calculation, 3dem, Global mapper20 were used to derive DEM from STRM and generate contour while 3dem was used to fill missing STRM values. Generally, slopes were calculated and reclassified in a GIS environment. Topographic maps (1:50,000) were used as auxiliary data for such calculations. Accordingly, the area was classified into five (5) slope classes. Slope Suitability Class 0- 8%, 8-15%, 15-30%, 30-50%, and >50%.

Table 4.4: Slope Suitability Class and area coverage

Slope Class (%)	Area(ha)	Area (%)	Land form	Suitability Class
0-8	21810.80	37.20	Flat to undulation plain	S1
8-15	10763.58	18.36	Rolling to undulating	S2
15-30	9931.19	16.94	Hill to Rolling	S3
30-50	5489.23	9.36	Steep	N1
>50	10638.60	18.14	Very steep escarpment	N2
Total	58633.39	100.00		

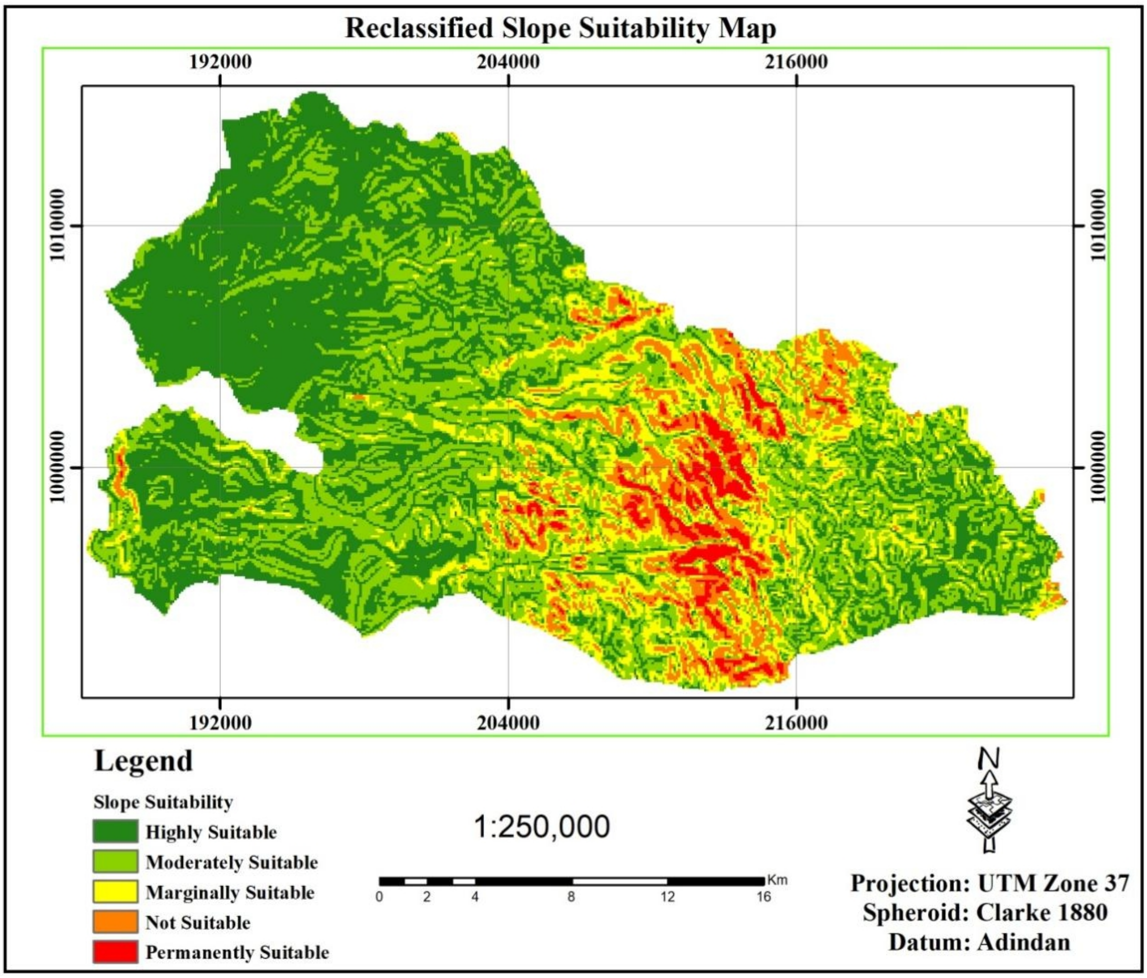

Figure 4.4: Reclassified Slope Suitability map of the Study area.

4.2.4 Suitability analysis for elevation

According to (FAO. 1984, Dula. 2010, and Negasa. 2013), land suitability analysis, the elevation of the study area was derived from ASTER DEM of 15m resampled to 10m spatial resolution. Elevation plays an important role in agricultural activities in general, and specifically for crop production. The altitude of the study area ranges between 1124m to 2,342m a.m.a.s.l. and is categorized into three suitability classes namely highly suitable, moderately suitable, and marginally suitable.

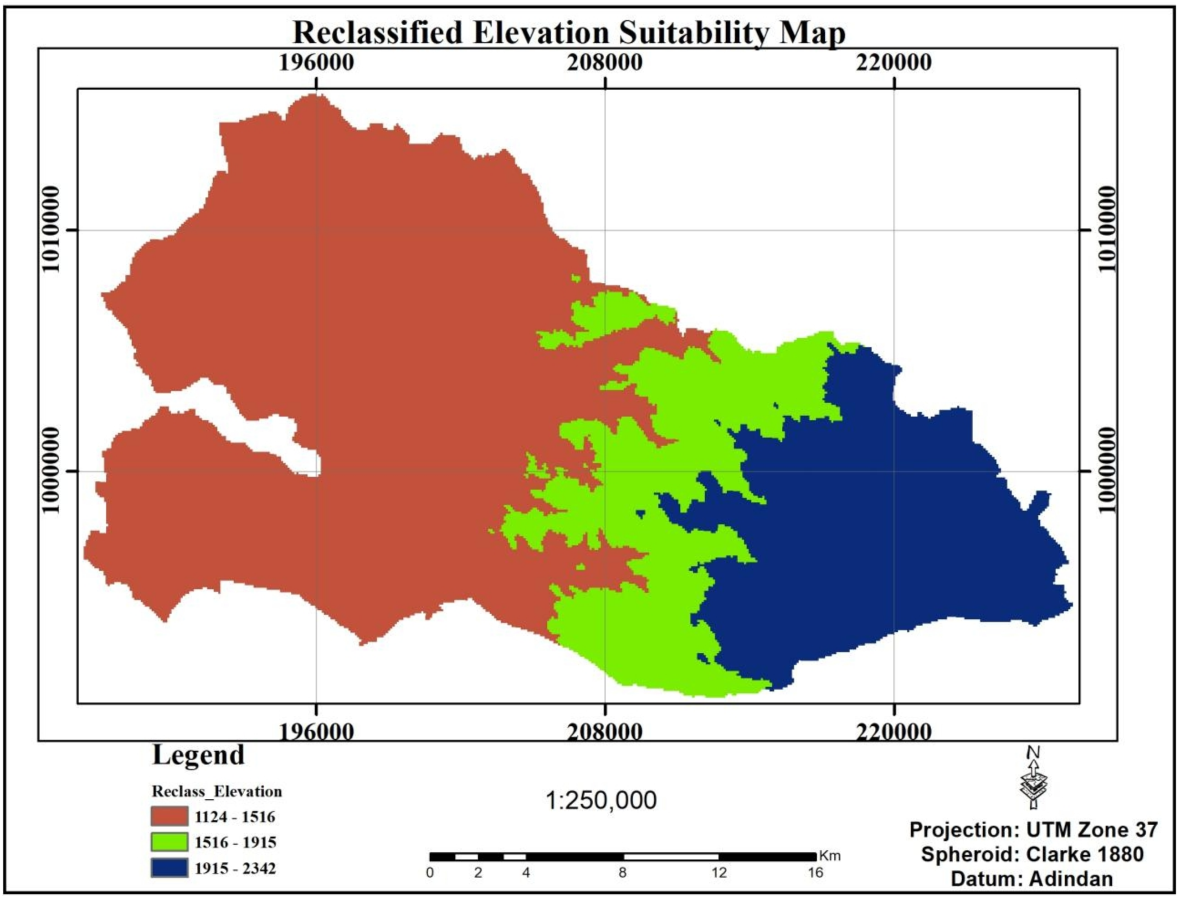

Figure 4.5: Reclassified Elevation Suitability map of the Study area.

4.2.5 Suitability analysis for climate

4.2.5.1 Suitability analysis for temperature

According to FAO, (1984), as cited in Tadesse (2010), Temperature and rainfall are the most important climatic factors for agricultural production in Ethiopia. The elevation is a factor that determines the distribution of climatic factors and land suitability; this influences the crops to be grown, rate of crop growth, natural vegetation types, and their species diversity. There is strong inter-annual variability of rainfall all over the country. Despite variable rainfall which makes agricultural planning difficult, a substantial proportion of the country gets enough rain for rain-fed crop production. Climate plays an important role in the suitability of lands for crop production. Agricultural activities and land use patterns are closely related to the temporal and spatial pattern of climatic elements and the success of land use strongly depends on the climatic situation of an area.

Agricultural activities and land use patterns are closely related to the temporal and spatial pattern of climatic elements and the success of land use strongly depends on the climatic situation of an area. Rainfall and temperature are the major climatic factors that influence agricultural processes.

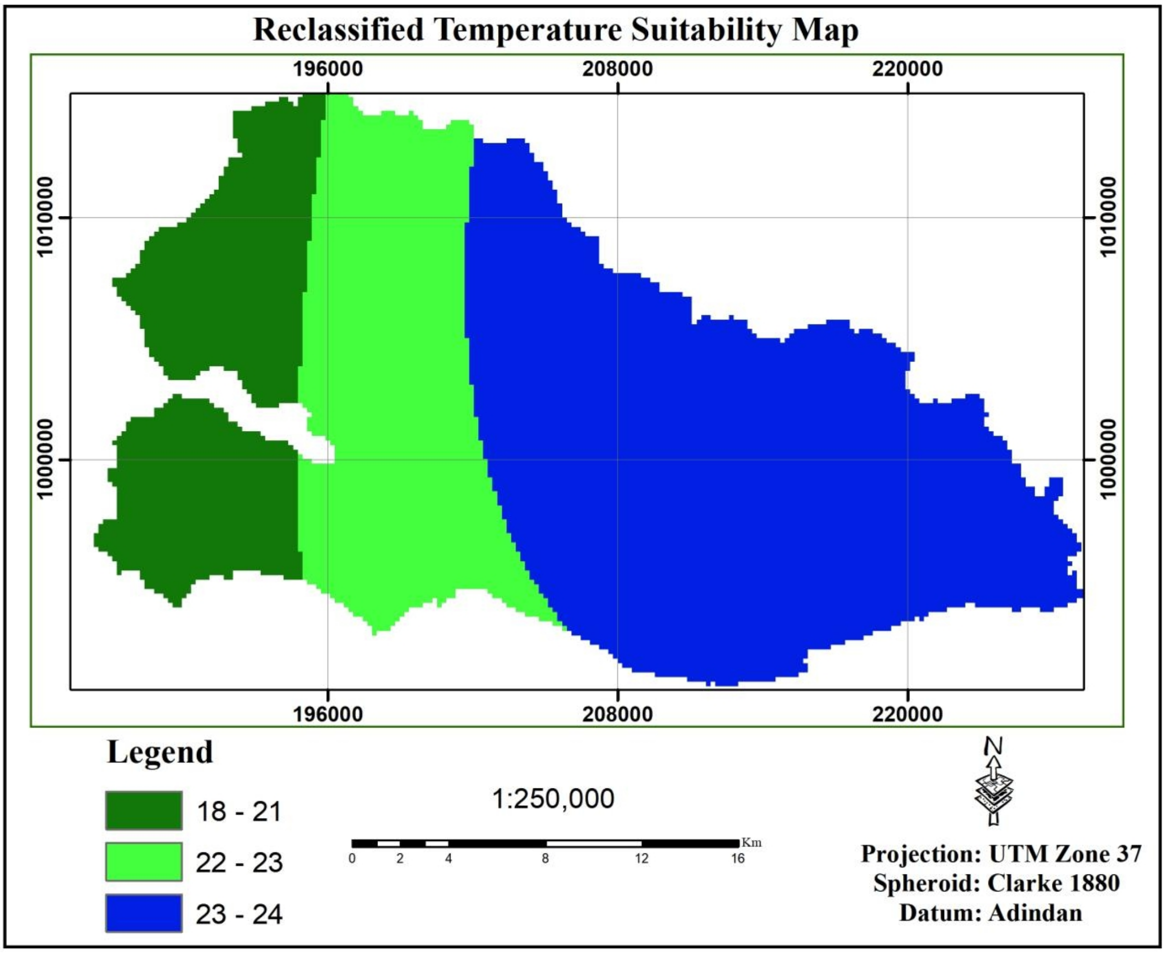

Figure 4.6: Reclassified Annual Temperature Suitability map of the Study area.

Based on the reclassified temperature shown in figure 15 above, the temperature ranges between 18-21^{0}C, 22-23^{0}C, and 23-24^{0}C were classified as highly suitable, moderately suitable, and marginally suitable for teff, wheat, and barley respectively.

4.2.5.2 Suitability analysis for rainfall

Rainfall and temperature are the major climatic factors that influence agricultural processes. The Source of water for rain-fed agriculture is rainfall; its distribution and dependability play a significant role in optimizing agricultural production. Thus, the average rainfall distribution together with its variation in both frequency and extent entails its agronomic importance. The Source of water for rain-fed agriculture is rainfall; its distribution and dependability play a significant role in optimizing agricultural production. Thus, the average rainfall distribution together with its variation in both frequency and extent entails its agronomic importance. Figure 16 below reveals that the rainfall ranges between 1742-1991mm, 1702-1741mm, 1665-1701mm, and 1520-1664mm was classified as highly suitable, moderately suitable, marginally suitable, and not suitable for teff, wheat and barley respectively.

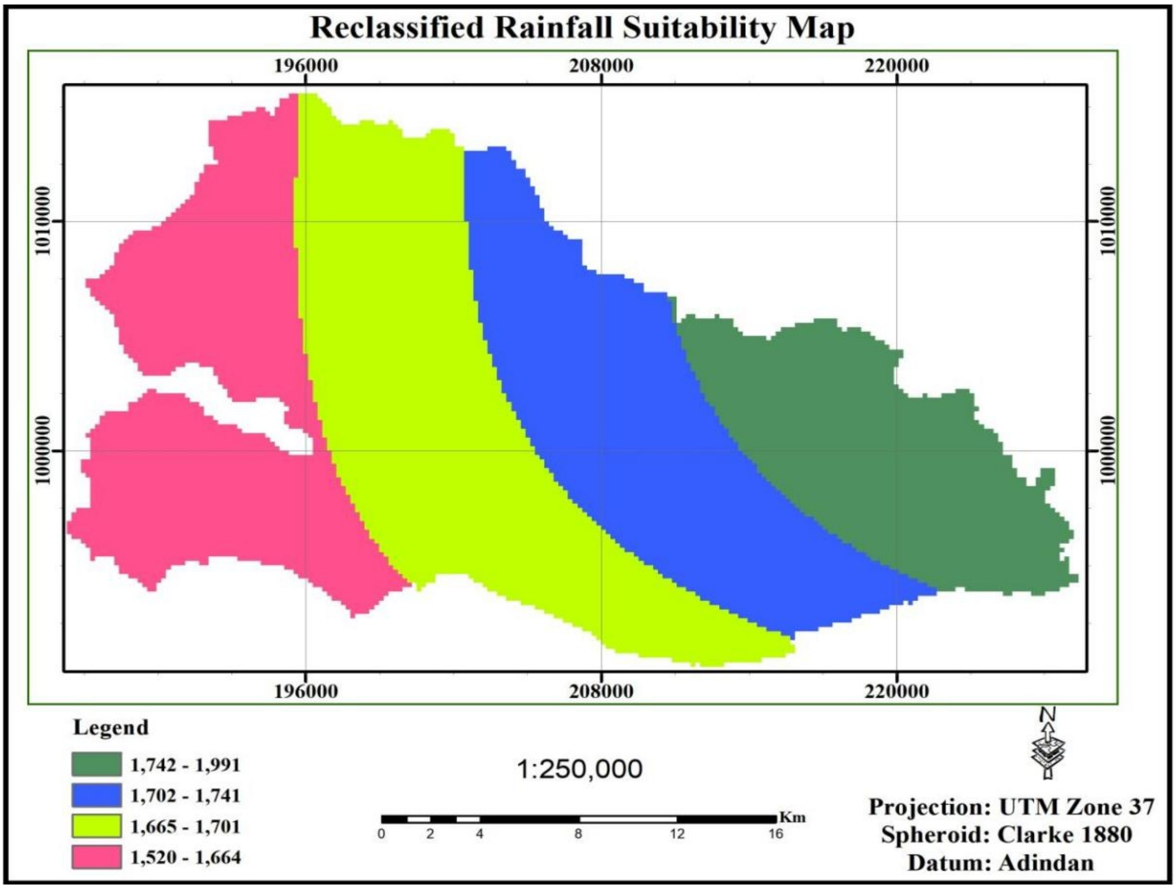

Figure 4.7: Reclassified Mean Monthly Rainfall Suitability map of the Study area.

4.2.6 Suitability analysis for land use land cover

4.2.6.1 Satellite image analysis

Land use/land cover of the study area was mapped from Sentinel-2 of 2020. The shapefile of the study area was also used as auxiliary information during image classification.

4.2.6.2 Image classification

The overall objective of the image classification procedure is to automatically categorize all pixels in an image into land cover classes or themes (Lillesand et al., 2004). Image classification is thus required to convert remote sensing data into thematic data. The present study used supervised classification techniques to categorize the images into different land use/land cover categories. Supervised classification can be used to cluster pixels in the data set into classes corresponding to user-defined training classes. This classification method requires selecting training areas for use as the basis for classification.

Supervised classifications: require prior knowledge of the scene area to provide the computer with unique training classes. Accordingly, the Shapefile of the study area was used as guidance to identify representative land cover classes. This was used for solving the problems of identifying features of similar reflectance like green area with forest, open land and agricultural, open land with agricultural land. Moreover, representative points thought to represent the various land cover classes were marked using Google Earth during field visits to inaccessible places. Finally, supervised classification has been carried out using ERDAS Imagine2015 software from the images of Sentinel-2 of 2020. Accordingly, 6 land use/land cover types namely: built up, cultivated lands, grasslands, plantations cover, forest area, and water body were identified (Table. 14).

Satellite Image Classification: is to classify pixels in the image to the same information, class identification of training signature editor was used on ERDAS Software. The most common supervised classification techniques are the maximum likelihood classifier for parametric input data and the parallel-piped classifier for non-parametric data. The area was classified into six major different classes of land use types practiced based on the data from the office as well as by cross-checking the image with Google Earth. The land use land cover of the study area was classified from the Sentinel-2 (2020). The classified pixels were grouped into the following six general categories: built-up, cultivated lands, grasslands, plantations cover, forest area, and water body (Figure 17). The classification of land use land cover involves evaluation and grouping of particular areas of land based on their suitability for a defined use.

Table 4.5: Land Use Land Cover Class and area coverage of the study area.

No	Land Use Land Cover	Area (ha)	Area (%)
1	Water Body	170.3	0.3
2	Agricultural Area	26210.6	44.7
3	Vegetated Area	14052.7	24.0
4	Built up	3195.1	5.4
5	Plantation Cover	1451.3	2.5
6	Grass Land	13553.3	23.1
	Total	58633.00	100.00

Large parts of the study area are covered by agricultural area which accounts for about 44.7%. Vegetated area, Grass Land, Plantation Cover, Built-up, and Water body account for 24.0%, 23.1%, 5.4%, 2.5%, and 0.3% of the total study area, respectively. The land use/land cover of the study area is shown in Figure 4.8.

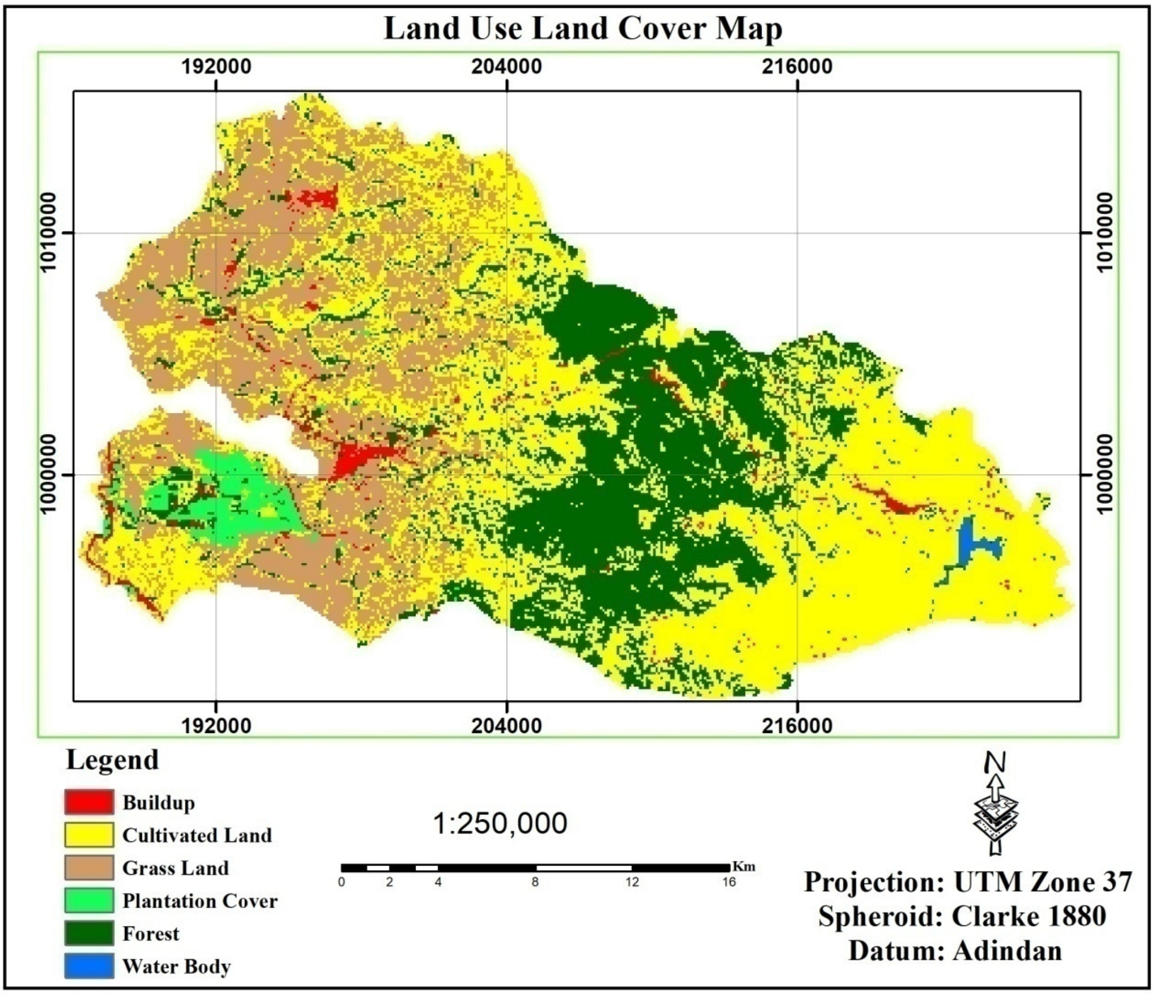

Figure 4.8: Reclassified land Use Land Cover Suitability map of the Study area.

4.2.6.3 Accuracy assessment

According to Lillesand et al., (2004), as cited in Gizachew, (2011), Accuracy assessment should be done as image classification without accuracy assessment is incomplete 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. Therefore, accuracy assessment performed for image classification is used to tell how accurately the land use/land cover maps were classified.

Errors are inevitable in any digitally generated land cover maps obtained from remote sensing imagery. These errors may occur from the source itself because of errors during data acquisition or from classification techniques during image processing. As a result, a robust and thorough assessment of the classification accuracy is required to guaranty the reliability of the result. (Congalton, 1991; Lillesand *et al*., 2004).

It is important to note that the producer's accuracy is calculated as the total number of correct pixels in a category divided by the total number of pixels of that category as derived from the reference data. This accuracy measure indicates that the probability of a reference pixel being correctly classified. On the other hand, if the total number of correct pixels in a category is divided by the total number of pixels that are classified in that category, it is said to be user's accuracy is reliable.

Table 4.6: Error matrix showing classification accuracy of the land use/ land cover

LULU	Waterbody	Agricultural Area	Vegetated Area	Built -up	Plantation Cover	Grass Land	Total	User Accuracy	Producer accuracy
Water Body	14	0	0	0	0	1	16	87.5%	100%
Agricultural area	0	15	0	0	0	0	15	100%	93.75 %
Vegetated Area	0	0	13	0	0	2	15	86.7%	100%
Built up	0	1	0	13	0	0	14	92.9%	92.86 %
Plantation Cover	0	0	0	1	17		18	94.4%	100%
Grass Land	0	0	0	0	0	16	16	100%	94.12 %
Total(producer)	14	16	13	14	17	17	94		

$$\text{Users accuracy} = \frac{\text{Number of correctly classified pixels in each category}}{\text{Total Number of classified pixels in that category (the row total)}} \times 100$$

$$\text{Producer accuracy} = \frac{\text{Number of correctly classified pixels in each category}}{\text{Total number of reference pixels in that category (the column total)}} \times 100$$

$$\text{Overall accuracy} = \frac{\text{Total Number of Correctly classified pixels (diagonal)}}{\text{Total number of reference pixels}} \times 100$$

$$\text{Kappa coefficient (T)} = \frac{(TS \times TCS) - \sum(\text{Column total} \times \text{row total})}{TS^2 - \sum(\text{Column total} - \text{row total})} \times 100$$

Overall accuracy= 80% and Kappa coefficient (T) = 0.758

4.2.6.4 Normalized difference vegetation index

To avoid soil erosion during cassava production, land covered by low vegetation can reduce the rate of surface runoff. Vegetation index variations were assessed using a satellite-based measure: the normalized difference vegetation index (NDVI). The NDVI is a vegetation index that is correlated with several important biophysical properties and that generates different crop indices (Ahamed et al. 2013; Elhag2014). The NDVI is calculated from two channels, the near-infrared (NIR) and the visible part the red portion of the electromagnetic spectrum using the following algorithm:

$$NDVI = \frac{NIR-Red}{NIR+Red}$$

The first task in the NDVI analysis was removing below zero NDVI values. This was done to avoid confusion negative NDVI with negative values. This was performed in ArcGIS environment on raster calculator, [input data < = 1] & [input data > = 0] and define the output new value as "1", then reclassify the output value as "No data" for "0" and "1" for all others and finally multiply the original data with reclassified data and make the data permanent (Esubalew,2014).

A vegetation index calculated by NDVI is an index based on the spectral reflectance of the ground surface feature. Each feature has its characteristic reflectance varying according to the wavelength. NDVI value ranges between -1 to +1. A Higher value of NDVI infers the presence of healthy vegetation in the area while its lower value is the indicator of sparse vegetation. The NDVI value was calculated from Sentinel-2 satellite image of the 2020 year "This index outputs values between -1.0 and 0.09, mostly representing greenness, where any negative values are mainly generated from clouds, water, and snow, and values 0.1 - 0.2 are mainly generated from bare soil, built up and rock. Moderate values represent vegetated grassland and sparsely distributed crop(0.3 to 0.4), while high values indicate temperate and tropical rainforest (0.4 to 0.5)".

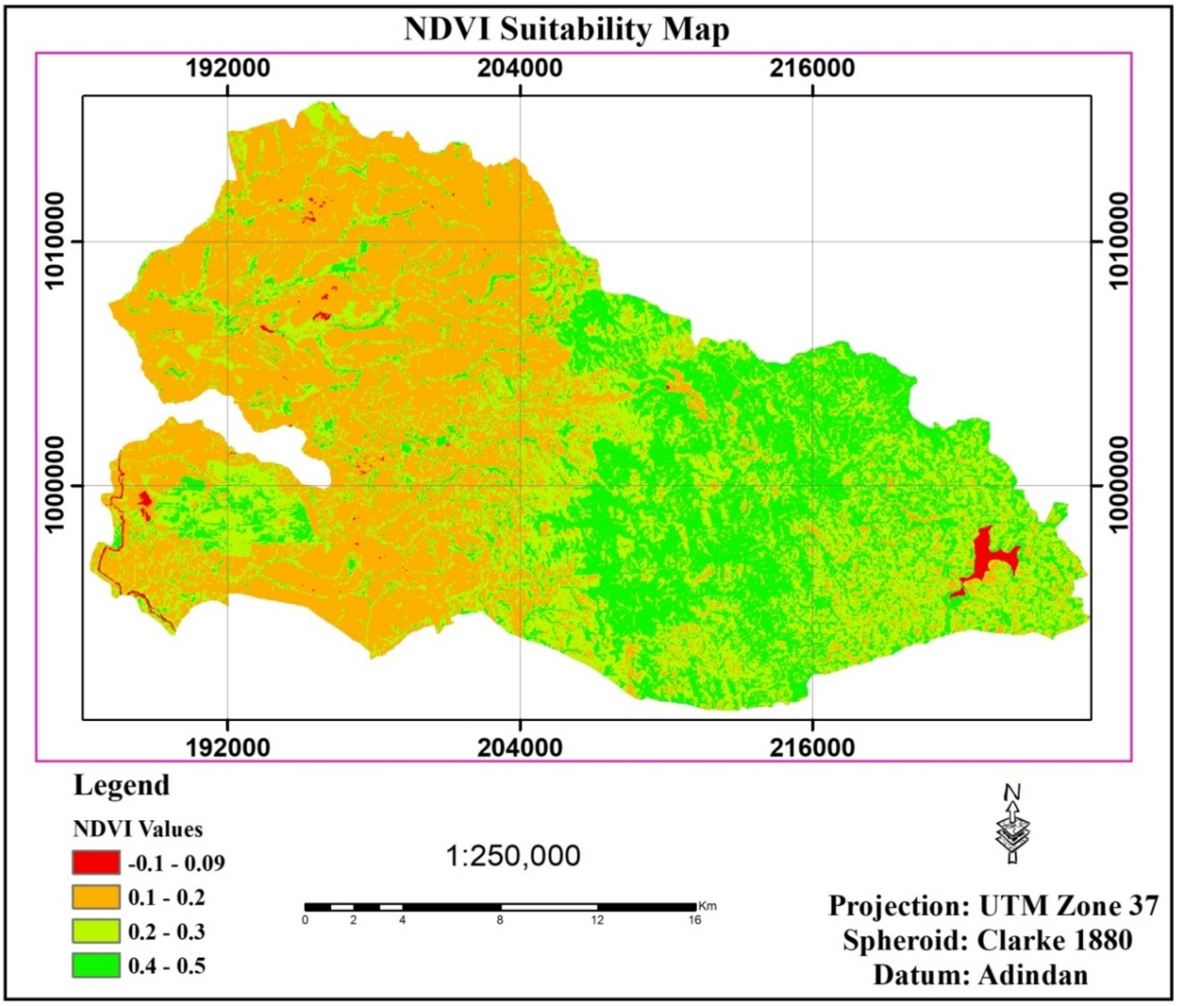

Figure 4.9: Map of NDVI of Annual season of diga district in 2020.

4.2.7 Road Suitability

Accessibility of road to agricultural land is important for raw material transportation as well as to get a good market for crops produced. Most of the villages of the district are connected with a gravel road. The figure 19 below reveals that using spatial analyst tool Euclidean distance of the road proximity analysis the agricultural land far from the road by 0-2km, 2-4km, 4-7km, and 7-10km are classified as very high suitable, high suitable,moderately suitable and low suitable due to the distance from the cropland respectively Widiatmaka (2016).

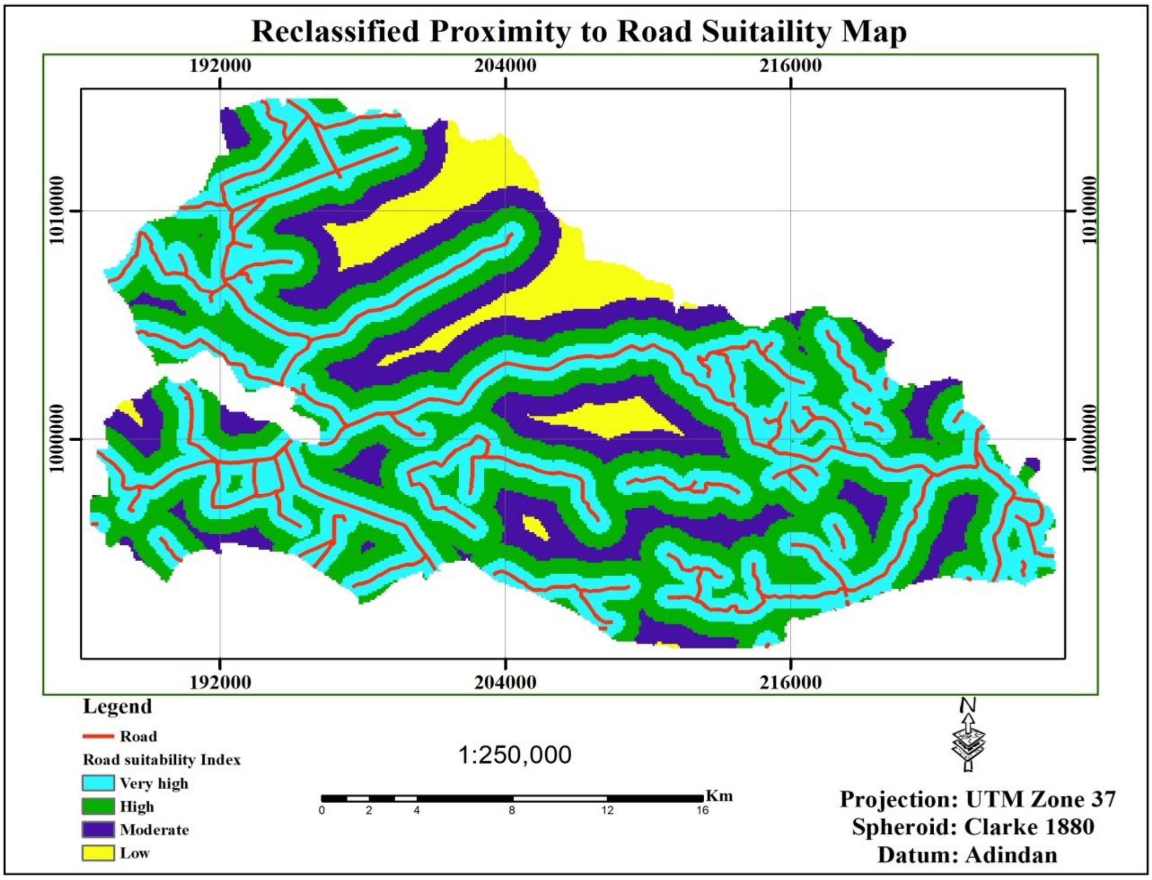

Figure 4.10: Reclassified Road Suitability map of the Study area.

4.2.8 Weight Overlay Analysis of all Factors

The weighted overlay tools of ArcGIS functions from arc toolbox with scale 1 to 5 has been computed to generate a composite map of factors map, was multiplied to the composite map to produce suitability maps of residential areas.

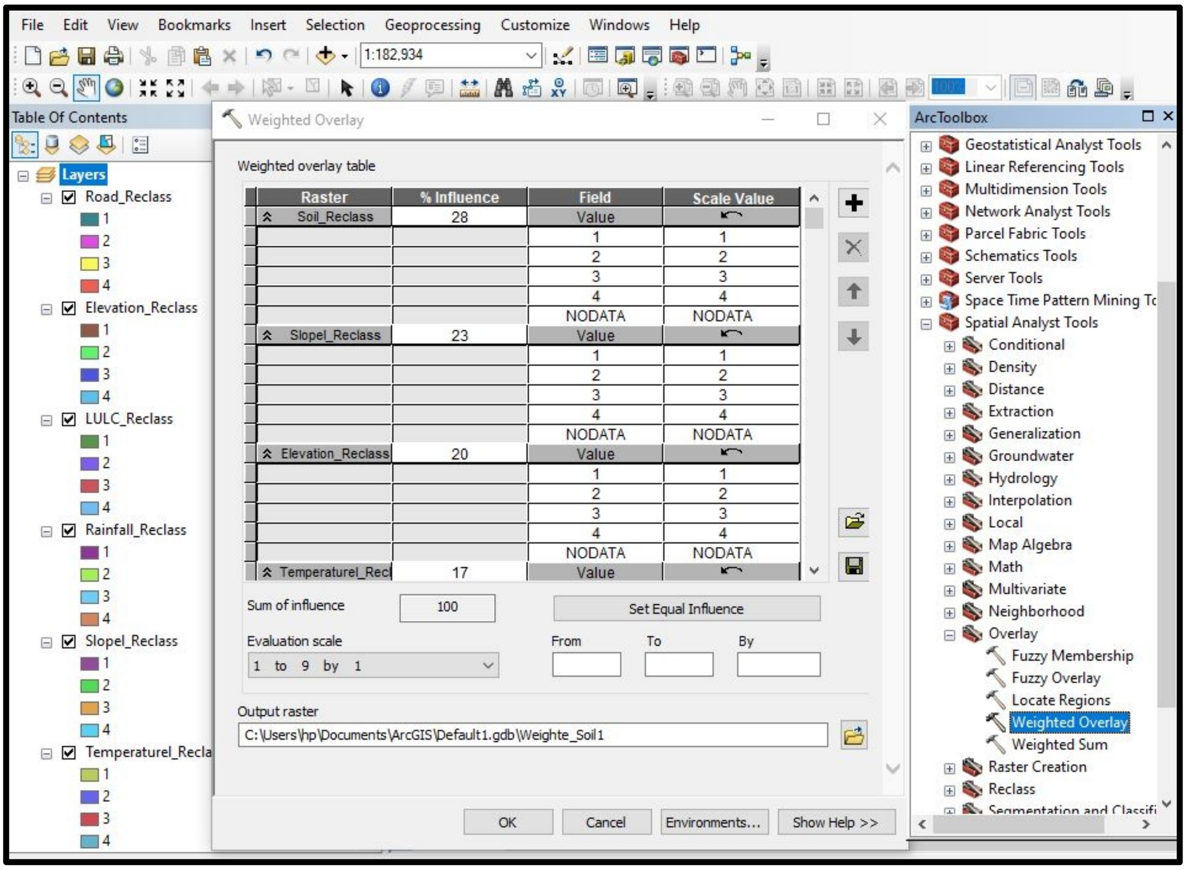

Figure 4.11: Weighted Overlay toolbox sample Map for Teff Production

Accordingly, Figure 4.12 below reveals that Diga District can be divided into four suitability indexes. Table 4.7 below shows that 19.88% of the whole area is unsuitable for teff agricultural crop production. This is due to restrictions to the agricultural land influenced by legal and environmental conditions of the District. From the composite agricultural suitability map below (Figure 4.12) areas with deep green color represent for high suitable, areas with slight green color stand for moderate suitable while yellow represents marginally suitable, and red color represent for currently not suitable suitable respectively.

4.3 Land Suitability Analysis for Selected Agricultural Crops Production

Teff is used only in Ethiopia as a staple food although its presence as a cultivated forage grass or a naturally occurring grass is reported in Kenya, Uganda, and Pakistan. It is a cereal grain with high nutrient content particularly protein (11%) which is higher than in any other cereals found in the country. The grain is also rich in minerals such as iron, potassium, calcium, and phosphorous. The great advantage of the grain is that it can be stored for many years in the traditional storehouse without being damaged by insects and that represents a very suitable safeguard against famine (Seifu Admassu, 2004).

According to (Seifu, 1997 and Behailu, 2014), Teff is grown under diverse agro-climatic conditions at an altitude ranging from 1800-2800meters above mean sea level. It requires an annual rainfall up to 2500mm and elevation ranging from 1800- 2800m above mean sea level with high tolerance to waterlogging (Slehak, 2007). According to experiences gained so far from national yield trials, conducted at different locations across the country, teff performs excellently at an altitude of 1800 – 2100 m above sea level, annual rainfall of 750 –850 mm, growing season rainfall of 450 – 550 mm and a temperature range of 10°C – 27°C (Seyfu, 1997).

Figure 4.12 below shows that 12255 hectares (20.93%) of the total area is highly suitable, 11668hectares (44.6%) is moderately suitable, 26001 hectares (19.92%) is marginally suitable and 8709 hectare (14.64%) is currently not suitable teff production respectively.

Table 4.7: Land Suitability Status for Teff in area and percentage

Crops	S.no	Score	Suitability Class	Area (ha)	Area (%)
	1	3	Highly Suitable	12255	20.93
	2	2	Moderately Suitable	11668	44.6
	3	1	Marginally Suitable	26001	19.92
Teff	4	0	Currently not Suitable	8709	14.64
Total				58633.00	100.00

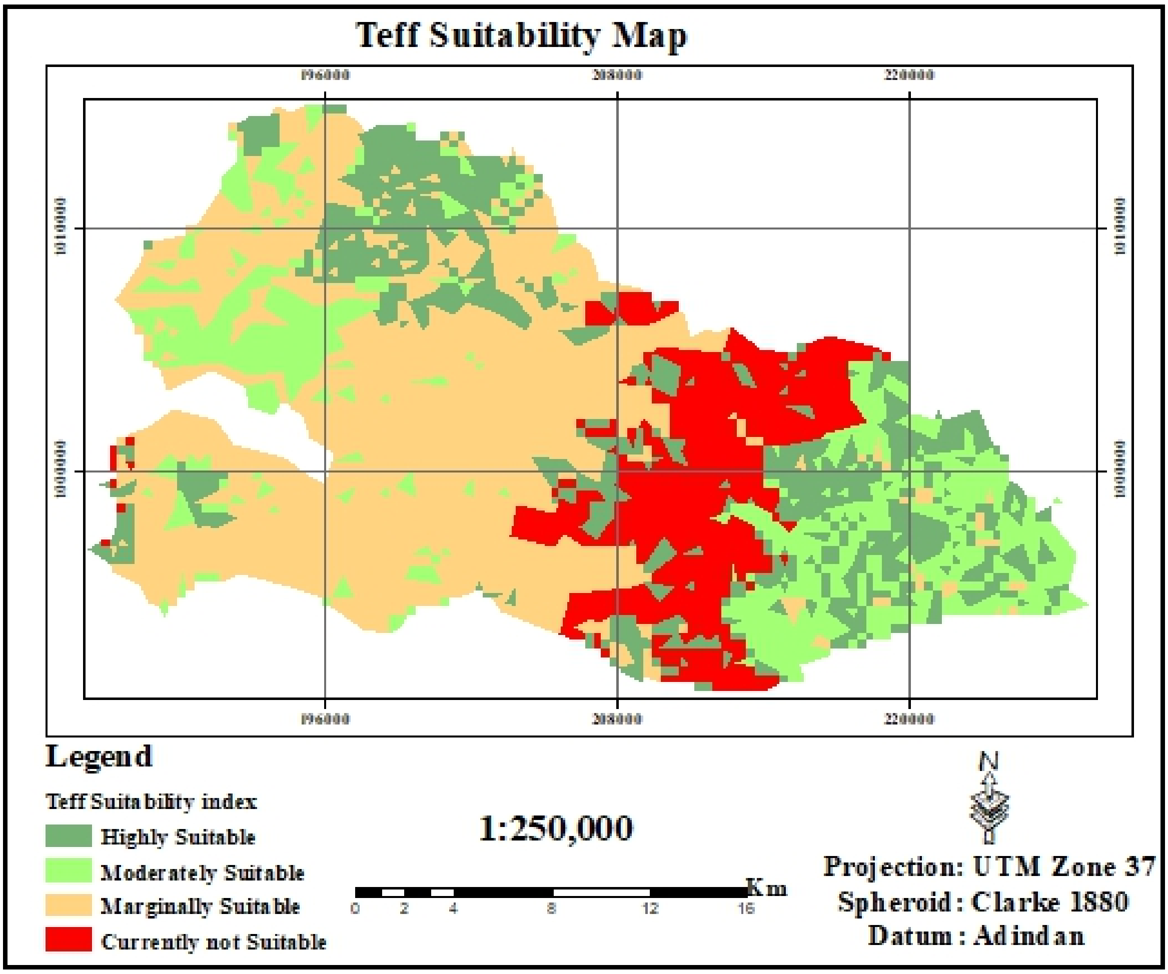

Figure 4.12: Land suitability analysis results along with suitability classes for Teff production.

Wheat

Wheat is an important crop in the highland of Ethiopia. It is very sensitive to drought and it is recommended to avoid growing in dry areas. Wheat production is affected by

• Lack of proper management recommended techniques and care within the actual peasants, farming system.

• Poor quality planting materials, and to a lesser extent frost, waterlogging, diseases, and pests affect the yield of the crop in many areas of the country.

The most suitable areas for wheat production are those with an average annual rainfall of 1200mm with 600mm well distributed during the growth period. For high yield, water requirements are 450 to 650 mm depending on climate and length of the growing period (Seifu, 2004).

As depicted in Figure below from the total land of the study area 7417.60 hectares (12.65%) is highly suitable, 22500.35hectares (38.37%) is moderately suitable, 17255.75 hectares (29.44%) is marginally suitable, 11459.05 hectares (14.61%) is currently not suitable for wheat production.

Table 4.8: Land Suitability Status for Wheat in area and percentage

Crops	S.no	Score	Suitability Class	Area (ha)	Area (%)
	1	4	Highly Suitable	7417.60	12.65
	2	3	Moderately Suitable	22500.35	38.37
	3	2	Marginally Suitable	17255.75	29.44
Wheat	4	1	Currently not Suitable	11459.05	19.54
Total				58633.00	100.00

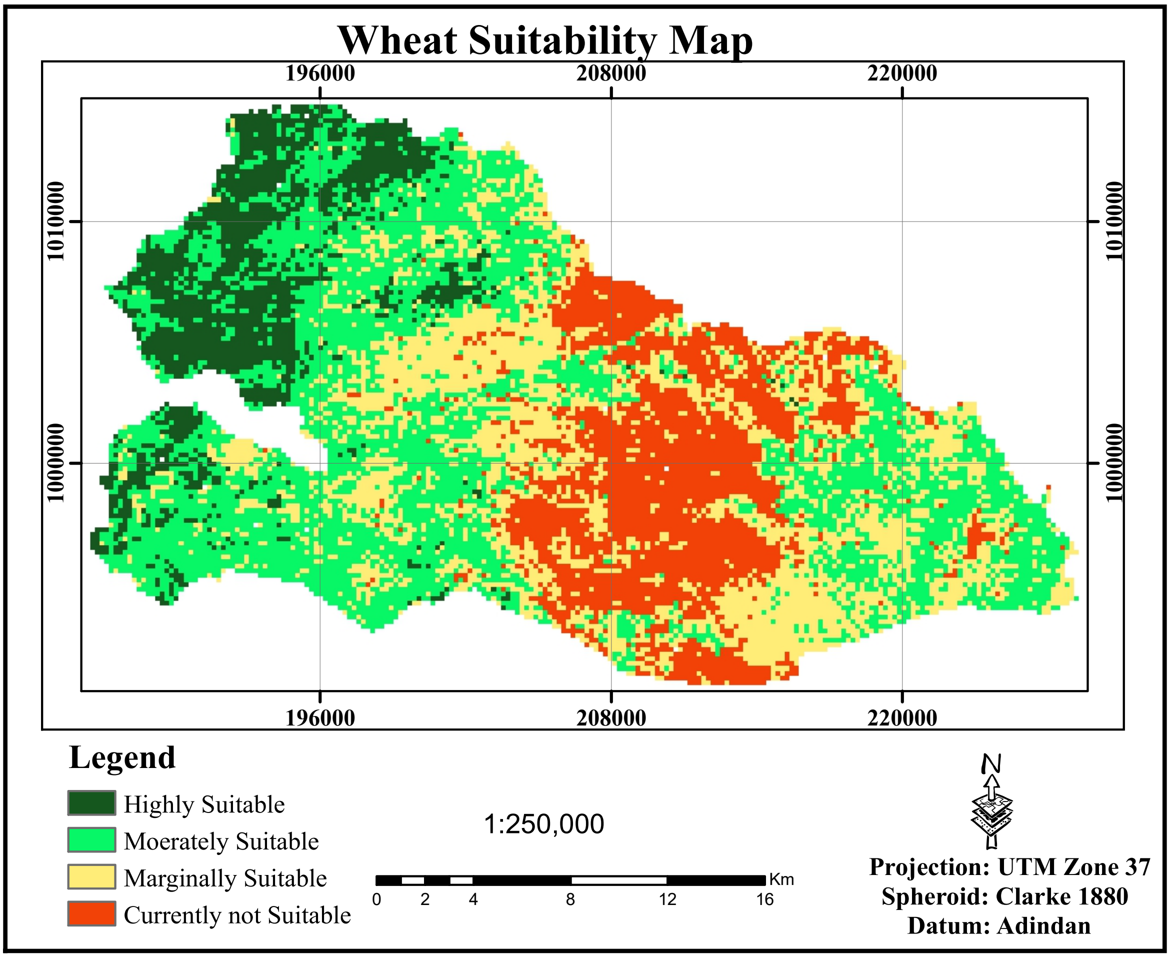

Figure 4.13: Land suitability analysis results along with suitability classes for Wheat production.

Barley

As stated by Muluken (2013), Barley is an important grain crop in Ethiopia and has diverse ecologies being grown from 1800 to 3400 m altitude in different seasons and production systems.

Figure 4.14 below reveals that from the total area of the study 6961.16hectares (11.87%) is highly suitable, 20103.20 hectares (34.29%) is moderately suitable, 16631.30 hectares (28.37%) is marginally suitable, 14937.10hectares (25.48%) is currently not suitable for barley production respectively.

Table 4.9: Land Suitability Status for Wheat in area and percentage

Crops	S.no	Score	Suitability Class	Area (ha)	Area (%)
	1	4	Highly Suitable	6961.16	11.87
	2	3	Moderately Suitable	20103.20	34.29
	3	2	Marginally Suitable	16631.30	28.37
Barley	4	1	Not Suitable	14937.10	25.48
Total				58633.00	100.00

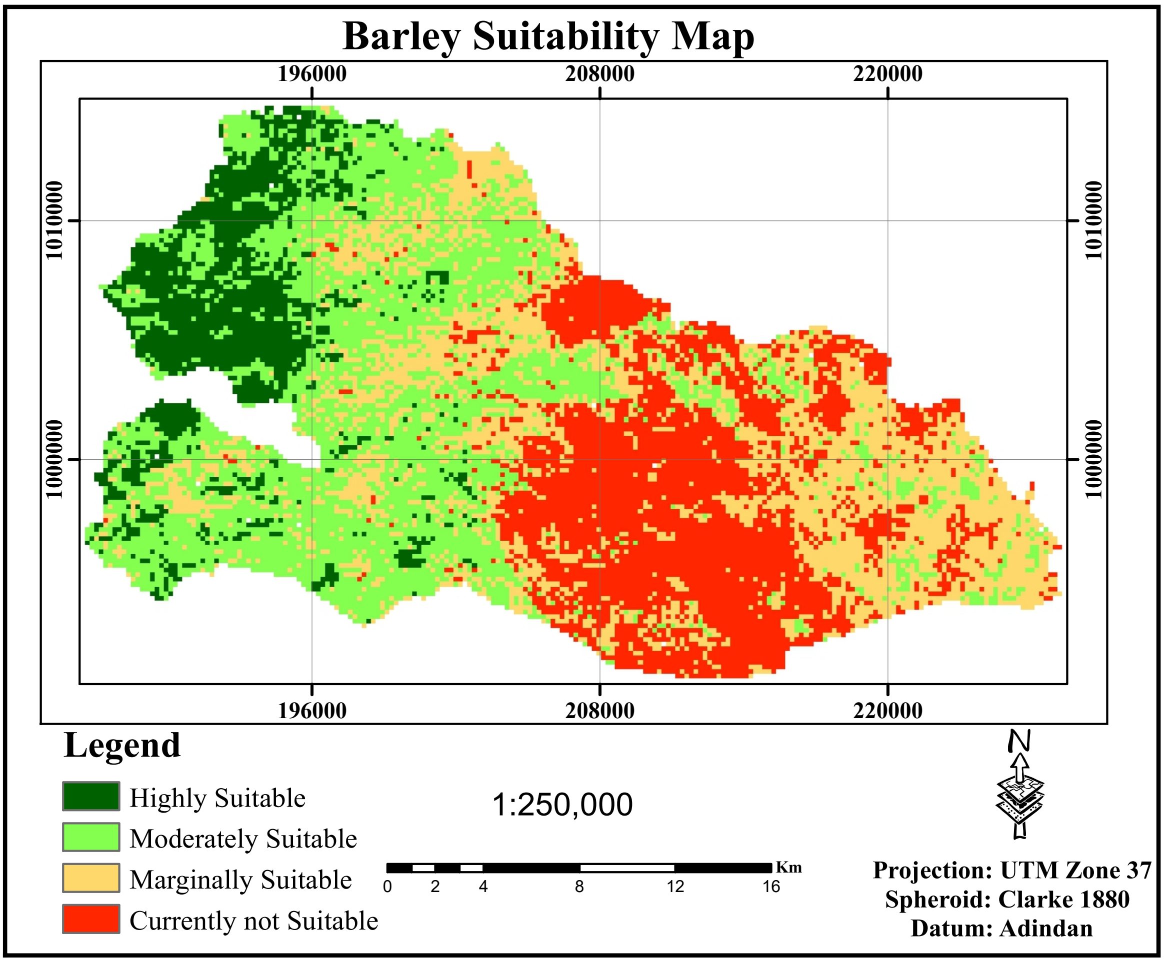

Figure 4.14: Land suitability analysis results along with suitability classes for Barley production.

4.4. Optimum Land Suitability Allocation for Selected Crops Production.

Land suitability result obtained for specific land utilization type only indicates that the different suitability classes for that land utilization type in the study area. When different land utilization types are involved in the evaluation, it seems good to indicate the appropriate parcels of land best suitable which compete for the same parcel of land at its best suitability class.

Overall land suitability analysis indicates that the overall suitability of the land for each land utilization type. It also indicates which land utilization types compete for a parcel of land at the same level of suitability class. Overall land suitability analysis is indicative of appropriate land allocation.

This overall suitability analysis result is obtained after the conversion of the raster data to the vector data format for all land utilization types. The analysis is performed in a vector overlay analysis in a GIS environment using Spatial Analysis Tool. Table 4.10 below demonstrates that the result of appropriate land allocation for the selected land Utilization types along with their best suitability classes. The result demonstrates that the condition where a plot of land is suitable for one or more than one Land Utilization type at the same level of suitability class. This indicates that competing for the nature of land utilization types for the same parcel of land. For example, 5.22%, 6.77%, and 8.77% of a single plot of land is currently not suitable for teff, wheat, and barley respectively.

Table 4.10: Overall Land suitability analysis result along with suitability classes for all crop production.

Code_Name	Area in (ha)	Area in (%)
T_S1	3946.35	6.73
T_S3	8510.42	14.51
T_S2	3781.55	6.45
T_N1	3063.49	5.22
B_S2	6558.35	11.19
B_S1	2427.67	4.14
B_S3	5540.72	9.45
B_N1	5139.65	8.77
W_S2	7581.15	12.93
W_S1	2583.49	4.41
W_S3	5532.95	9.44
W_N1	3967.39	6.77
Total	58633.00	100.00

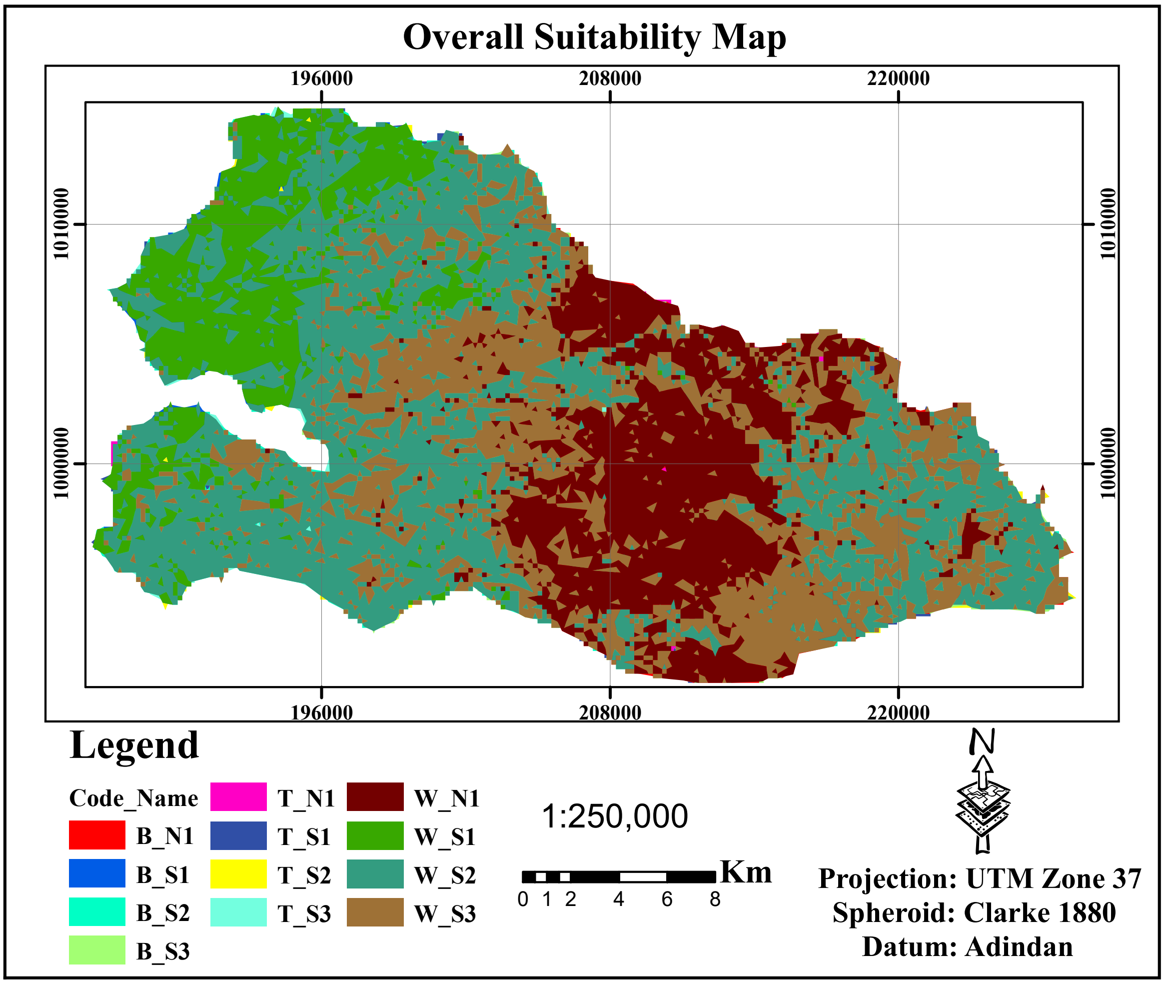

Figure 4.15: Overall Land suitability analysis result along with suitability classes for Teff, Wheat, and Barley production.

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The main objective of the study was to analyze land suitability analysis for agricultural crop production in Diga District, Western Oromia, Ethiopia GIS and Remote Sensing techniques with MCE and AHP approach. The study demonstrated that utilization of geospatial technique and MCE in agricultural land suitability analysis area is appropriate, necessary, and needed in agricultural land use and development under Ethiopian contexts.

GIS and Remote Sensing with multicriteria evaluation and analytical hierarchy process nowadays have been put forward with a series of functional capabilities and applications to solve conflicts and complexities in any geospatial decision making.

Spatial parameters upon which suitability decisions could be made were determined based on the relevant literature review and availability of data. Accordingly, ten factors namely: land use land cover, proximity to major roads, slope conditions, soil depth, soil texture, soil drainage, soil pH, elevation, temperature, and rainfall were considered as a suite of physical and environmental criteria that have principal effects on suitability analysis for agricultural land production in Diga District.

Each criterion was standardized, reclassified, and assigned a suitability score. Criterion standardization was based on different literature reviews. All criteria were reclassified to a common scale of measurement.

The weighted overlay analysis tool of ArcGIS 10.8 software was adopted to integrate all weighted factors to produce the final suitability map. The resultant map was computed as all reclassified factors were multiplied by their weights and summed up together.

This analysis developed five levels of suitability indexes of influencing factors for future agricultural land suitability based on literature reviews. Highly suitable, moderately suitable, marginally suitable, Not suitable, and permanently not suitable areas where the classified study area for future agricultural production suitability indexes. Among these, highly suitable areas have the highest potential for future agricultural activities and should be used first.

The final suitability map result classified the whole Diga District area into four suitability classes. Accordingly, 6.73% highly suitable for teff, 4.41% highly suitable for wheat and 4.14%, for barley, were found to be highly suitable from the whole area of the district, While 6.45%, 12.93%, and 11.19% were found to be moderately suitable, 14.51%, 9.44%, and 9.45% were found to be marginally suitable for teff, wheat and barley, and 5.22%, 6.77, % and 8.77% were currently not suitable for teff, wheat, and barley according to this final vector overlay analysis.

5.2 Recommendation

In this study, an attempt is made to analyze agricultural land suitability analysis for future crop production areas using GIS and Remote Sensing technique augmented with MCE, in Diga District, East Wollega Zone. The suitability analysis was done in the area using several criteria related to agricultural areas' suitability and their weight of influence was performed by asking local experts of the study area.

- ❖ The parameters used for land suitability analysis in this study were entirely physical parameters like soil, temperature, rainfall, land use/land cover, road, altitude, and slope; much improvement can be made if some socioeconomic variables were considered.
- ❖ The land utilization types considered in this study were limited to three major selected crops such as teff, wheat, and barley whereas further studies can be made to increase the choice and identify the best alternative use of land for different land utilization types by considering other cereal crops.
- ❖ The agricultural office of diga district has the responsibility to show the place where the suitable area for teff, wheat and barley production to the farmers because it seems difficult to a farmer to know which area is highly suitable or unsuitable.
- ❖ The findings of this study will be beneficial to various parties. From the finding, planners, decision-makers, and developers can identify and recognize that where is optimal land for future agricultural practice to keep land suitable while utilizing the land type properly.
- ❖ This suitability study map shows that the area where land utilization type for all crops mapped above, so the farmers expected to use this study for their yield increment because if they use the land identified for teff instead of other types of crops the amount.
- ❖ Therefore, land-use planners of the district and developers should have to give attention to unsuitable areas which are located in different areas. The above

scientific classification is can be used as a guide map to the proposed land use for agricultural areas in the study area. The result confirms that geospatial techniques and multi-criteria evolution with analytical hierarchy process are very applicable and effective in analyzing, mapping, and interpreting agricultural land suitability.

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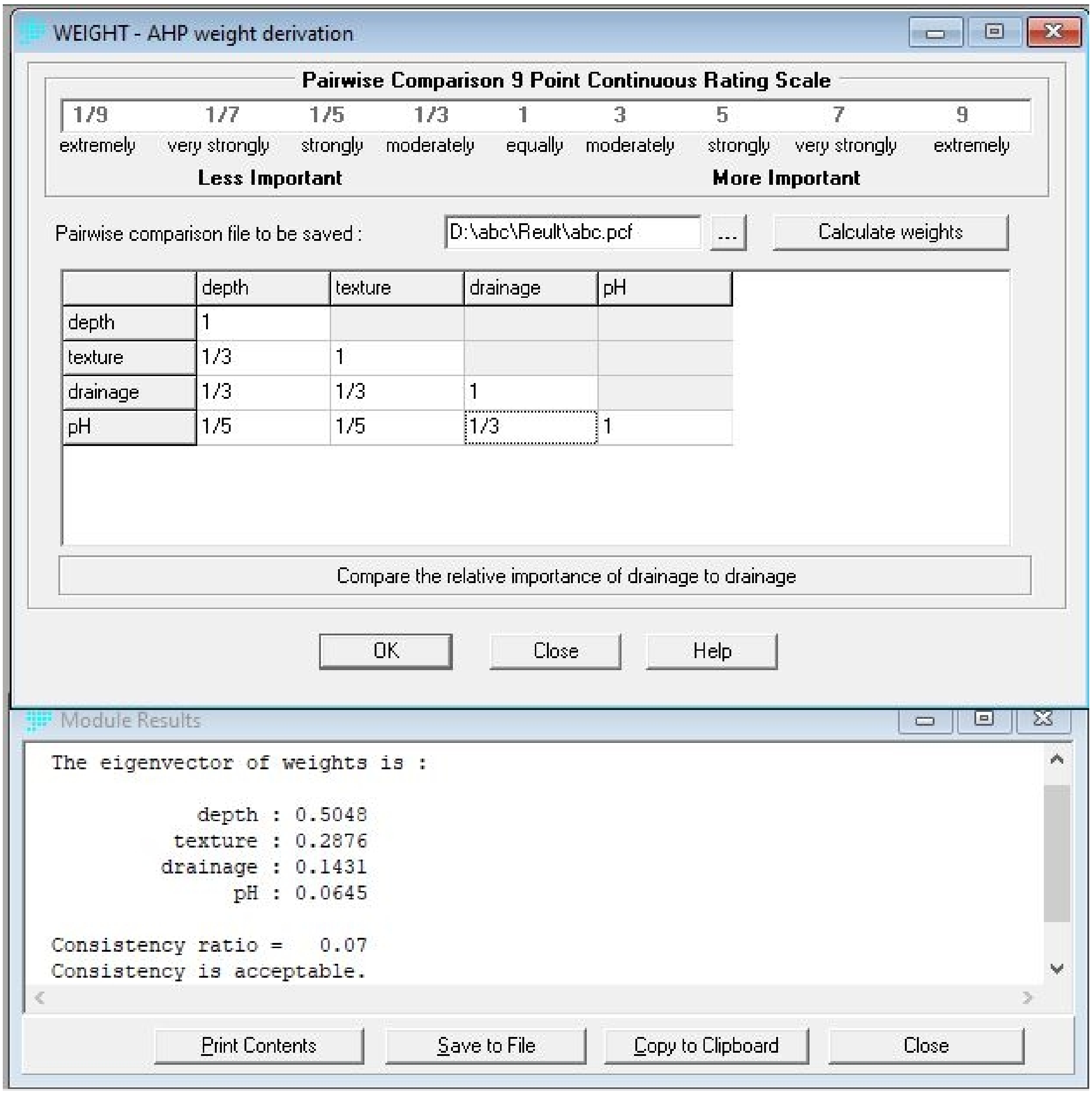
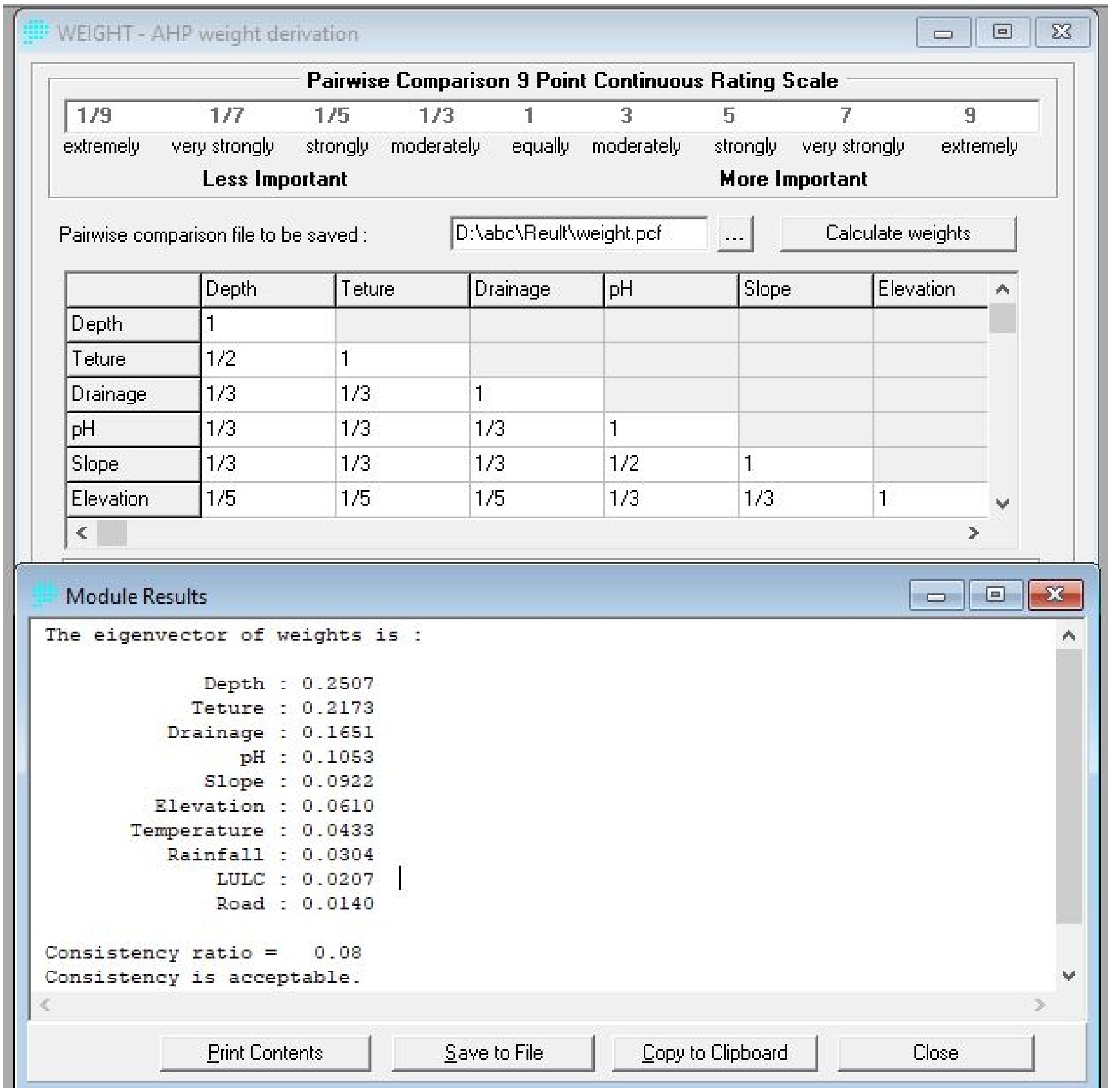
APPENDIX

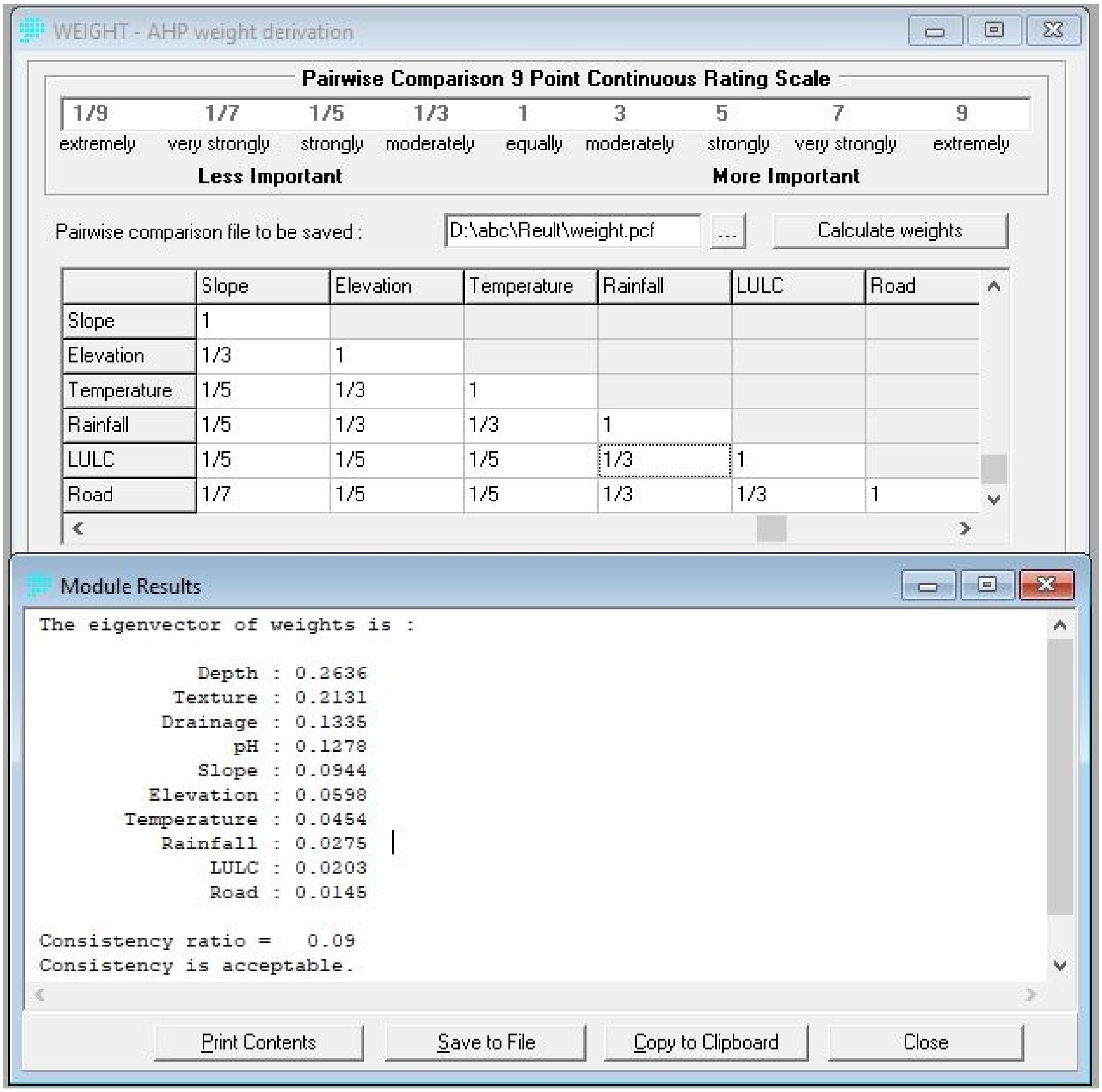
Appendix 1: Factor Weights for Soil



Appendix 2: Factor Weights for Wheat



Appendix 3: Factor Weights for Barley


WEIGHT - AHP weight derivation

Pairwise Comparison 9 Point Continuous Rating Scale

1/9	1/7	1/5	1/3	1	3	5	7	9
extremely	very strongly	strongly	moderately	equally	moderately	strongly	very strongly	extremely

Less Important — More Important

Pairwise comparison file to be saved : D:\abc\Reult\weight.pcf ... Calculate weights

	Slope	Elevation	Temperature	Rainfall	LULC	Road
Slope	1					
Elevation	1/3	1				
Temperature	1/5	1/3	1			
Rainfall	1/5	1/3	1/3	1		
LULC	1/5	1/5	1/5	1/3	1	
Road	1/7	1/5	1/5	1/3	1/3	1

Module Results

```
The eigenvector of weights is :

             Depth : 0.2636
           Texture : 0.2131
          Drainage : 0.1335
                pH : 0.1278
             Slope : 0.0944
         Elevation : 0.0598
       Temperature : 0.0454
          Rainfall : 0.0275
              LULC : 0.0203
              Road : 0.0145

Consistency ratio =   0.09
Consistency is acceptable.
```

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