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**ADDIS ABABA UNIVERSITY
COLLEGE OF SOCIAL SCIENCES
POSTGRADUATE PROGRAM
DEPARTMENT OF GEOGRAPHY AND ENVIRONMENTAL
STUDIES**

**GIS BASED LAND SUITABILITY ANALYSIS FOR WHEAT (*Triticum
aestivum*) PRODUCTION: THE CASE OF DELO MENNA AND HARENA
BULUK DISTRICT, OROMIA REGIONAL STATE OF ETHIOPIA**

BY Mendrina Esmael

**Advisor: DR ASEFA ABEGAZ
(Associate Professor)**

**A Thesis Submitted to: School of Graduate Studies of Addis Ababa University for
Partial Fulfillment of the Requirements for the Degree of Master of Art in GIS,
Remote Sensing and Digital Cartography.**

July 2022

ADDISS ABABA, ETHIOPIA

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Addis Ababa Ethiopia**

DECLARATION

Addis Ababa University

School of Graduate Studies

Department of Geography and Environmental Studies

I, the researcher, declare that this thesis is my original work, has not been presented for a degree in any other university and all sources of material used has been acknowledged in this entire study.

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CONFIRMATION

This thesis have been submitted for examination with my approval as a university advisor

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APPROVAL

This is to certify that the research project thesis by Mendrina Esmael, entitled: GIS based land suitability analysis for wheat production: The case of Delo Menna and Harena Buluk District that submitted in partial fulfillment of the requirements for Master of Arts in Geography and Environmental Studies complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

Approved by board of examiners

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List of Acronyms

AHP	Analytic Hierarchy Process
BMNP	Bale Mountain National Park
CR	Consistency Ratio
DEM	Digital Elevation Model
ERDAS	Earth Resource Data Analysis
GDP	Gross Domestic Product
GIS	Geographic Information System
GPS	Global Positioning System
FAO	Food and Agriculture Organization
LSA	Land Suitability Analysis
LU/LC	Land use/ Land cover
MCDM	Multi-Criteria Decision Making
MoA	Ministry of Agriculture
NGO	Non-Governmental Organization
USGC	United States Geological Survey
USDA	United States Department of Agriculture

Abstract

Appropriate land use decisions have a vital role to achieve optimum productivity of land and to ensure environmental sustainability. Land suitability analysis can support decision maker to make a wise decision in order to get optimum benefit out of the land and to sustain production. This study is targeted in evaluating actual land suitability, in a case study of Delo Menna and Harena Buluk district, Bale Zone, Southeast of Ethiopia for wheat production using GIS and remote sensing method. It covers a total area of 1230km² of seven rural Kebeles from both districts. The Analyses process is depending on FAO land evaluation guideline. It uses two suitability orders which are suitable and not suitable and then five suitability classes have been used: Highly Suitable (S1), Moderately Suitable (S2), Marginally Suitable (S3), currently not suitable (N1) and permanently not suitable (N2). In support of this classification slope, elevation, soil drainage, soil texture, soil depth, soil pH, soil organic carbon (SOC), temperature, rainfall and present land use/land cover (LULC) of the study area were considered in this study. Protected area is considered as a constraint in the area for crop production. Multiple factors are taken into account for making decision, in doing so weighted overlay analysis of ARCGIS environment aggregate factors based on their influence derived from pairwise comparison. Result of weighted overlay and Boolean constraint map are aggregated to produce suitability map of the area for wheat production. Accordingly, the result showed three suitability classes: moderately suitable, marginally suitable, and currently not suitable, with 57.19% (146519.21 Km²), 39.51% (101233.33 Km²) and 57.19% (146519.21 Km²) of the study area, respectively. Generally, the districts agricultural authorities targeted in making wheat as an alternative cereal crop, this study can be used as a primary instrument for better planning. However the factors used area not the only criteria for making decision inclusion of socioeconomic issue may complement for better suitability analysis of wheat in the area. Based the finding it is highly recommended that agricultural practice need to modify and follow strict production management, limiting factor that has a probability of treatment need to be treat, wheat species that tolerate those limiting factor have to be select to get better production yield. Protected area should be strictly considered while using the result.

Keywords: Factors, Suitability Analysis, Suitability, Weighted Overlay Analysis, Wheat.

CHAPTER ONE

1. INTRODUCTION

1.1. Background of the study

Agriculture is a process or practicing growing crop and livestock. It offers most of the world's food, textiles cotton, wool, leather and wood for construction as well as paper products. It is the most important source of livelihoods of the world population (Mokarram *et al.*, 2017). It is a source of civilization which led human being to settle down and starts to cultivate year to year (Motuma, 2014).

In 2018, the global agricultural land was estimated to 4.8 billion ha, employing about 884 million people or 27 % of global workforce (FAO, 2020). In developing countries, agriculture is the most important sector. Likewise, Ethiopian economic activity is highly depending on agriculture. In the year 2019/2020, the total cultivated cropland of Ethiopia was 12.9 million hectares, of which 81.5, 12.2 and 6.4% was used for cereals, pulses, and oilseeds production, respectively. In stated year, the share of agriculture to GDP was 32.7%. Its contribution to the annual GDP growth was 22.9% (NBE, 2020).

Now agriculture is advanced as a science deals with crops with a profession name of commercial agriculture, precision agriculture and sustainable agriculture for the subsistence and sustains of human beings (Motuma, 2014). Recently, many agricultural practices are extensively applying the state-of-the-art agricultural technologies and practices. Among those, new disease resistant hybrids, biological pest control, Insect-specific chemicals and biological insect controls, and other climate smart agricultural practices can be mentioned. On top of this, GIS suitability analysis, Crop growth models and remote sensing can provide information to farmers for realizing these technologies and practices. These tools play an important role and also allow land users properly to manage agricultural land resources (Kumar *et al.*, 2016).

But beyond the growth of agricultural commodities and agricultural technology there is food insecurity in most part of the world especially in sub-Saharan Africa including in Ethiopia with rapid population growth which is beyond food supply and production yield. Globally, more than 820 million people are still at the state of hunger, 2 billion people are at the state of moderate

food insecurity (FAO, 2019), while about 8.5 million people are at severely food insecurity (FAO, 2020).

Major causes of food insecurity is low agricultural productivity, which aroused because of improper agricultural land-uses and land use decision and lack of sustainable agricultural technologies, particularly in developing countries.

In Ethiopian context, continuous, improper and over utilization of agriculture lands without proper land suitability analysis and land-use planning has caused much more destruction to land, indirectly affecting soil fertility as well as natural resources depletion and degradation. In turns it resulted to food insecurity, stagnated or declining agricultural productivity.

To setback food insecurity behind in addition to producing more high quality food using eco-friendly practices, concepts like precision farming, sustainable farming and organic farming are cop up. Now much agricultural attention was shifted from supposing homogenous fields into dividing the land into smaller zones then managing them separately and selection of crops, with the best land quality for the intended crop or comparison of land use type with land quality which we call it land suitability analysis (Motuma, 2014).

Land suitability refers to the ability of a given type of land for a specific land use (FAO, 1976) in its current condition (Actual Land Suitability) or after improvements (Potential Land Suitability). Appropriateness of a land for particular crop production is determined by topographic, climatic, soil, LULC and so on characteristics of the area under investigation (Rituing *et al.*, 2007).

Suitability analysis can identify main limiting factors for the agricultural production and enables decisions makers such as land users, land use planners, and agricultural support services to develop a crop management and to enhance agricultural productivity (Rabia, 2012). Therefore, the first step in agricultural land use planning has to be conducting land suitability analysis and determining which type of land use is suitable for a particular location before making any agricultural land use decision (Bodaghabadi *et al.*, 2009).

So as livelihood of many Ethiopians are depend on agricultural activity as the result proper utilization of each plot of land and updated management policies to increasing production yields and to avoid loss of soil fertility is a must.

Recently in Ethiopia, a number of studies were done to analyze suitability of lands for crops production both under rain fed as well for irrigation. As land characteristic of an area is different from one place to another and suitability analysis needed local evidence of a combination of land characters, analysis has to be done as much as we can for each plot of land carefully to make decision for proper utilization of resources.

According to data gain from district Agricultural, Disaster and Risk Management and Health Bureaus the study area is known by producing coffee, sesame, maize, teff as well as different kind of fruit as but beside this diverse production; production of yield is low, result for food insecurity. Many people in the area depend on neighboring market for the most consumed crop wheat. Many of the households of the area are supported by different governmental and non-governmental organization.

But recently by the support and motivation of district Agricultural Bureau towards farming wheat crop, farmers started producing wheat products in some Kebeles. But the result is not as expected by agricultural experts the production yield is not as good as neighboring district and there is huge yield variation. As there is no suitability assessment done before making a decision towards wheat production suitability of the area has to be assessed for wheat production.

Therefore, this study aims in assessing current suitability of the area for wheat production based on GIS and remote sensing process. Now a day application of GIS and remote sensing tools with varying spatial analysis techniques data acquisition, compiling, analyzing and displaying topological interrelations of different spatial information are enabled researchers to map suitable lands effectively, also geospatial tools being widely used to assess natural resources and monitor spatial changes. Moreover, the overlay analysis abilities of GIS can effectively facilitate and handling huge amount of spatial information for assessing suitability of intended purpose of the area under investigation make GIS and remote sensing application the chosen one in analyzing suitability of an area under investigation.

Land suitability analysis involves a number of criteria. The capability of GIS in Spatial Decision Support System through multi-criteria decision method (MCDM) allow in combining and analyzing large set of data's for better land use planning. In this study topographic, climatic, soil and land use/land cover data's are integrated on weighted overlay analysis of ArcGIS

environment in accordance of FAO, 1976 frameworks. Data used though the entire study is collected from different institute like Geospatial Information Institute of Ethiopia, Ethiopian Meteorological stations, Ministry of Agriculture (MOA), district agricultural bureaus and so on.

As food production increases, economic prosperity and environmental sustainability grow, therefore this study is supposed to solve food production problems by assessing and recommending suitable areas for wheat production based on set criteria and identifying factor affecting wheat production.

1.2. Statements of the problem

As many Ethiopian farmers are dependent on rain fed farm, farming activity of the study area is practiced traditionally without analyzing appropriateness of land for any intended purpose. Agricultural activity of the area is struggling with improper land use management which has resulted in land resource deprivation and low level of production yield in its adverse effect. Absence of selecting correct land for correct crop, poor agricultural technology and yield variation is also hindrance in agricultural activity of the study area.

Based on field observation those effects and high population growth rate leads the rural households to food insecurity, consequently forced to extend their hands for different government and non-governmental organizations. Nowadays food insecurity and low level of wheat production yield is an epic problem in the study area.

Wheat is one of cereal crops widely used for consumption; however it is not well produced in this area. People in the area are depending on nearby farmers from highland part of Bale Zone. For long period of time they have been suffering from supply scarcity and cost inflation which has led them to food insecurity and aid dependent. According to districts Disaster Risk Management and Health Bureau in the year 2013EC around 10468 numbers of people who faced hunger and malnutrition were under aid for survival in study area.

In the recent three and two years wheat farming is practiced in the study area based on agricultural expert recommendations in thinking of making wheat alternative cereal crop and tells of vast opportunity for good wheat production yield. However, the result is not as predicted. Production yield is not good as the rest of neighboring districts and there is clear yield variation.

So the area needs an urgent land suitability analysis to answer the why question. Why low yield, why yield variation and suitability level of each plot of land has to be identified to make decision. Since wheat is widely used as staple food crop and main focus of the country widely producing wheat is wise solution to overcome regional and national food scarcity. Therefore, the above mentioned reasons are bases for this project.

Here in Ethiopia, numbers of studies on crop suitability analysis were conducted. Yohannes and Soromessa (2018), Motuma (2018), Debesa *et al.*, (2020) and many other studies are taken place in many part of our country using GIS and remote sensing specially using weighted overlay analysis. But such study is not taken place previously in the area for the intended purpose. The present study is an input for agricultural expert and planner.

1.3. Objective of the study

1.3.1. General objective of the study

- To analyze current suitability of wheat production using GIS and remote sensing in the case of Delo Menna and Harena Buluk District.

1.3.2. Specific objectives include:

- ✓ To identify factors used to assess suitable land for wheat production
- ✓ To evaluate suitability of the area for wheat production.
- ✓ To identify factors affecting wheat production in the area.
- ✓ To categorize the land based on its suitability potential for wheat production.

1.4. Basic research questions

- ✓ What are the important parameters for assessing land for wheat suitability?
- ✓ Does land of the districts is suitable for wheat production?
- ✓ What factors are affecting wheat production in the study area?
- ✓ Which part of the area is more suitable for wheat production?

1.5. Significance of the study

In order to achieve sustainable agriculture and maximum food production agricultural land suitability evaluation is an essential issue. Land suitability examination is a prerequisite before deciding for any land use, it provides basic information on constraints and opportunities of the

land and to identify capability of lands based on incorporated criteria. As one of Ethiopian community People in the study area is also highly dependent on agricultural activity which is suffered from low production and imbalance between demand and supply.

In general this study is significant by:-

- The study will be a guide for rural land use planner by analyzing and mapping actual or current suitability of the areas for wheat production.
- It will be an input for agricultural expert by identifying suitability of each factor for wheat production.
- It will be stand point for agricultural expert by identifying factor affecting wheat production
- The study is applicable for local level planning will use as a future input and guide for rural land planners in rain-fed agriculture.
- This research will be an input for other researchers and will be a stand point.

1.6. Scope of the study

The study is in Delo Menna and Harena Buluk District which was conducted in seven Kebeles namely Ciri, Gomgoma, Hawo, Melka Amana, Malka Arba, Shawe and Sodo Welmel the rest Kebeles are not included in this study. Total area coverage of the study area is 1231 square kilometer. Those Kebeles are selected randomly in a view of including both low land and high land parts of the two districts. GIS based multi criteria decision making systems used to assess suitable of the study area for wheat production using ten factors and one constraint.

1.7. Limitations of the study

Luck of time and financial problem. Agricultural extension worker claimed that wheat yield production in the study area is not promising due to scarcity of rainfall in the three cropping seasons so the study needs future validation.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Concept Of land evaluation and land suitability analysis

Land is a complex combination of natural and artificial resources together whereas Land use is any kind of permanent or cyclic human interference on natural ecosystem, to satisfy human needs (Sys *et al.*, 1991). Land evaluation is formally a procedure of matching the features of land resources for certain land uses spending scientifically standardized technique. The outcomes can be used as a director for land users and planners to isolate substitute land uses. Land Suitability is the degree of appropriateness of land for a definite land use (Ritung *et al.*, 2007).

Land evaluation goals to rate the value of land for a particular land use comparative to other land. It offers an unbiased foundation upon which to base decisions on land management, land purchase, and land use planning whether for private, governments and NGOs. It answers where to launch a given project, determine scope of a project, use to implement strategic vision and help for personal decision. It should go before planning and development so that alternative uses can be assessed in terms of economic and social benefits and environmental effects. It should be recognized, however, that land evaluation does not prescribe best land uses but only indicates options (Webb & Wilson, 1995).

Major areas where land evaluation has direct application are: land resource planning, determining suitability of land for a change in use, assessment of sustainability and environmental influences of land use, evaluation of land suitability for effluent disposal, economic assessment of land use, land use interpretations based on soil surveys, land use capability (LUC) and development of concepts of versatility of land for intensive agricultural development (Webb & Wilson, 1995).

2.1.1. Types of Land Suitability

Land suitability analysis can be actual land suitability which could be evaluated for current condition of a given land or it could be Potential Land Suitability after doing some improvement for a given plot of land. Actual Land suitability is a land appropriateness based on current soil and land conditions, without adding any input. The information is based on physical data like soil characteristics, climate and topographic data related to growth requirements of crops being

evaluated. Potential Land Suitability is the suitability that could be reached after the land is improved, at a sub-optimal level of managing in such a way that the productivity can be enhanced by changing to more suitable crops (Ritung *et al.*, 2007).

2.2. Application of GIS and Remote Sensing In land-use suitability

Lately computerized systems of land suitability evaluation were developed to use quantified spatial information on land resources. The recent geo-information technology that has greatly improved spatial data handling and enabled spatial modeling of terrain attributes is GIS (Abushnaf, 2014). The advancement of GIS-based land-use suitability modeling has been a gathering of the development of information technology in general and geographic information technology, in particular. The GIS-based land-use appropriateness analysis has been applied in ecological approaches for defining land suitability for animal and plant species, geological favorability, for agricultural activities, landscape evaluation and planning, environmental impact assessment, choosing the best site for the public and private sector facilities and regional planning (Malczewski, 2004).

In the late nineteenth and early twentieth century American landscape architects used GIS-based approaches land-use suitability analysis in the applications of hand-drawn overlay techniques (Steinitz *et al.*, 2012; Malczewski, 2004). McHarg in 1969 advanced the overlay methods by proposing a manual overlay cartographic procedure. The method is broadly recognized as a pioneer to the classical overlay procedures in GIS. Computer-assisted overlay mapping, were developed to answer limitations of mapping and combining large datasets of manual methods (Steinitz *et al.*, 2012; Malczewski, 2004).

2.3. Multi-Criteria Suitability Analysis

Multi-criteria suitability analysis developed to advance spatial decision making it is an effective tool to investigate when there are many choice possibilities, multiple criteria also multiple objectives. Multi-criteria evaluation methods, has significantly advanced on the conventional map overlay approaches to the land-use suitability analysis. The method uses geographical data, decision maker's preferences and manipulation of the data and preferences according to stated decision guidelines. A MCDM method offers new opportunities to the land-use suitability analysis and planning. Soft computing or geocomputation includes modern computational

techniques that can help in modeling and describing complex systems for inference and decision making (Malczewski, 2004).

2.4. Suitability analysis in agricultural sector

Agricultural land evaluation often includes survey of natural resources; climatic conditions, soil, topography, vegetation, geology, availability of surface and ground water and possible dam site. Socioeconomic condition; land tenure, production pattern, size of farm and actual productivity per head and hectare, quality and quantity of crop and agricultural service in need; fertilizers and agricultural machinery, marketing center, storehouse and transport facilities. Agricultural Land suitability analysis aims to answer what types of soil are present in the area and where it is located, in identifying which kind of crop can be cultivated on these soil type, expected crop yield, what types of fertilizer in what amount can be added and identify the recommended irrigation practice and quantity of irrigation water as well as identify management practices in need. Generally agricultural land suitability can identify what kind of plant or crop can be plant, management to be taken and yield of those cultivated crop or plant (Sys *et al.*, (1991).

2.5. Land characteristics considered in agricultural suitability analysis

Land quality is the multipart attributes of lands which hold one or more land characteristics, which can be directly seen in the field or predictable based on land characteristics.

Table 1 Relationship between land quality and characteristics (Adopted from Djanudin *et al* 2003; Ritung *et al.* 2007).

Land Qualities	Land Characteristics
Temperature	Average temperature (°c)
Water availability	Rainfall (mm), moisture (%), Number of dry months
Oxygen availability	Drainage
Rooting condition	Texture, Coarse material (%), Soil depth
Peat	Depth (cm) of mineral interlayer or enrichment (if any), Maturity/ripeness
Nutrient retention	Clay CEC (cmol/kg), Base saturation (%), pHH ₂ O, Organic C (%)
Toxicity	Salinity (dS/m)
Sodicity	Alkalinity/ESP (%)
Sulfidic material	Depth of sulfidic materials (cm)
Erosion hazard	Slope (%), erosion
Flood hazard	Inundation

Accordingly, climate, soil and topographic factors are critical determinant parameters of land suitability evaluation which use to determine the overall suitability of the area for wheat

production. These factors are split up into particular parameters and evaluated in terms of their importance for that intended crop (Ritung *et al.*, 2007).

2.5.1. Soil factor

Soil is basic factor in land suitability analysis. It can influence crop choice, soil management, types of irrigation to be taken, type and quantity of fertilizer to be used and many other influences (Sys *et al.*, (1991). The main soil characteristics in land evaluation include soil depth, drainage, texture, nutrient retention, (pH, CEC), alkalinity, erosion hazard, and flood/inundation (Ritung *et al.*, 2007).

Soil drainage is one of soil factor that indicates speed of water infiltration. Soil drainage of an area could be excessively drained, somewhat excessively drained, well drained, moderately well drained, somewhat poorly drained, poorly drained and very poorly drained based on soil water holding capacity and soil hydraulic conductivity. Well drained and moderately well drained are the most preferred drainage classes by most plants. Water holding capacity of excessively drained and somewhat excessively drained is very low, somewhat poorly drained, poorly drained and very poorly drained are thus unsuitable drainage class for most plants (Ritung *et al.*, 2007). Soil texture is the particle size of fine soil particles containing of sand, silt and clay has a significant role in absorbing organic matter and nitrogen content also can affect water holding capacity of the soil (Webb and Wilson, 1995).

Texture of soil could be assessed manually in the field, but preferably determined quantitatively based on texture laboratory analysis and classified accordingly. Soil texture could be grouped as fine; moderately fine, moderate, somewhat coarse, coarse and very fine texture (Ritung *et al.*, 2007). Soil depth is an important physical soil property for assessing suitable land use. Soil depth is determined how far can roots of plant can grow and how much the soil can hold water. Soil depth can be categorized in to very deep, deep, moderately deep, shallow and very shallow (Motuma, 2014). Soil pH is the main variable of soil; that influences physical, chemical, and biological properties and processes of the soil. If soil pH declines beneath a critical level, the solubility of aluminum and manganese ions increases which causing in toxicity and lower yields. Soil pH lower than 5 adversely affects roots and if it is below 4 strictly restricts root growth. If pH is greater than 8.5 the soils are considered as alkaline soils. Most plants and soil micro-

organisms thrive best in soils of pH 5 - 7.5 (Nwer, 2005). Most commonly soil pH of a given area can be categorized as follow.

Table 2 pH classification (USDA natural resource conservation service, 1998)

No	pH classes	Soil pH
1	Extremely acid	3.5 – 4.4
2	Very strongly acid	4.5 – 5.0
3	Strongly acid	5.1 – 5.5
4	Moderately acid	5.6 – 6.0
5	Slightly acid	6.1 – 6.5
6	Neutral	6.6 – 7.3
7	Slightly alkaline	7.4 – 7.8
8	Moderately alkaline	7.9 – 8.4
9	Strongly alkaline	8.5 – 9.0

2.5.2. Topographic factor

Topography is leveled or sloppiness of surface earth, It can affect crop growth indirectly. As Altitude increase it cause a decrease in temperature and increase in precipitation and wind velocity of the area the reverse is true. While a given is too Steep in slope, it results in run off of rain water and loss of nutrient rich top soil. Slope / Relief and elevation are the most important elements in topography. Relief formation is related to geological and climatic formation of the present and past (Sys *et al.*, 1991). It is important aspect for surface as well as for internal soil water drainage it is also related to land management and erosion hazard while elevation is related to temperature and solar radiation and thus closely linked to plant requirements (Dadhich, 2017).

2.5.3. Climatic factor

For successful rain-fed crop, climatic phenological requirement has to meet within entire growth cycle from germination to crop maturation. Growing period, sun radiation, temperature, rainfall and relative humidity are climatic factors considered in land evaluation (Sys *et al.*, 1991). Water stress will affect crop growth and yield. Temperature can also determine growth rate and development any vegetation. Low temperature may cause poor seed set and delay in flowering and maturation (Sys *et al.*, 1991).

2.6. Agricultural Land Suitability Analysis Procedures

Generally, the recommended process of land-suitability analysis and mapping follows steps.

1. Identifying of land characteristics-land characteristics is identified based on topographic factor, soil factor, climatic LULC, and socioeconomic factor of a given area.
2. Identifying of crop requirements- requirements for growth of different crops can be obtained from available literature and based on the right expert opinion.
3. Matching between land characteristics and crop requirements- this is a phase where land characteristics matching (comparing) with crop requirements.
4. Screening of land suitability options into land use recommendation,

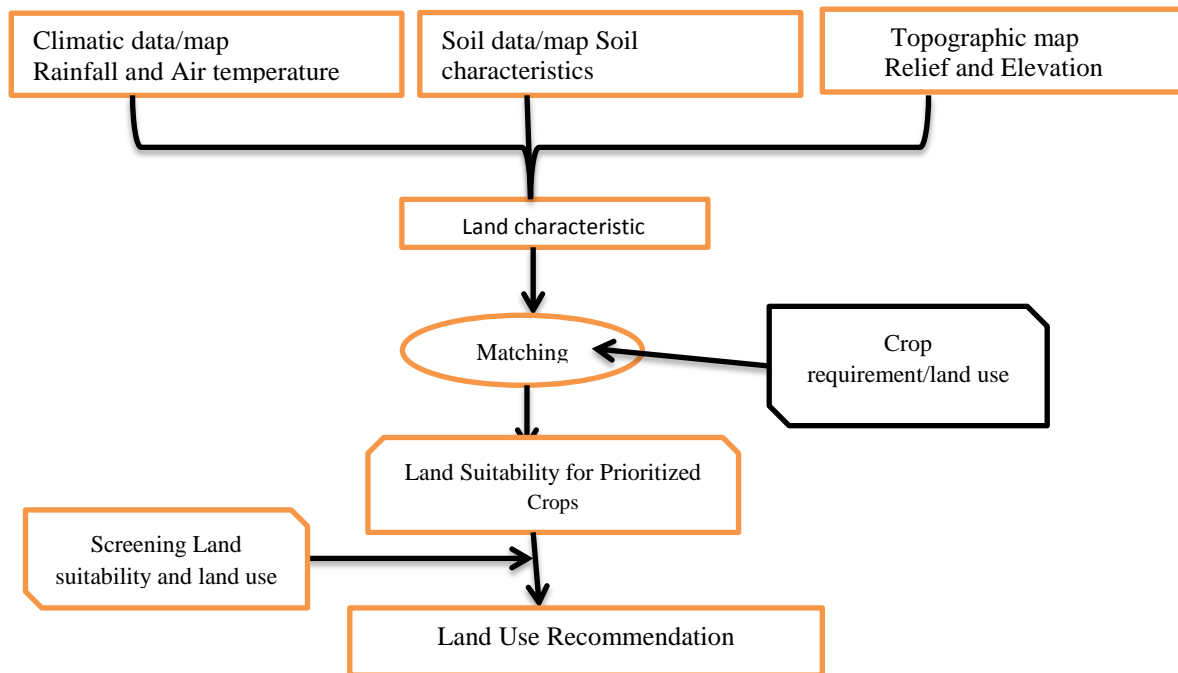


Figure 1 Schematic presentation of the process of land use suitability analysis (Adapted from Ritung *et al.*, 2007)

2.7. Standardization and Ranking

Factor ratings are usually made in terms of five classes: highly suitable, moderately suitable, marginally suitable, currently not suitable, and permanently not suitable.

Table 3 Land suitability classification framework (Adapted from FAO, 1976, 1985 Kassaye *et al.*, 2017).

Order	Class	Description
Suitable(S)	S1 (highly suitable)	Land having no, or in significant limitation to the specified type of use
	S2 (moderately suitable)	Land having minor limitation to the particular type of land use
	S3 (marginally suitable)	Land having sever limitation to the certain type of land use
Not suitable (N)	N1 (currently not suitability)	Land having severe limitations that preclude the given type of use, but can be improved by specific management
	N2 (permanently not suitability)	Land that have so severe limitations that are very difficult to be overcome

2.8. Analytical Hierarchical Process (AHP)

Analytical hierarchical process is the most widely accepted MCDM developed by Prof. Thomas L. Saaty in 1977. AHP is a method in which best decision to be made, it provides measures of judgment consistency, derives priorities among criteria and alternatives, and simplifies preference among criteria using pair wise comparisons (Khwanruthai, 2012)

According to Saaty (1980), AHP factor weight is calculated by comparing two factors with a value range from 9 to 1/9. A rating of 9 indicates that in relation to the column factor, the row factor is more important. On the other hand, a rating of 1/9 indicates that relative to the column factor, the row factor is less important. In cases where the column and row factors are equally important, they have a rating value of 1 (Mugiyo, H *et al.*, 2021).

Table 4 Scale of rating influence (Adopted Saaty, 2001)

Index	Definition	Index	Definition
1	Equally important	6	Strong to very strong importance
2	Equal to moderate importance	7	Very strong importance
3	Moderate importance	8	Very to extremely strong
4	Moderate to strong importance	9	Extreme importance
5	Strong importance		

2.9. Wheat

Wheat is one of the grass family that produces modified fruit which is fused with its single seed, forming the grain. The fruits are borne together in a panicle and the edible part of the seed or grain is called kernel. Wheat is geographically originated in Middle East (ISAAA, 2009). It is a staple food processed into flour and used for different food types; it can be breads, pastries,

pastas, and cereals. It is also can be used for alcoholic beverages and biofuels fermentation of. *Triticum aestivum* L. (bread wheat) and *Triticum durum* (durum or macaroni wheat) are the commonly grown species today (ISAAA, 2009).



Figure 2 Wheat crop (Adopted from MoA wheat production method manual)

2.10. Wheat Production in Ethiopia

In Ethiopia, wheat can be produced by both small-scale farmers and large-scale commercial farms. But small scale farmers are the dominant one interim of area coverage and amount of production (Anteneh *et al.*, 2020).

Ethiopia is one of the top three wheat producers in Africa, which account 20% of the nation's total cereal production. In Ethiopia more than 90% of wheat production is produce on small farms within rain fed farming method (Reidy, 2019).

Due to transformation of cotton land and replacing old sugarcane farms in the northern and southern lowlands with wheat, production of wheat has increased over the last years. In 2020/21 wheat production in Ethiopia is estimated five million tons, which increased by 2% over the 2019/20 product estimation. The 2020/21 harvested area is estimated at 1.85 million hectares and yield estimated 2.76 tons/hectare if we get favorable rainfall all over the growing season in wheat

growing areas. Improved seed varieties and fertilizer application has increased wheat production yields. In addition, as farmers supported by extension agents hope to harvest up to 6.5 t/ha, while the national average wheat production yield are about 2.6 t/ha, which have more than 50% yield gap between commercial and subsistence farmers. This shows there is possibility of increasing production yield with proper agricultural extension to help and adequate inputs (Tefera, 2020).

2.11. Wheat Production Requirement

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, proximity to market and road. These are the most important requirements needed for wheat production. Requirement Factor ratings are sets of values that indicate how well each factor is satisfied by particular conditions of the corresponding land quality (Hunduma, 2012).

CHAPTER THREE

3. RESEARCH METHODOLOGY

3.1. Description of Study Area

3.1.1. Location

The study is a case study conducted in Delo Menna and Harena Buluk District Bale Zone, Oromia National Regional State of Ethiopia, Hawo,Shawe, Sodo Welmel Gomgoma Chiri and Melka Amana Kebeles. Geographically, the study area lies between 6°10'0" to 6°40'0" N and 39°20'0" to 40°0'0" E and found at a distance of 544 km from Addis Ababa capital of Ethiopia.

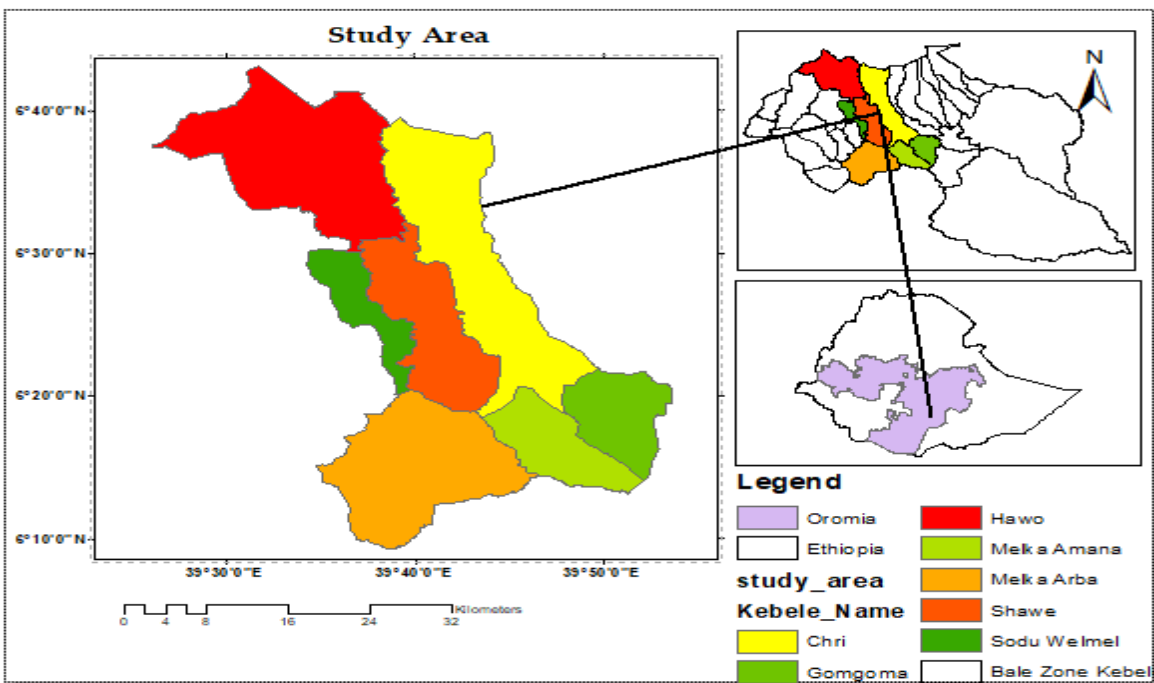


Figure 3 Study area

3.1.2. Topography

Elevation of study area rises from 951 to 3075 meter above sea level. The study area is characterized by a number of landform. The slope is differs from 0 to 38 % large part of the landscape is characterized by flat to almost flat terrain.

3.1.3. Soil

As per FAO soil map, soil types of the study area is varied in Vertisol, Luvisols, Nitosols and Leptosols, Much more the landscape defined by Vertisol which is medium to high potential for agricultural activity, and followed by Luvisols soil type. According to MoA soil data soil depth of the study area was found between 70cm and 175cm. Majority of the area is characterized by very deep and moderately deep soils which is good for crop production. Whereas study area has different soil texture types which are clay, sand clay, clay loam sandy clay loam, loam and sandy loam. Clay loam is dominant soil texture types in the study area. Soil drainage of the study area has poor and moderately poor drainage. Soil pH of study area is in between of 5.118 to 7.125.

3.1.4. Climate

Climate is combination of temperature and rainfall it varies depending on elevation. According to Ethiopian agro ecological zone developed by MoA the study area is much more characterized by temperate zone and same part of the area is characterized as hot temperate agro ecological zone. Annual rainfall of the area varies in between 1182 and 695 mm whereas temperature is in between 30 to 18°C.

3.1.5. Economic Activities

Mixed Agriculture is the major economic activity in the study area which means a mix of animal rearing and farming, particularly farming is the dominant means of earning. There are large uncultivated lands in the area and low farming densities. The first major products of the study area are coffee, maize, different kind fruit and sesame; besides crop production the farmers of the district raise livestock, beekeeping and some commercial activity.

3.2. Data types and source of data

3.2.1. Data

The successfulness of any study is dependent on reliable, latest data and source of data. Which is the most expensive and time taking especially for GIS is marked as a critical stage which can contain a wide variety of geographic data types originating from many diverse sources. As the nature of investigated problem, need diverse data sets, both primary and secondary data and source of data is triangulated in order to fill information gap one by another. Primary data like satellite image, ground truth and interview with different experts are primary data's were used in

this study. Raster and vector spatial data's like climate, soil, topography, GPS point and different shape files is the main secondary data's of this study. Published articles and journals, books, office documents, records and standards like FAO and Minister of Agriculture guide line are secondary data used for this research.

3.2.2. Types of data and their source of data

Table 5 Used data and corresponding data source

Data types	Data source	Format	Purpose of the data
Soil data	Minister of Agriculture	Raster	To generate soil characteristics of the study area
DEM	Geospatial Institution	Raster	To generate slope
Satellite image	https://earthexplorer.usgs.gov	Raster	For mapping LULC of the area
Shape files	Geospatial Institution -BMNP head quarter	Vector	To clip the study area boundary To delineate protected area
Climate data	Meteorology Agency	MS excel	To generate temperature and rainfall surface
Different X and Y coordinate point	Filed survey, Harena district Environment Protection Commission and Agricultural Bureau	MS excel	Used as a ground truth while mapping LULC For suitability analysis validation
Description of the study area	Harena & Delo Menna district Municipality Office	PDF	For description of the study area
Yield data	Interview with farmers and agriculture extension workers	PDF	For result validation

3.3. Software and Hardware devices

In this study the following software's and instrument were used for data collection, acquisition, design, analysis and presentation of the final research results:

Table 6 Hardware device and software used

No	Name	Type of Instrument	Application use
1	ARCMAP 10.7.1	Software	Data visualization, doing map layout, climate factors surface creation and suitability analysis
2	ERDAS IMAGINE	Software	Image classification
3	Google Earth pro	Software	For train sample selection
4	Handheld GPS (GARMIN_78)	Device	To collect ground control point (GCPs)
5	Mobile phone	Device	For photo capturing
6	ExtAhp 2.0 AHP calculator	Software	Calculating weight of the factor

3.4. Data Processing Methods

Since the case involves varieties of spatial and non-spatial data's, numerous methods used in processing those data's to make ready for the analysis. Classification, kiriging interpolation, buffering, land use land cover classification, conversion and analytical hierarchy process are techniques used to process data's in this study.

3.4.1. Processing land use factor

Land use/cover of the area is one factor for assessing suitability of a place for crop production, so mapping LULC of study area is the first obligation. Input data were generated from satellite imageries, field survey and office document.

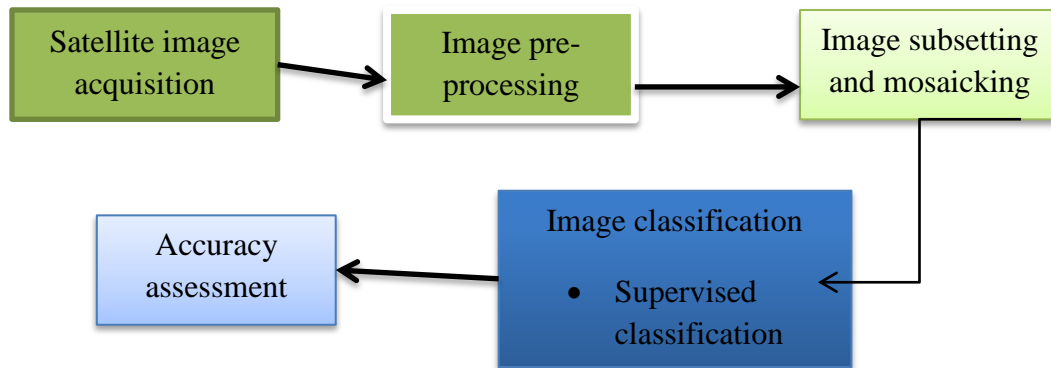


Figure 4 LULC mapping process

In creating land cover spatial data sets two satellite images used because the study area is not covered by one image. The study area is located on two scenes lower edge of (Path=168 Row 055) and upper edge of (Path=167 Row 056). The images on those adjacent scenes were mosaicked to one image covering the study area. Both scenes were acquired on the same year, month and day.

Table 7 Used satellite image

No	LANDSAT_SCENE_ID	SPACECRAFT_ID	WRS_PATH	WRS_ROW	DATE_ACQUIRED
1	"LC81670562021030LGN00"	"LANDSAT_8"	167	56	2021-01-21
2	"LC81680552021021LGN00"	"LANDSAT_8"	168	55	2021-01-21

All bands except panchromatic and eighth bands are layer stacked. Pre-processing techniques were employed before any data analysis and extraction of information, image, in order to more

effectively display for subsequent visual interpretation of image. Image atmospheric noise is corrected through radiometric correction and enhanced by contrast stretching technique using ERDAS IMAGINE 2015 software. After that mosaicking the two images, subsetting study area and classification of image were taking place carefully.

In mapping land use land cover of the area supervised classification techniques and USGES classification scheme were used, as well as maximum likelihood classification algorithm was chosen as a classifier because it assumes that the statistics for each class in each band are evenly distributed and calculates the probability that a given pixel belongs to a specific class. Each pixel is assigned to the class that has the maximum probability. Accordingly seven possible LULC types were identified in the study area.

Table 8 LULC class and their description

Class	Descriptions
Settlement	Scattered rural settlement
Forest land	Tropical evergreen forest with closed canopy. Natural forest including <i>Hagenia Abyssinica</i> bamboos, same deciduous forest, forest coffee and many other endemic trees
Shrubs:	Areas covered with different species of shrubs and bushes
Grassland	Lands has grass cover used for communal grazing
Coffee farm	Planted and forest/natural coffee
Bare land	Un used open and exposed to rock lands
Crop land	Crop fields for perennial or seasonal crop

In order to map 2021 LULC of the area training samples that are known to be representative for each particular land cover type were selected in ERDAS IMAGINE 2015 software using prior knowledge of the area, tour on Google earth pro by synchronizing with ERDAS IMAGINE 2015 software and GPS points from field visit for accessible areas and office records. 18 spots of settlement, 9 spots of forest 11 spots of shrub lands, 8 spots of grass land, 11 spots of coffee farm, 15 spots of bare lands and 20 spots of crop lands in general 92 training samples were collected from study area. Succeeding this, supervised LULC classification has been carried out carefully.

Once again using ERDAS IMAGINE 2015 software, accuracy assessment has been done to check level of error of the classified image. A common ways to assessing accuracy is error matrix which compares pixels or polygons in a classified image against ground reference data

(Jensen 2005) in this study accuracy assessment has done accordingly using 139 ground truths from field visit and different office documents as a reference data for mapping LULC of the area in the year 2021 in this study. Lastly the result is overlaid with other factor in ArcGIS environment for assessing suitability of the area for wheat production based on its influence in wheat production.

3.4.2. Processing climatic data

Likewise climatic distribution of the area is one factor that has to be considering in wheat suitability analysis. Both rainfall and temperature climate data were collected from the Ethiopian Meteorology Agency. Daily rainfall and temperature from 2008 to 2017 for five stations namely Goba, Beriberi, Delo Menna, Melka Amana, Nensebo and Angetu weather station were taken into account in this study for creating rainfall and temperature surface. Creating rainfall and temperature surface is started by checking available data, missed or unrecorded data's are fulfilled using arithmetic mean method which takes the average value of before and after missed point. As the weather stations are poorly distributed, kriging interpolation method used to interpolate climatic factors of the area by checking and exploring data for getting better understanding of the data. After rainfall and temperature surface of the study area is generated, climatic suitability classes for the parcel were created by classifying factor using wheat crops requirement standard. Lastly, factors were overlaid with others for mapping suitability of the area for wheat production based on their influence.

3.4.3. Soil data

Soil data is also other parameter for crop land suitability analysis. Likewise identification of soil characteristics for the area followed by soil data classification based on adopted requirements ranking. The classified soil characteristics overlaid with other criteria for mapping wheat suitability analysis for the study area based on its influence for wheat production. The attribute table of soil texture used in this study originally prepared in code but renamed based on legend taken from MoA.

3.4.4. Topographic data

Slope and elevation are topographic factor to evaluate land suitability they were derived from digital elevation model (DEM) by using ArcMap10.7.1. As similarly as all of above stated

factors, topographic data is also classified and overlaid with other criteria based on their weight of influence for mapping wheat suitability analysis of the study area.

3.5. Data Analysis Methods

Since the case involves many spatial decision issues, GIS-based multi_ criteria decision making (MCDM) has been used to analyze set of criteria's in order to solve problems and making judgments in land use planning by mapping suitability of the area for wheat production.

3.6. Methods of Wheat Suitability Analysis

Assessing suitability of land for crop production is influenced by numerous factors and requires comprehensive and complex set of procedures. The champion weighted overlay analysis has been used to integrate set of criteria's in order to analysis suitability of the area for intended purpose and solve agricultural planning and management problems. So as to produce a virtuous suitability map that shows suitability class for wheat production of the study area, the following activities were sequentially executed.

3.6.1. Factor and constraint Identification

Identification of factors and constraint is the first steps of land suitable analysis. Selecting those criteria was supported accordingly by light of literature review of related previous works and consulting agricultural experts of MoA and Sinana Research Center. Physical and chemical properties of soil, climate, topographic and land use factors such as soil depth, texture, drainage, pH and organic matter, rainfall, temperature, slope, altitude and LULC of the area were taken in to account as a factor and protected area is take as a constraint to analysis suitability of the area for wheat production but it does not mean these are the only parameters requisites for crop land suitability analysis, socioeconomic and political factors are not including in this study due to lack of data availability, financial constraint and time. Hunduma (2012), Motuma (2014) and Mulugeta (2010) also use those above mention factors for analysis suitability of agricultural land using GIS and remote sensing method.

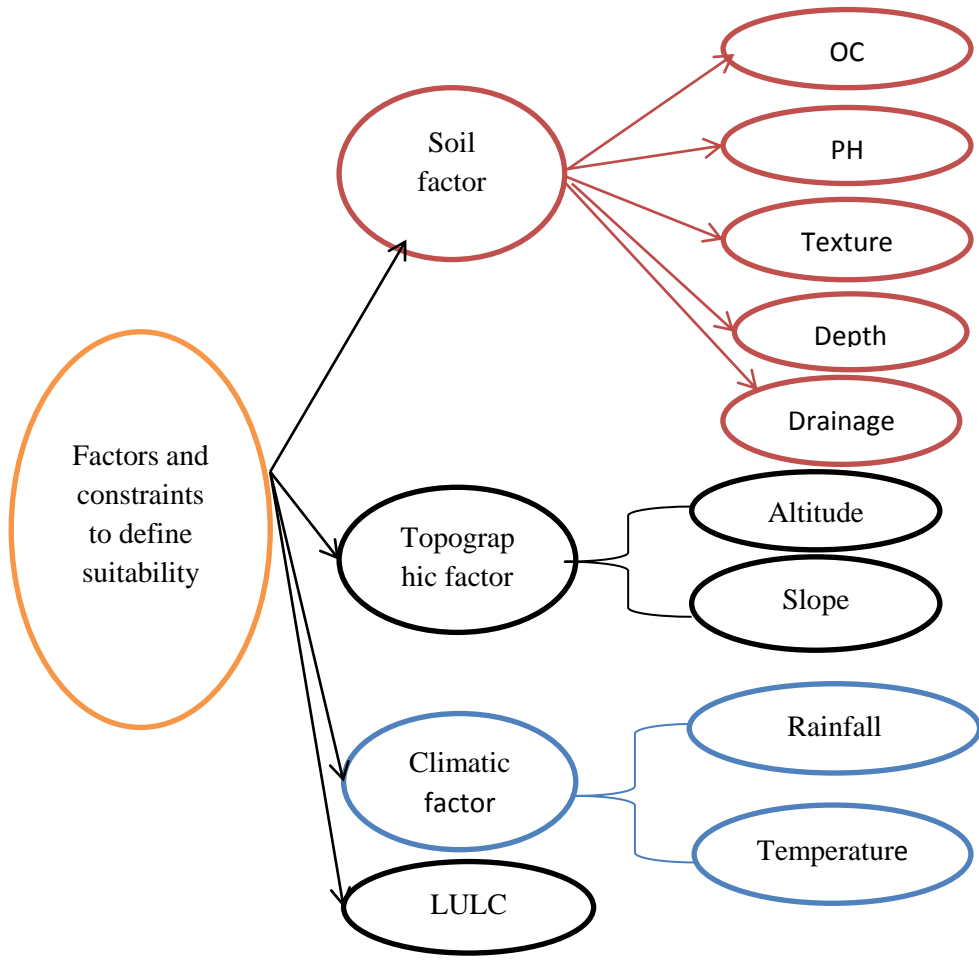


Figure 5 Criteria considered in the study

Based on legal restriction protected area is assumed as a constraint. According to country land use policy practicing agricultural activity specially farming or plowing land is not allowed in and around parks. Geographically the study area shares around 150 km² from Bale Mountain National Park. In the area peoples already settled illegally in and around the park boundary but now district authorities negotiate to make buffer zone in 100m and prohibiting the use. The assessment of constraint factor in terms of land use is represented in true or false condition. Zero value is impossible, and 1 value is possible to use. Constraint Boolean map with value of 0 and 1 aggregate with weighted overlay analysis result.

3.6.2. Suitability ranges and degree of limitation

Wheat Suitability requirement standard and degree of limitation are selected on the light of literature review and expert opinion. The standard is mainly adopted from Girmay et al. (2018) Land capability classification and suitability assessment for selected crops in Gateno watershed,

Ethiopia. Recently Fekadu & Negase (2020) also used this crop requirement in studying GIS assisted suitability analysis for wheat and barley crops through AHP approach at Yikalo sub watershed, Ethiopia. As this standard used in many part of our country Ethiopia this implies the crop requirement is applicable and relevant for assessing suitability of an area for wheat production.

The most commonly used degree of limitation by (Sys et al., 1993) is used in ranking suitability class. In this phase, all considered factors were classified and mapped accordingly which varies in between suitable and not suitable. Highly suitable (S1) means land having no or in significant limitation with >85 degree of limitation, moderately suitable (S2) means land having minor limitation with 85–60 degree of limitation, marginally suitable (S3) means land having moderate limitations with 60-40 degree of limitation, currently not suitable (N) means land with severe limitations got 40-25 degree of limitation and permanently not suitable (N2) means land that have so severe limitations that are very difficult to be overcome with 25-0 degree of limitation.

Table 9 Wheat requirement factors and their suitability range Adapted from Sys et al. (1991; 1993), Teshome and Verehye, (Hunduma, 2012, Lupia 2014, Girmay et al. (2018) and Fekadu & Negase (2020)

Factors/ Criteria	Range of Suitability				
	Highly Suitable (S1) >85%	Moderately Suitable (S2) 85–60%	Marginally Suitable (S3) 60-40%	Currently not suitable(N1) 40-25%	Permanently not suitable(N2) 25-0%
Texture(class)	C, Si, SiC, SiL, SC	L, CL, SiCL	SCL	SL	S
Drainage(class)	W, SE, E	MW	I	P	V
Soil depth(cm)	>90	50–90	20–50	10-20	<10
Soil pH	6.5-7.5	5.6-6.5 or 7.5-8.2	5.2-5.6 or 8.3-8.5	<5.2	>8.5
Soil OC (%)	1.5-2.5	1.0-1.5	0.5-1.0	<0.5	
Temperature	14.9-18.4	14.4-14.9 or 18.4-19.4	13.4-14.4 or 19.4-20.8	12.4-13.4 or 20.8-21.3	< 12.4, >21.3
Rainfall(mm)	700-1000	1000-1250	1250-1500	1500-1750	< 700, > 1750
Slope (%)	< 8	8-16	16-30		>30
Elevation(m)	2000-2600	1500-2000 or 2600-3000	3000-3300	< 1500, > 3300	
Land use/cover	Cultivated land	Barren land	Shrub land	Grazing land, coffee farm	Water body, Forest, Settlement

Note: W = well drained, MW = moderately well drained, I= imperfectly drained, P = poorly drained, VP = very poorly drained, E = excessively drained, SE = somewhat excessively drained,

C= clay, Si= silty, SiC = silty clay, SiCL = silty clay loam; CL = clay loam; SiL = silt loam; SL = sandy loam; L = loam; SCL = sandy clay loam; SL = sandy loam, S = sand SC=sand clay

3.6.3. Weight standardization

Suitability analysis involves different parameters, but all parameters do not have the same influence on growth rate, crop yield or production of that specific crop. So weight of influence has to be assigned for each criterion's. AHP method introduced by Saaty (1980) technique is used in order to compute weights by comparing two particular parameters for the intended purpose. Based on expert opinion weight of all climatic, topographic, soil and LULC factors were calculated by pairwise comparison. For decision-making all factors are automatically computed using this AHP calculator which is extAhp 2.0 software based on their comparative significance.

Table 10 Pairwise comparison matrix

Factor	Elev.	Slope	Drainage	Depth	pH	OC	Texture	Land use/cover	Rainfall	Temperature
Elevation	1	0.167	0.2	0.125	6	2	0.2	0.2	0.167	3
Slope	6	1	0.5	0.2	5	0.3	5	2	0.25	6
Drainage	5	2	1	5	3	2	3	0.2	0.167	0.25
Depth	8	5	0.2	1	7	2	0.25	0.2	0.143	0.5
pH	0.167	0.2	0.3	0.143	1	5	6	4	6	4
OC	0.5	3	0.5	0.5	0.2	1	0.5	2	0.5	0.333
Texture	5	0.2	0.3	4	0.167	2	1	5	7	3
Land use/cover	5	0.5	5	5	0.25	0.5	0.2	1	0.25	0.2
Rainfall	6	4	6	7	0.167	2	0.143	4	1	8
Temperature	0.3	0.167	4	2	0.25	3	0.3	5	0.125	1

3.6.4. Land suitability analysis

Land suitability analysis is an aggregation of all factors and constraint based on factors influence of for intended purpose. In doing all reclassified thematic layers:-climatic, topographic, soil and land use land cover layers are overlaid using weighted overlay analysis in ArcGIS environment using equation 1.

$$S = \sum_{i=1}^n W_i X_i \dots \dots \dots \text{equ-1}$$

Whereas:-

- S is suitability,
- W_i is factor map, and

- Xi is weight of factor i.

Constraint aggregation

For mapping suitability of the area for wheat production constraint Boolean map with value of 0 and 1 whereas 0 represent areas that not allowed and 1 for permitted to use, aggregated with result of weighted overlay analysis in raster calculator by using equation 2. At the end the result will be analyzed accordingly for each land map unit.

$$LSA=S* Bo/1.....equ-2$$

Whereas:-

- LSA is land suitability analysis,
- S is result of weighted overlay analysis
- Bo/1 is constraint map with Boolean of 0 and 1.

3.6.5. Suitability result validation

Validation is done for checking whether suitability analysis result is logical or not. The result is validated through correlating the observed yield with average expected yield of suitability analysis result. Actual yield was obtained from study area wheat producer of three production season and expected production yield for suitability class is prepared based on production yield of wheat in Bale Zone. In the study area there is little number of farmers produce wheat so actual production yield data used to validate suitability analysis result is too few.

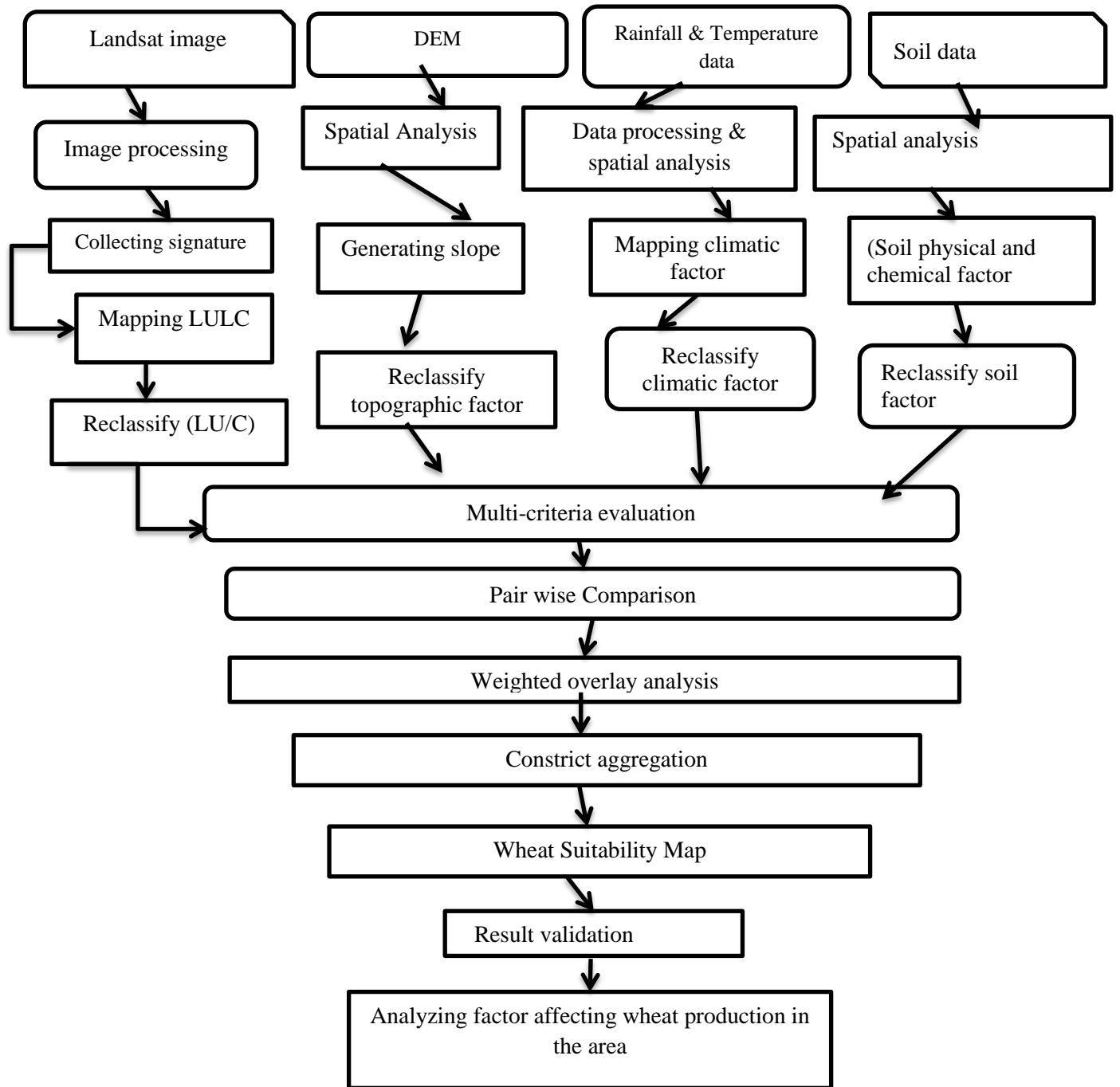


Figure 6 Schematic flow chart of research methodology

CHAPTER FOUR

4. RESULT AND DISCUSSION

4.1. Result of factor and constraint analysis

Weighted overlay is used to produce land suitability for wheat production, by integrating different factors which have different weight and constraint on doing the analysis. All factors were reclassified on the roots of FAO (1976; 1984) framework for land evaluation in five-suitability classes. Reclassification classes were represented by 1 to 5 numbers. Where 1 is highly suitable (S1); 2 moderately suitable (S2); 3 marginally suitable (S3); 4 is currently not suitable (N1); and 5 permanently not suitable (N2). As all factors do not have equal importance on analyzing suitability of wheat production, weight of those criteria is done through pairwise comparison. Finally all climatic, topographic and soil as well as land use parameter were overlaid in GIS environment. Result of weighted overlay analysis is aggregated with constraint map for mapping suitability of the area for wheat production. Estimation of area coverage is undertaken accordingly and finally the result was validated carefully.

4.1.1. LULC suitability analysis for wheat production

Mapping of current land-use land cover

In the area seven LULC types were identified for the purpose of this study. Accordingly, crop land, forest, shrub land, grassland, rural settlement, coffee farm and bare land are identified (Table 11). The spatial distributions of land use/land cover of the study area (Figure 7).

Table 11 Current LULC and their corresponding area coverage of the study area

LULC	Area (km ²)	Percent% of the total area
1 Crop Land	493.3	40.1
2 Forest	284.3	23.1
3 Shrub Land	105.6	8.6
4 Grassland	13	1.1
5 Rural Settlement.	17.9	1.5
6 Coffee Farm	173.9	14.1
7 Bare Land	142.6	11.5

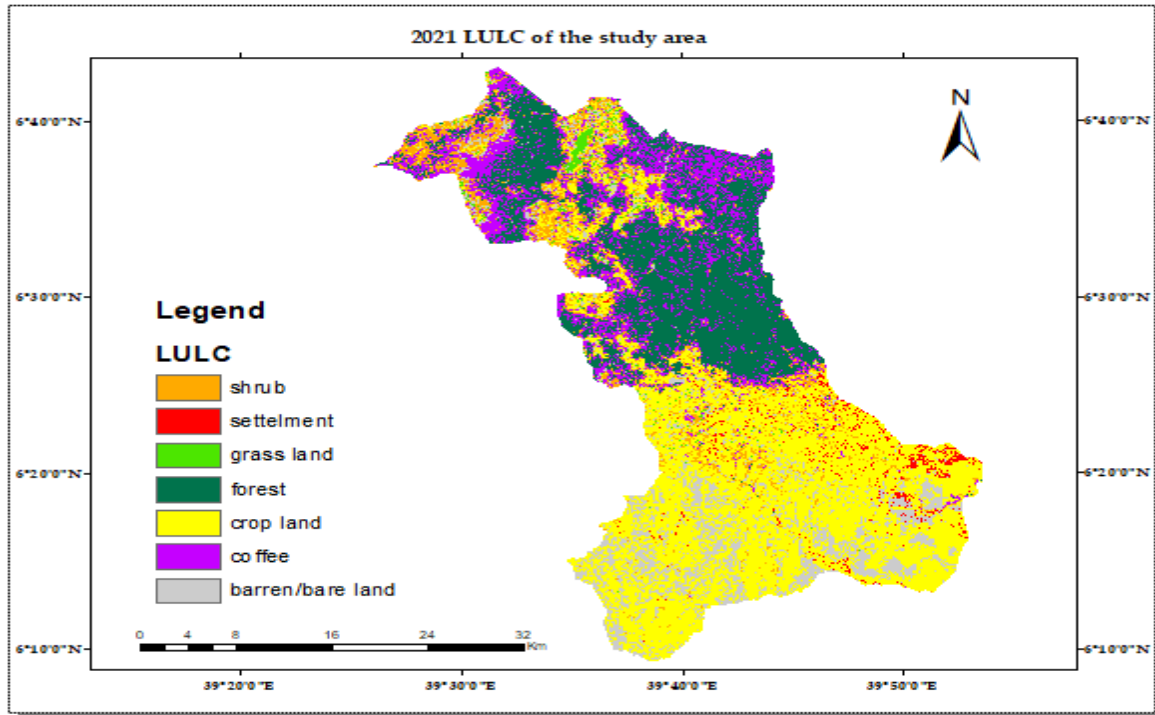


Figure 7 Current LULC map of the study area

Overall classification accuracy of the LULC of the area for the year 2021 was computed by building error matrix (Table 12), producers and user accuracy measures (Table 13), and conditional Kappa statistics (Table 14). Accordingly, with 89.21% of overall classification accuracy and 0.8674 of overall Kappa statistics, classification and mapping of the current LULC was verified.

Table 12 Error matrix

		Reference Data							Total
		Forest	Crop land	Rural settlement	Grassland	shrub	Coffee farm	bare	
Classified Data	Forest	35	0	0	0	0	2	1	38
	Crop land	0	29	0	2	1	0	1	33
	Settlement	0	0	1	1	2	0	0	4
	Grassland	0	0	0	5	0	0	0	5
	Shrub	0	0	0	1	17		0	18
	Coffee farm	1	0	0	0	0	21	0	22
	Bare	0	0	2	1	0	0	16	19
	Total	36	29	3	10	20	23	18	139

Table 13 Producer and user classification accuracy

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
Crop land	29	33	29	100.00%	87.88%
Bare land	18	19	16	88.89%	84.21%
Rural settlement	3	4	1	33.33%	25.00%
Grassland	10	5	5	50.00%	100.00%
Forest	36	38	35	97.22%	92.11%
Coffee	23	22	21	91.30%	95.45%
Shrub	20	18	17	85.00%	94.44%
Totals	139	139	124		

Overall Classification Accuracy = $\text{number of correct} \times 100 / \text{total number of plots}$
 $124 \times 100 / 139 = \underline{89.21\%}$

Table 14 Conditional kappa statistics

Conditional Kappa for each Category	
Class Name	Kappa
Crop land	0.8468
Bare land	0.8186
Rural settlement	0.2335
Grassland	1.0000
Forest	0.8935
Coffee	0.9455
Shrub	0.9351

Overall Kappa Statistics = 0.8674

Current LULC suitability analysis for wheat production

After mapping the LULC, the area was reclassified based on considered suitability requirements. (Table 15) presents LULC suitability class and their corresponding area coverage in Km² and %. With this reclassification, 493.3 km² (40.1%) of the study area was highly suitable, 142 km² (11.6%) of the study area was moderately suitable, 105.6km² (8.6%) is marginally suitable, 187km² (15.2 %) was currently not suitable while the remaining, i.e., about 24.6% LULC of the area was permanently not suitable for intended purpose.

Table 15 LULC Suitability class for wheat production and their corresponding area coverage

Suitability Class	Area (km ²)	Percent%
S1	493.3	40.1
S2	142.6	11.6
S3	105.6	8.6
N1	187	15.2
N2	302.3	24.6

Then after, the general LULC suitability map of the area was prepared for intended purpose (Figure 8). As it can be seen from Figure 9, highly to moderately suitable land for farming is at the southern part of the study area; however, with patch of marginally suitable areas. On the other hand, permanently not suitable land area is situated at the center-and-eastern part of the area, while the northern and north-western parts were classified as currently not suitable with patches of marginally to highly suitable areas (Figure 8).

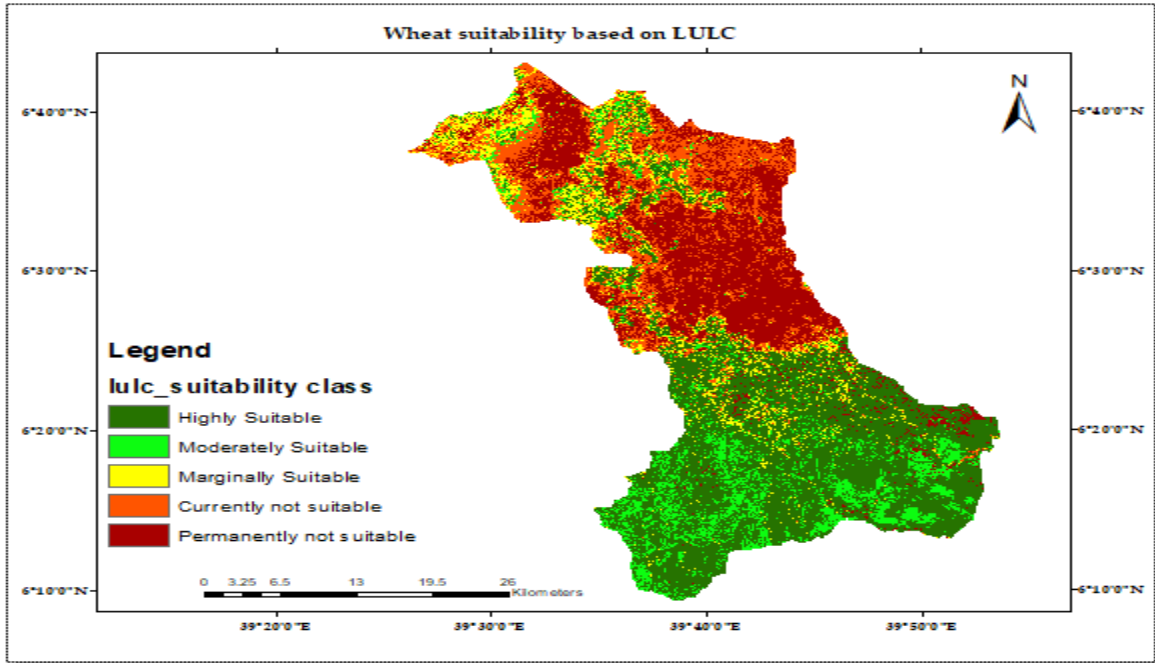


Figure 8 LULC suitability

4.1.2. Topographic suitability for wheat production

Slope and elevation were two topographic factors taken in to account in this study which analyzed in ArcGIS environment as follow.

I. Slope suitability for wheat production

Slope is the inclination of land surface, it has enormous influence on agricultural activity and land management, as steepness of land change land utilization and management also change (Henok Mulugeta, 2010). Slope of the area is classified into five as flat; gently sloppy, sloping, hilly and mountainous (Figure 9).

Table 16 Study area by slope class and corresponding area coverage

Slope class	Slope Range (%)	Area (km ²)	Percent%
Flat	0-3	966.1	80.3
Gently sloppy	3-8	133.3	10.3
Sloping	8-15	82.3	6.1
Hilly	15-30	49.1	3.3

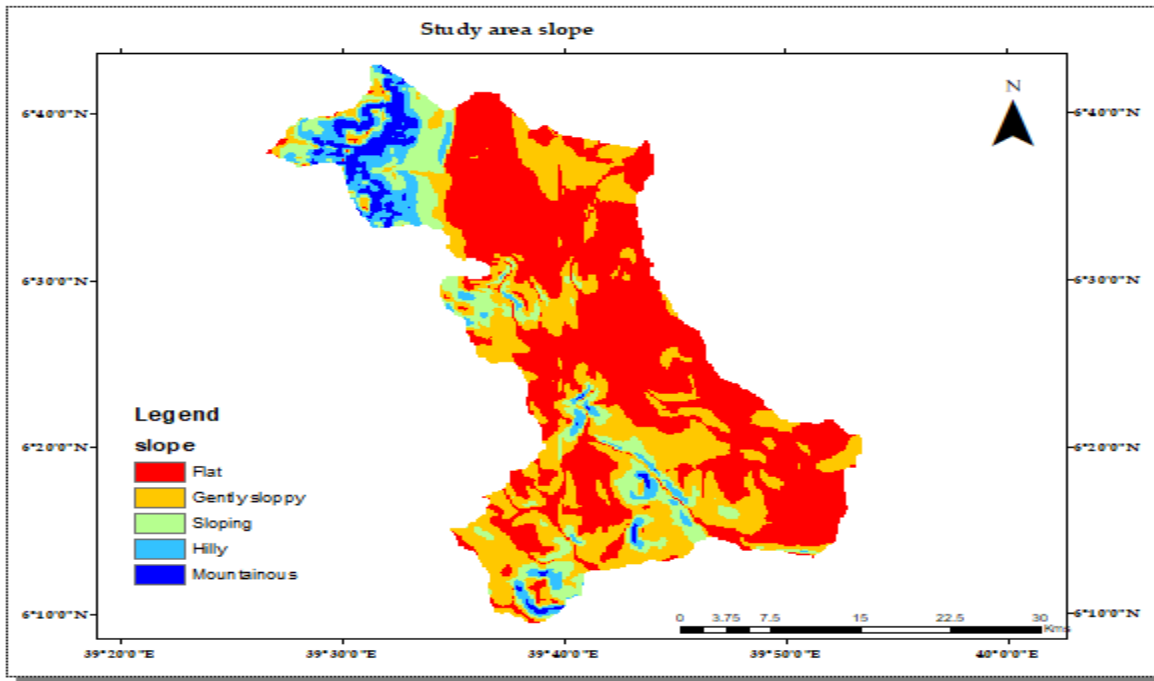


Figure 9 Study areas by slope class

Based on the slope range of the area, the study area is classified in to four wheat suitability class which is S1, S2, S3 and N1 (Figure 10). Accordingly 78.7% of the study area was found to be Highly Suitable, while 11.8, 6.0, and 3.5 % of the area is moderately and, marginally suitable and permanently not suitable for wheat crop production respectively (Table17).

Table 17 Slope based wheat suitability class and their corresponding area coverage

Suitability Class	Area (km ²)	Percent%
S1	968	78.7
S2	145	11.8
S3	74	6.0
N2	43	3.5

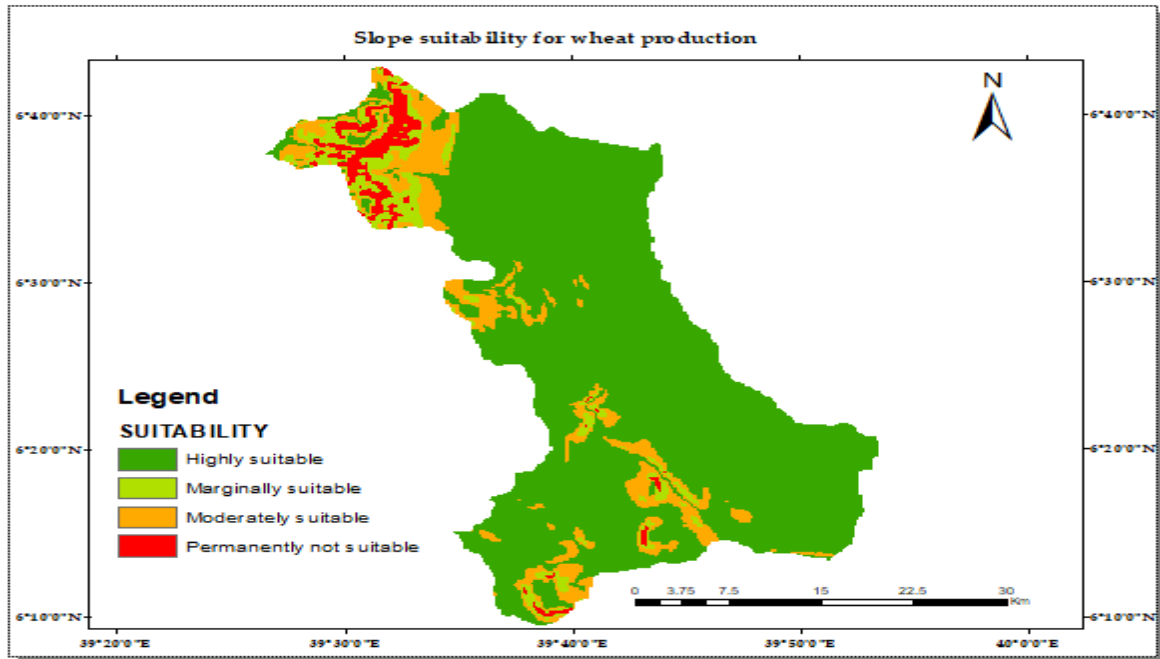


Figure 10 Slope suitability

Wheat suitability based on elevation

Elevation of a place can matter temperature, rainfall and solar radiation, it can affect selection of crop variety, growth rates, and reproductive capacity. (Ritung, 2007) Elevation of the study area is raise from 3075 down to 951 m above sea level as (Figure11).

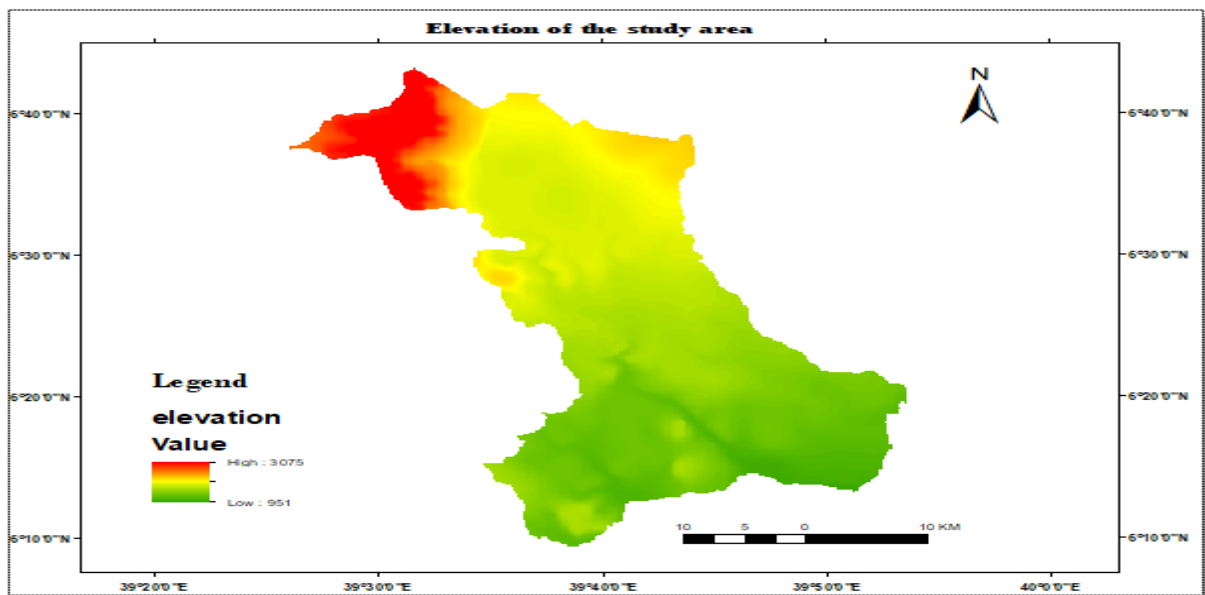


Figure 11 Elevation of the study area

Based on elevation requirement of wheat, elevation of the study area was classified in to four suitability classes (Figure 12). As a result the dominant area of the study area is currently not suitable for wheat production based on elevation of the area. As shown on (Table 18) 6.02% of the study area was found to be highly suitable, 38.49% of the area was moderately suitable, 0.25% is marginally suitable and 55.24% of the area was currently not suitable for wheat crop production.

Table 18 Elevation suitability class for wheat production and their corresponding area coverage

Suitability Class	Area (km ²)	Percent%
S1	74.13	6.02
S2	473.74	38.49
S3	3.05	0.25
N1	679.84	55.24

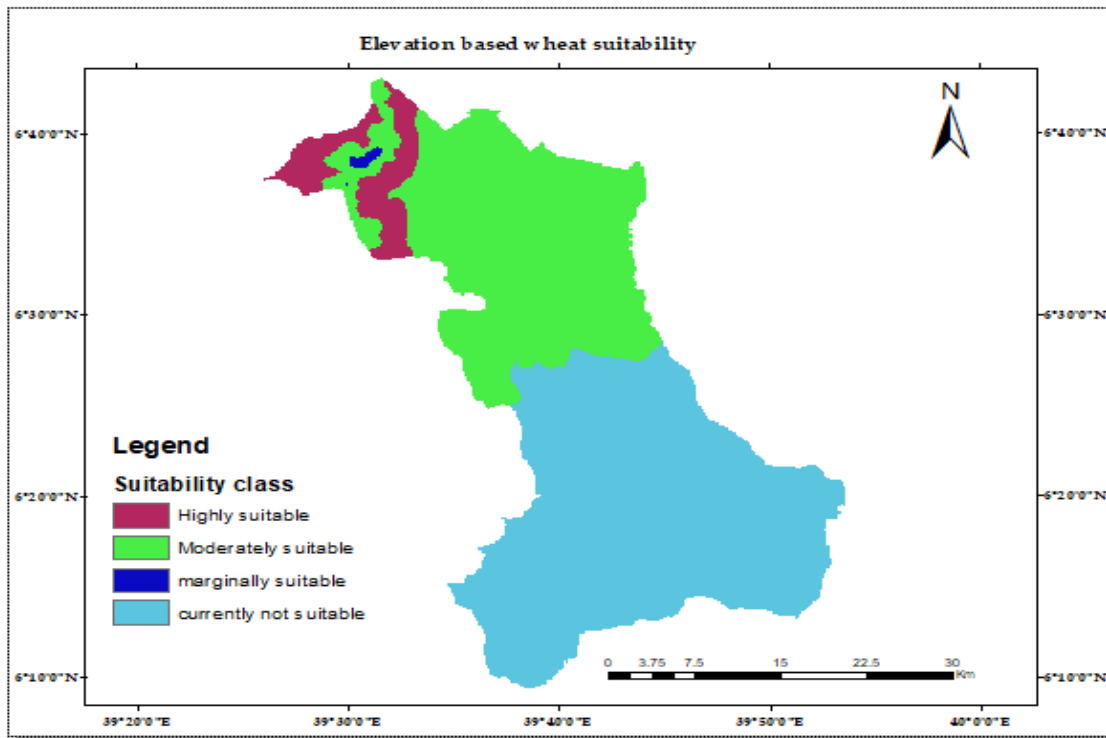


Figure 12 Elevation of study area suitability for wheat production

4.1.3. Climatic factors Suitability analysis for wheat production

As agricultural activity of the study area was highly depending on rain-fed so its distribution plays a vital role in assessing agricultural suitability. So the study considers climatic factor as criteria to assess land suitability for wheat production. Rainfall distribution of the study area was

found between 1182 and 695 mm per a year and the temperatures ranges from 18^oc to 30^oc (Figure 13).

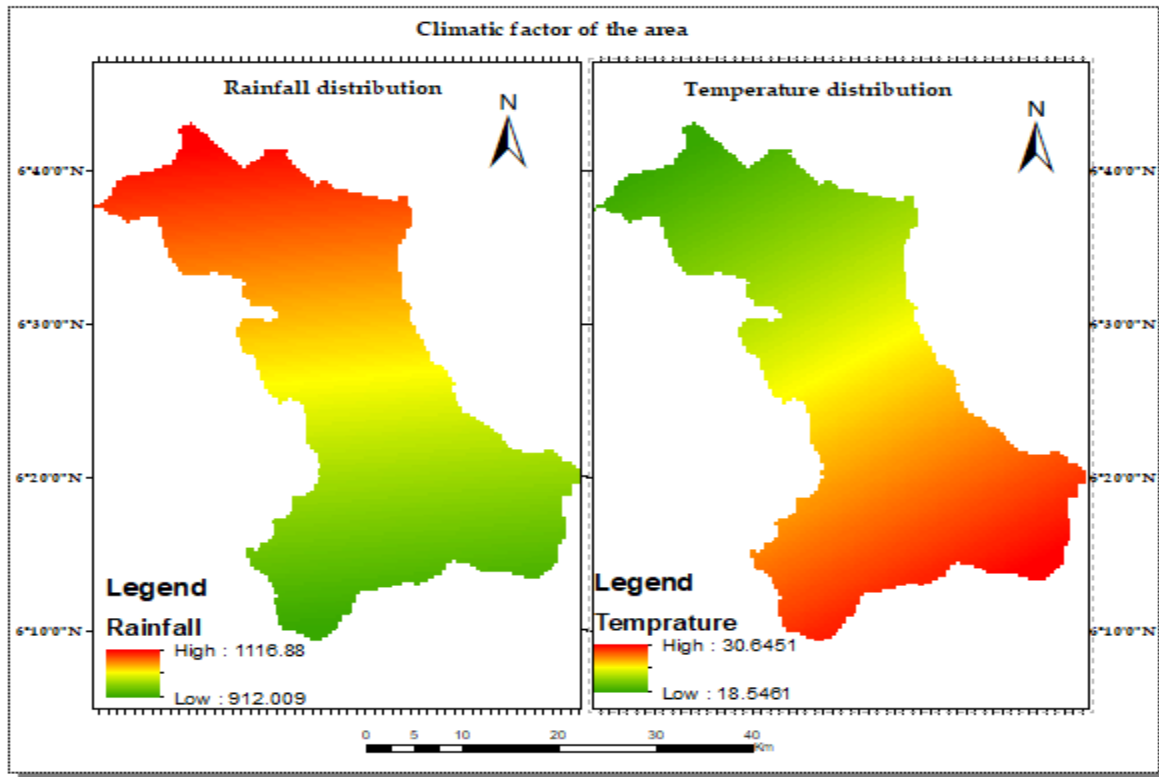


Figure 13 Climatic map of the study area

I. Wheat suitability analysis based on rainfall distribution

Rainfall was one of climatic factor in evaluating suitability for wheat production of the study area. After the evaluation made rainfall distribution of the area was classified into three suitability classes which was highly suitable, moderately suitable and permanently suitable class were identified for wheat production (Figure 14). 68 % of the area was highly suitable and 31% of the area is moderately suitable and 0.12 % of the area was permanently not suitable for wheat production based on rainfall distribution of the area.

Table 19 Rainfall suitability class for wheat production and their corresponding area coverage

Suitability Class	Area (km ²)	Percent%
S1	842.5	68.48
S2	386	31.4
N2	1.5	0.12

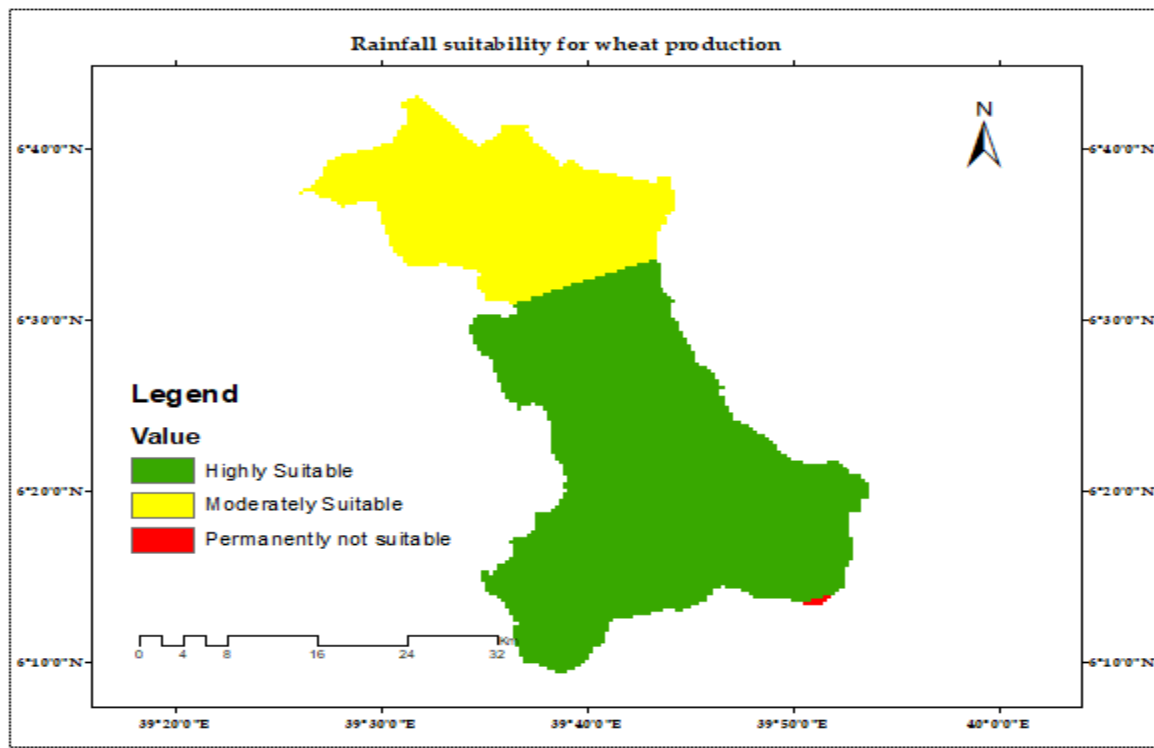


Figure 14 Rainfall suitability

II. Temperature suitability analysis for wheat production

After the analysis done on temperature distribution of the study area four suitability classes for wheat production based on stated suitability requirement standard that was moderately suitable, marginally suitable, currently not suitable and permanently not suitable class is identified (Figure15). As a result 83% of the area was permanently not suitable for wheat production based on temperature distribution this implies temperature of the area was the main limiting factor for producing wheat. 3% was moderately suitable, 10% was marginally suitable and 4% of the area was currently not suitable for wheat production (Table20).

Table 20 Temperature suitability classes for wheat production and their corresponding area coverage

Suitability Class	Area (km²)	Percent%
S2	34.2	3
S3	116.9	10
N1	49.9	4
N2	1028.7	83

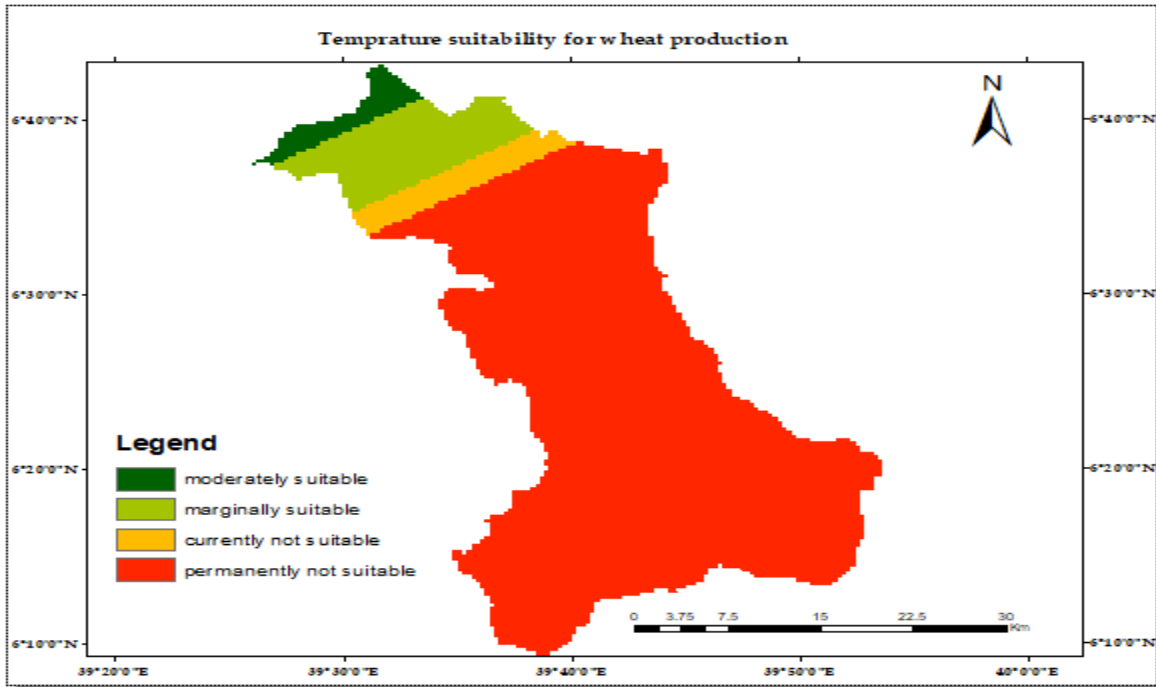


Figure 15 Wheat suitability based on temperature

4.1.4. Soil factors Suitability analysis for wheat production

Soil characteristics were taken into account in this study was analyzed in ArcGIS accordingly as follow for mapping wheat suitability for the area based on used suitability limitation range.

I. Wheat suitability based on soil depth

Soil depth of the study area is in between 70cm and 175cm. Soil depth of the area can be grouped into three depth class based on class range adopted from Mulugeta (2010). The result showed 56.85% was very deep said to be good for crop production, 43.03% was deep and 0.12% of the area was moderately deep (Table 21).

Table 21 Soil depth class and their corresponding area coverage

Soil depth	Slope range (cm)	Area (km ²)	Percent%
Moderately deep	70-100	1.48	0.12
Deep	100-150	529.2	43.03
Very deep	>150	699.04	56.85

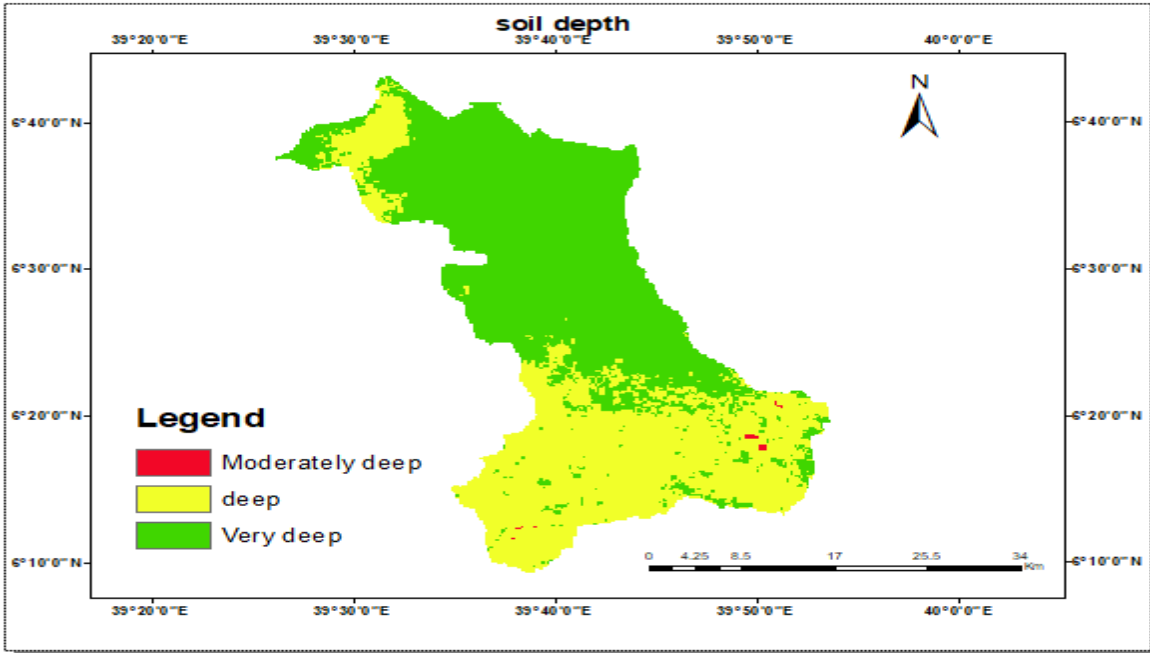


Figure 16 Soil depth of the study area

In analyzing suitability of the area for wheat production, soil depth of the area classified based on specified requirement suitability range. Classification result done on soil depth of the area show highly suitable and moderately (Figure 17) which is 99.98% and 0.02% coverage respectively (Table 22).

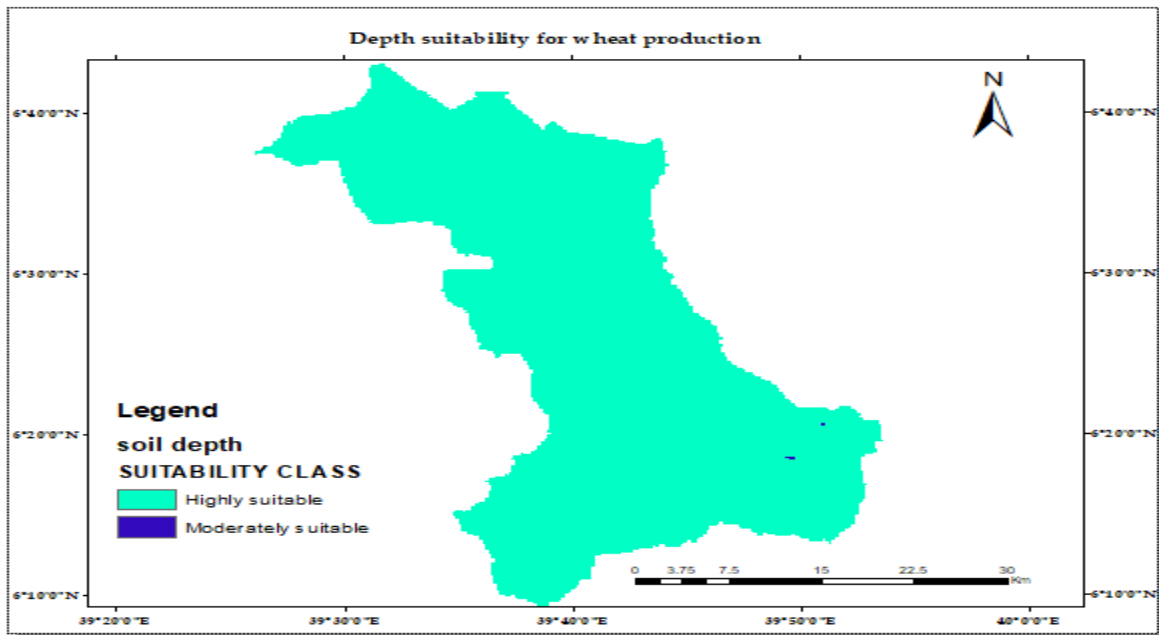


Figure 17 Wheat suitability based on soil depth

Table 22 Soil depth suitability class for wheat production

Suitability Class	Area (km ²)	Percent%
S1	1229.49	99.98
S2	0.17	0.02

II. Wheat suitability based on soil texture

The study area had six soil texture types which were clay, sand clay, clay loam sandy clay loam, loam and sandy loam (Figure 18). Clay loam was dominant soil texture types in the study area.

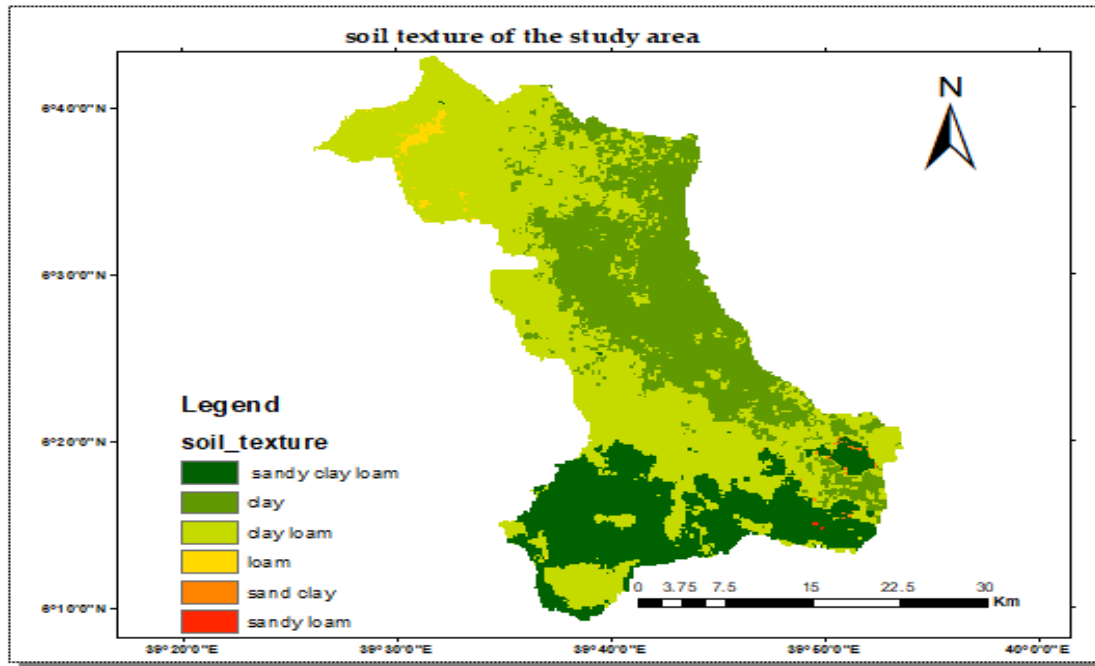


Figure 18 Soil texture of the study area

Table 23 Soil texture types and their corresponding area coverage

Soil texture types	Area (km ²)	Percent%
Clay	357.94	29.12
sand clay	1.79	0.15
clay loam	614.43	49.98
sandy clay loam	246.53	20.06
Loam	8.42	0.69
sandy loam	0.13	0.01

Result of suitability analysis for wheat production based on soil texture of the area shows four suitability classes (Figure 19). 50.68% of the area was moderately suitable, 29.26% is highly

suitable, 20.05% was marginally suitable and 0.01% goes to currently not suitable for wheat production (Table 24).

Table 24 Soil texture suitability class for wheat production and their corresponding area coverage

Suitability Class	Area (km ²)	Percent%
S1	359.69	29.26
S2	623.1	50.68
S3	246.5	20.05
N1	0.13	0.01

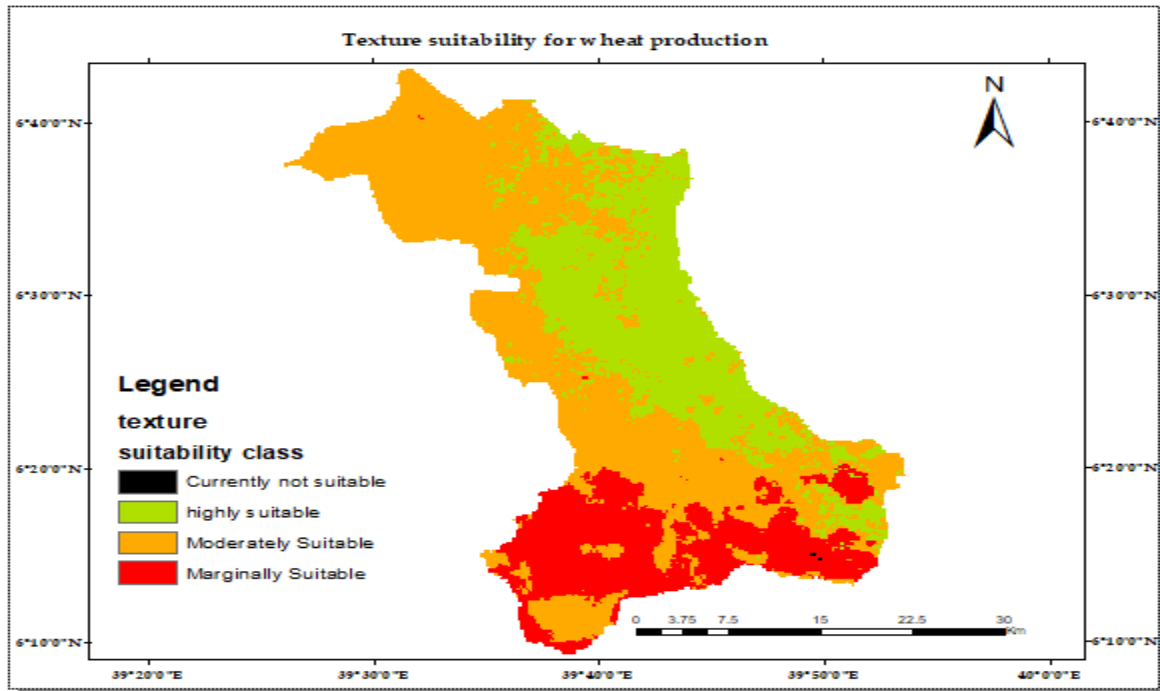


Figure 19 Wheat suitability analysis based on soil texture

III. Wheat suitability based on soil drainage

Soil drainage is also one of soil factor in analyzing suitability of land for crop production. The study area had two soil drainage classes which were poor and moderately poor (Figure 20). 46.8% of the area had moderately poor drainage and 53.2% was poor drainage (Table 25).

Table 25 Soil drainage types and their corresponding area coverage

Soil drainage types	Area (km ²)	Percent%
Poor	651.31	53.2
Moderately poor	572.92	46.8

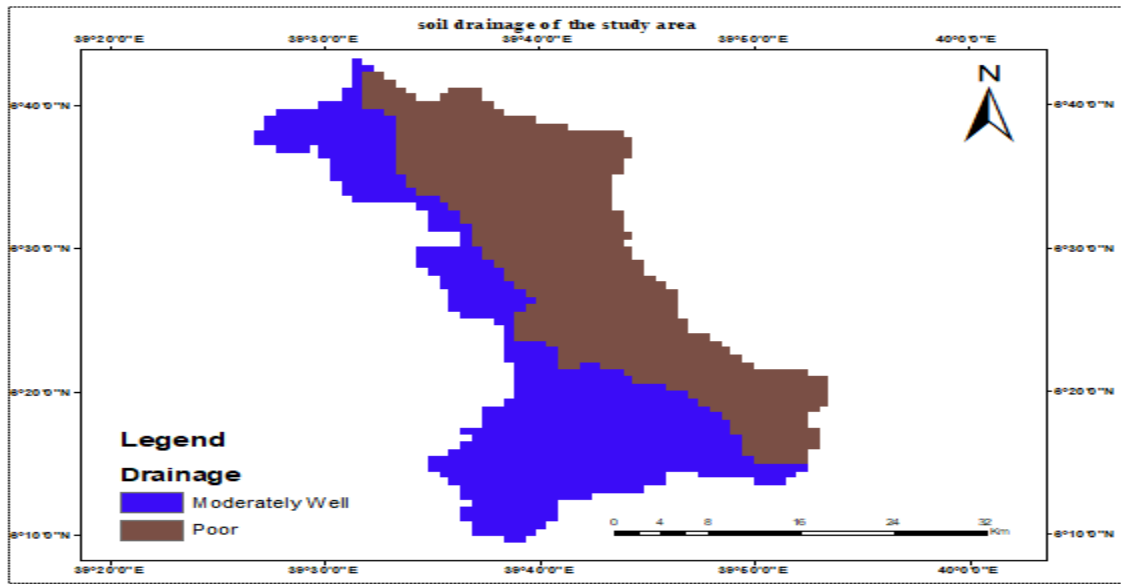


Figure 20 Soil drainage of the study area

The result of suitability analysis shows that as soil drainage of the area was classified into two which was moderately suitable and currently not suitable (Figure 21). 53.2% of the area was moderately suitable and 46.8% was for marginally suitable for wheat production (Table 26). This indicated that poor soil drainage is not currently suitable, whereas moderately well drain is moderately suitable for wheat production.

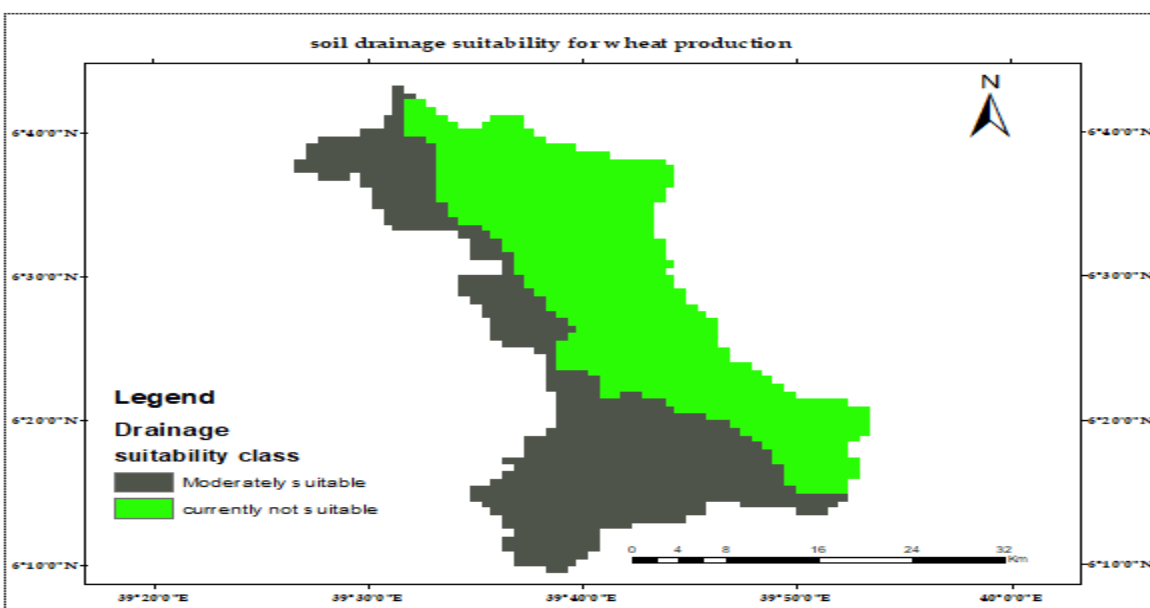


Figure 21 Wheat suitability based on soil drainage

Table 26 Drainage suitability class for wheat production and their corresponding area coverage

Suitability class	Area (km ²)	Percent%
Moderately suitable	651.31	53.2
Currently not suitable	572.92	46.8

IV. Wheat suitability based on soil pH

Soil pH is an important factor for plant growth and it is one of requirement for assessing suitability of wheat production. Soil pH of the area raise from 5.118 to 7.125, according to USDA Natural Resources Conservation Service, the area is classified into four soil pH types (Figure 22). Soil pH types of the area and their corresponding area coverage is shown as follow (Table 27).

Table 27 Soil pH types of the area and their corresponding area coverage

Soil pH types	Area (km ²)	Percent%
Strongly acid	448.57	36.53
Moderately acid	64.91	5.29
Slightly acid	478.39	38.96
Neutral	235.94	19.22

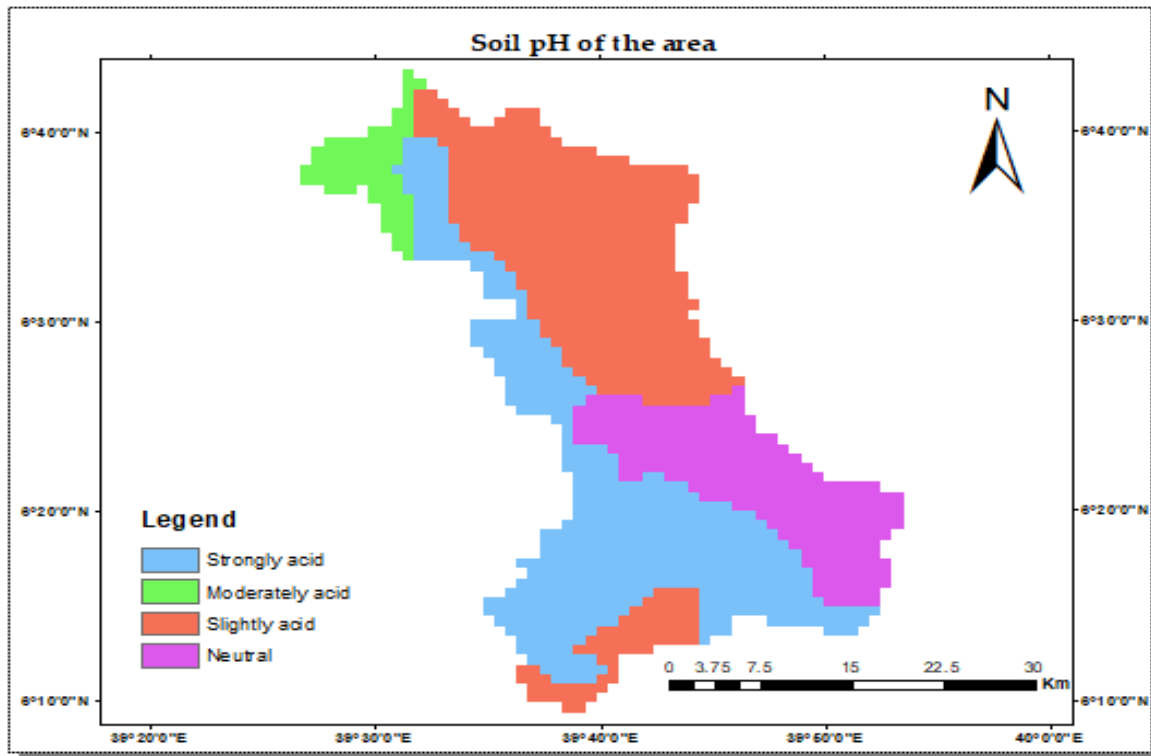


Figure 22 Soil pH types of the study area

As the result pH of the study area was classified into three suitable classes based on used wheat requirement suitability range (Figure 23). 20.73% of the study area was highly suitable, 43.01 and 36.27% of the study area was moderately suitable and currently not suitable for wheat production respectively (Table 28).

Table 28 Soil pH suitability class for wheat production and their corresponding area coverage

Suitability Class	Area (km ²)	Percent%
S1	253.6	20.73
S2	526.24	43.01
N1	443.8	36.27

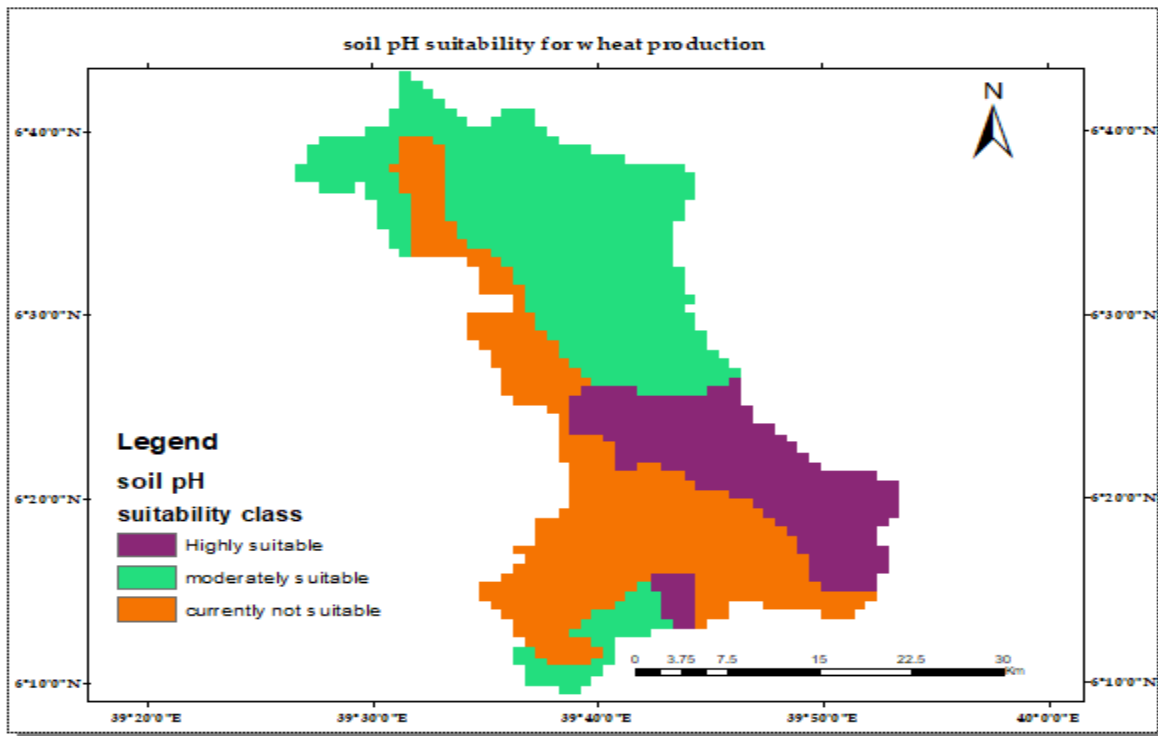


Figure 23 Wheat suitability based on soil pH

V. Wheat Suitability based on soil organic carbon

Organic carbon content of study area was between 0.78% and 0.45% which is said to be low and the main limiting factor of the area for wheat production (Figure 24).

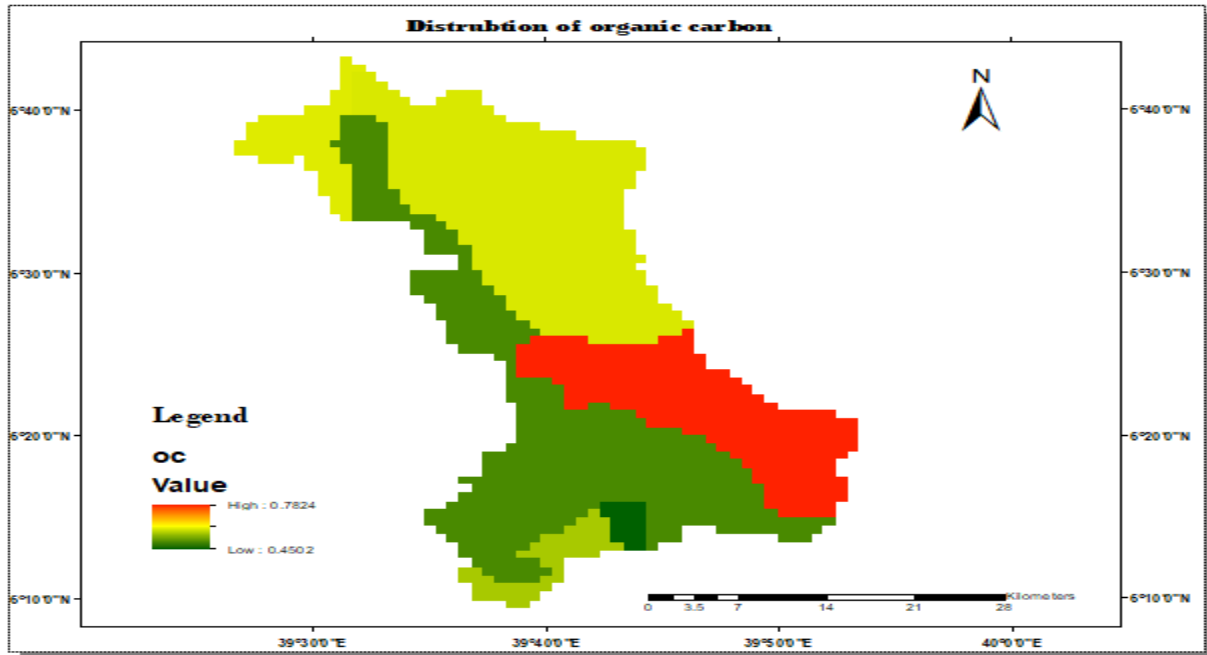


Figure 24 Soil organic carbons content of the area

Based on analysis done on organic carbon, the result implies as 62.4% of the area was marginally suitable and 37.6% currently not suitable for wheat production based on organic carbon of the area (Table 29). The results revealed that the area had very low organic matter, which limit factor for wheat production.

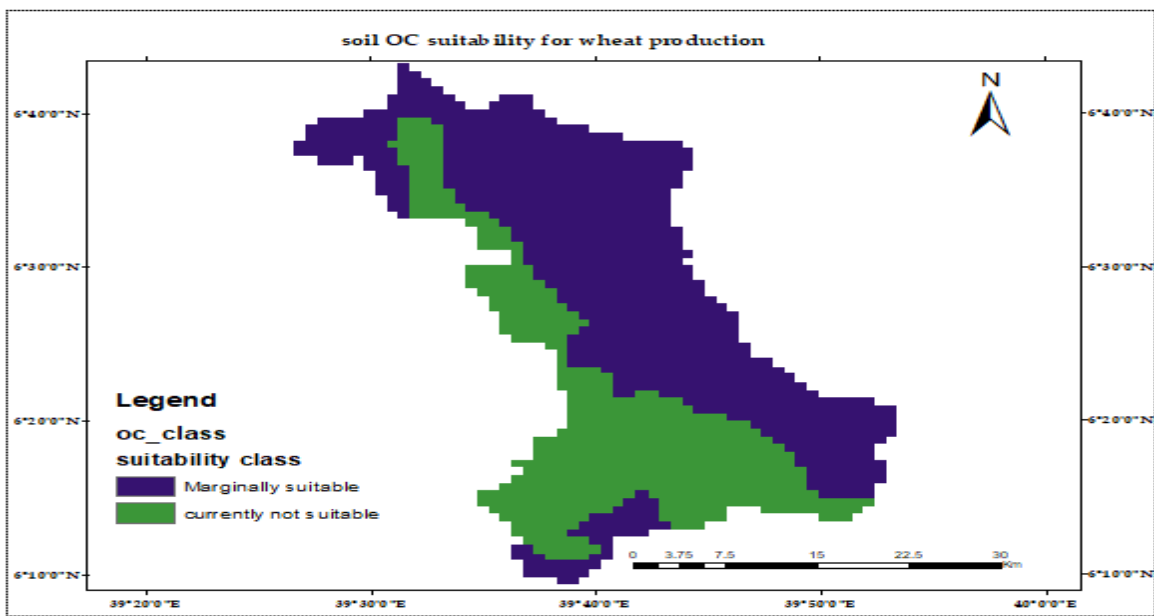


Figure 25 Wheat suitability based on SOC

Table 29 Soil OC suitability class and their corresponding area coverage

Suitability Class	Area (km ²)	Percent%
S3	769.7	62.4
N1	460.3	37.6

4.1.5. Constraint mapping

Geographically Bale Mountain National Park shares around 150 km² from study area. Even if peoples illegally settled even inside the national park the authorities prohibited those 150km² parcel of national park and 100m buffer zone around boundary of the park from settlement and agricultural practice except for beehive and forest coffee. The assessment of constraint in terms of land use is represented in 0 or 1 condition (Figure 26). Zero shows area prohibited to use was 12.7% and the remaining 87.3 % of the area was permitted for use (Table 30)

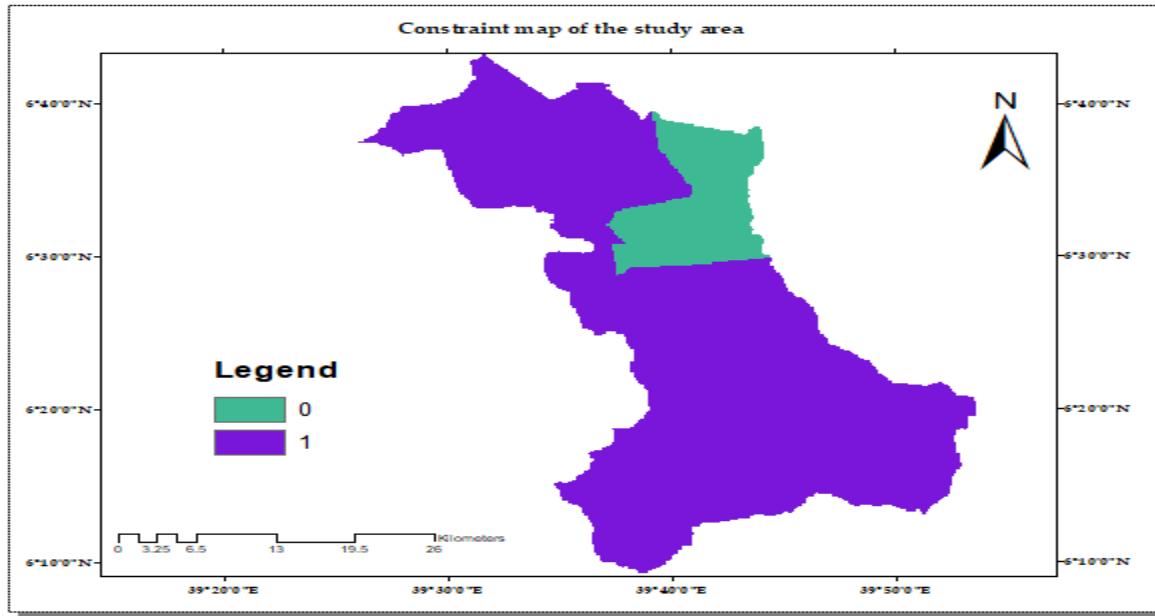


Figure 26 Constraint map

Table 30 constraint and corresponding area coverage

Value	Condition	Area (km ²)	Percent%
0	Not allowed	157	12.7
1	Allowed	1073	87.3

4.2. Result of Pairwise Comparison

Pairwise comparison matrix is prepared based on expert outlook; weight influence of all factors is automatically calculated once the matrix is entered in AHP calculator. As a result consistency

ratio of pairwise comparison is 0.08 that indicated the comparison were consistent which means acceptable. Consequently as indicated in Table 31 soil pH and soil texture are found to be the three most influencer of wheat crop.

Table 31 Weight of influence

Criteria	Weight	Percent
Soil drainage	0.10	10
Soil depth	0.11	11
Soil texture	0.13	13
Soil organic carbon	0.05	5
Soil pH	0.12	12
Elevation	0.06	6
Slope	0.11	11
Rainfall	0.16	16
Temperature	0.08	8
LULC	0.08	8

4.3. Land suitability analysis (LSA)

The above mentioned result showed suitability of the area for wheat production of each individual parameter separately. Using weighted overlay analysis all factors overlaid based on their weight of influence gained by AHP.

$$S = \sum W_i X_i$$

$$S = \text{drainage} * 0.10 + \text{slope} * 0.11 + \text{elevation} * 0.06 + \text{depth} * 0.11 + \text{texture} * 0.13 + \text{oc} * 0.05 + \text{pH} * 0.12 + \text{rain fall} * 0.16 + \text{temperature} * 0.08 + \text{LULC} * 0.08$$

Based on the result of weighted overlay analysis the study area has three suitability classes which were moderately suitable, marginally suitable and currently not suitable. To conclude mapping suitability of the area for wheat production, result of weighted overlay and constraint Boolean map having a value of 0 and 1 aggregated in Arc Map environment using raster calculator of special analysis tools. As a result 26% of the area is moderately suitable, 60% is marginally suitable, 0.8% is currently not suitable for wheat production and 12% of the area is protected area which is not allowed for farming activity currently (Table 32).

Table 32 Wheat suitability class of the area and their corresponding area coverage

Suitability Class	Area (km²)	Percent%
Moderately suitable (S2)	326.3	26.5
Marginally suitable (S3)	736.4	60
Currently not Suitable (N1)	10.3	0.8
Protected area	157	12.7

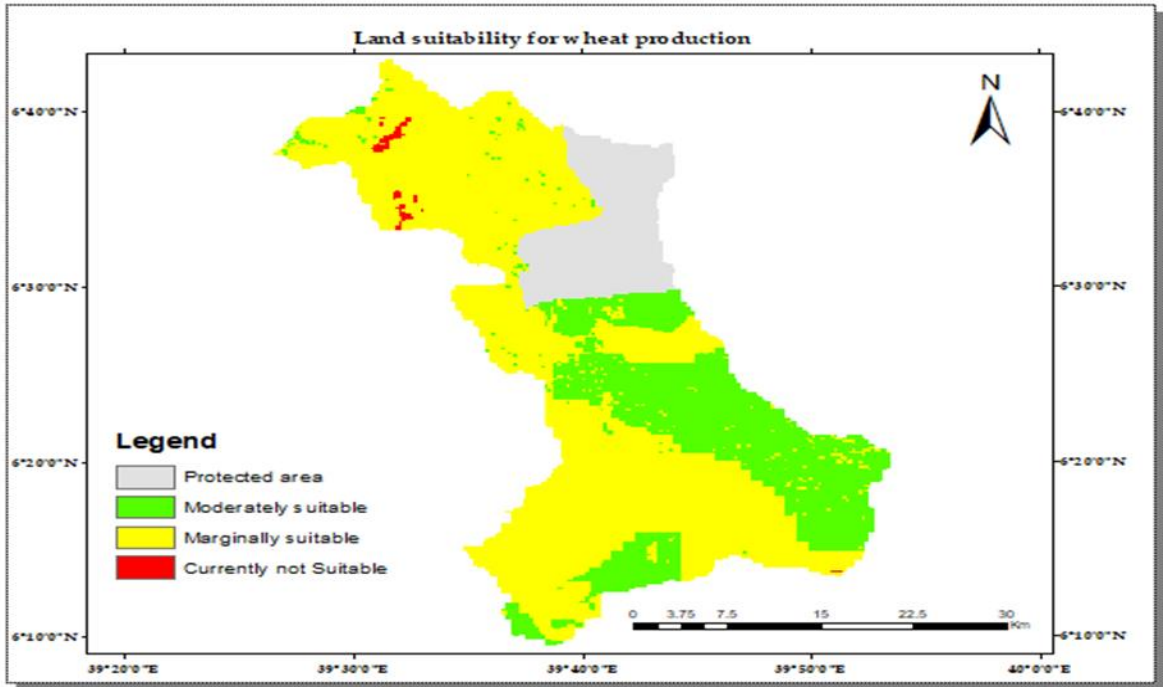


Figure 27 Wheat suitability of the study

From study area Kebele Gomgoma Kebele was the most suitable Kebele for wheat production. About 93% of the Kebele was moderately suitable as stated in the below (Table 33).

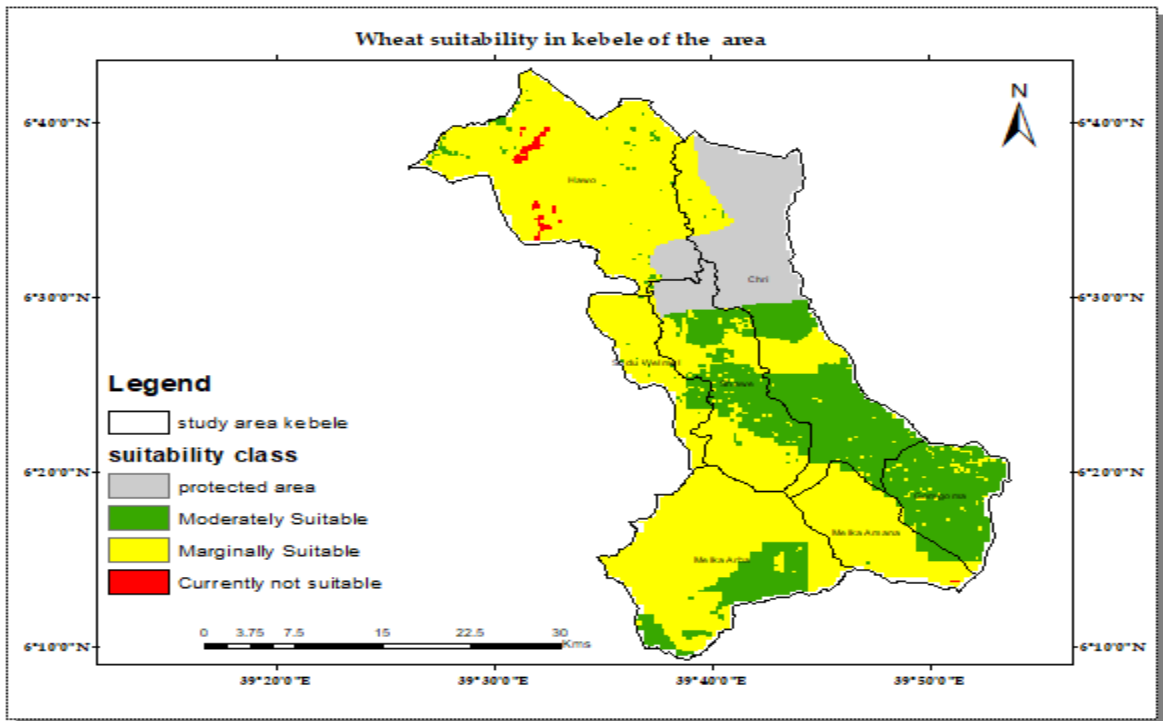


Figure 28 Wheat suitability of the area with study area Kebeles

Table 33 Wheat suitability in each study area Kebeles and their corresponding area coverage

Kebele	Suitability Class	Area (Km ²)	Percent%
Hawo	Protected area	14.6	5.3
	Moderately suitable (S2)	4.6	1.7
	Marginally suitable (S3)	252	91.1
	Currently not Suitable (N1)	5.3	1.9
Shawe	Protected area	20.6	12.9
	Moderately suitable (S2)	62	38.9
	Marginally suitable (S3)	76.8	48.2
Sodu_Welmel	Moderately suitable (S2)	7	11
	Marginally suitable (S3)	54.1	89
Melka_Amana	Moderately suitable (S2)	7.1	7.7
	Marginally suitable (S3)	85.4	92.1
	Currently not Suitable (N1)	0.2	0.2
Melka_Arba	Moderately suitable (S2)	44	19.7
	Marginally suitable (S3)	179.3	80.3
Gomgoma	Moderately suitable (S2)	83.5	93.1
	Marginally suitable (S3)	6.2	6.9
Chiri	Protected area	114	41.4
	Moderately suitable (S2)	102.8	37.4
	Marginally suitable (S3)	58.4	21.2

4.4. Result validation

Correlation between actual observed yield and expected yield of suitability analysis result indicates 89% of agreement between them land suitability assessment carried out for the crops and existing actual production yield in the area.

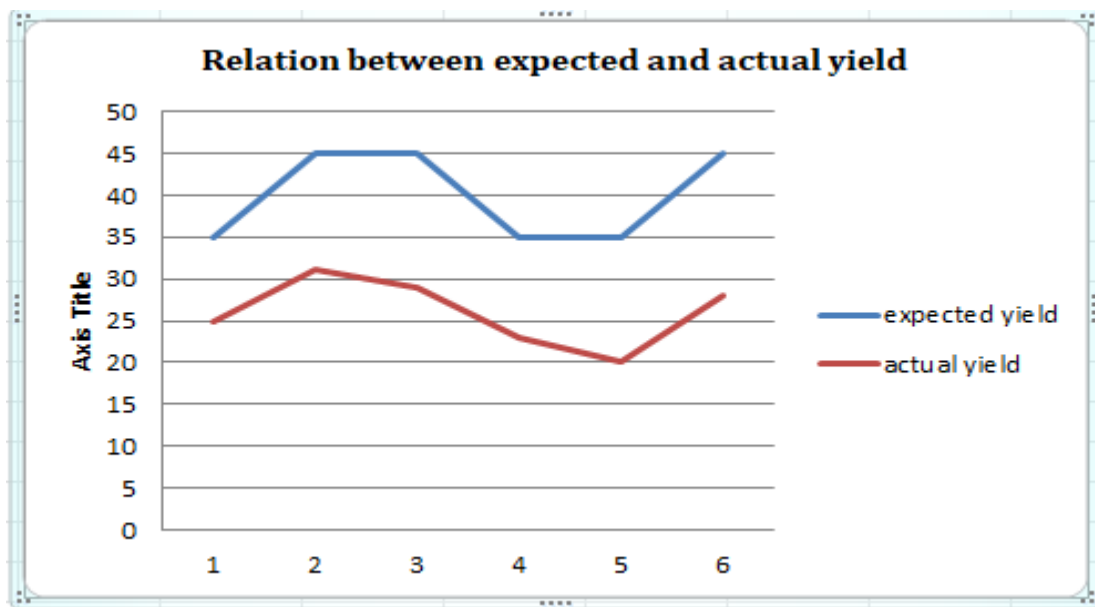


Figure 29 Relation between expected and actual yield

4.5. Factor affecting wheat production in the area

Based on investigation during field visit and interview with different experts the following is limiting factors that affect productivity of wheat in the study area.

- Farmers working habit and awareness of improved crop management practices are the first problem that faces agricultural extension workers.
- Getting pure improved variety seed on time is also another problem.
- Low soil fertility and soil acidity and the price of fertilizers become problematic for wheat production.
- Crop disease specially Stem rust, Armyworm and certain of Russian wheat aphid.

4.6. DISCUSSION

Suitability class result of each parameter used in analyzing suitability of the area for wheat production (temperature, rainfall, soil depth, soil texture, soil drainage, soil organic carbon, soil pH, elevation, slope and LULC) were produced by matching distribution of those parameters with crop requirement standards and suitability levels of each factors or parameters was ranked from very highly suitable to permanently not suitable for wheat production.

Each parameter has its own effect in suitability of the area for intended purpose as a result shows suitability of the study area for wheat production was affected by LULC of the area in which 302.3 km² (24.6%) of area covered by forest and rural settlements which was permanently not suitable for wheat production means areas that have so severe limitations that are very difficult to be overcome, 187km² (15.2 %) was covered coffee farms and grasslands which was currently not suitable for wheat production that means areas having severe limitations that preclude the given type of use, but can be improved by specific management, 105.6km² (8.6%) was marginally suitable which has shrub land cover, 142 km² (11.6%) of the study area was covered with bare land which has moderately suitable class for wheat production, and 493.3 km² (40.1%) of the study area was covered by farm lands which was highly suitable for wheat production.

Slope was the other parameter or factor that affects suitability class of the area for wheat production. 43km² (3.5%) slope of the study area was >30% which was permanently not suitable for wheat production, 74 km² (6.0%) of the study area has slope between 16 and 30% which was marginally suitable for wheat production, 145 km² (11.8%) of the area has 8 to 16% slope which was moderately suitable and 968 km² (78.7%) of the area has < 8% slope which was highly suitable for wheat production. Elevation was one of topographic factor in this study based the analysis 679.84 km² (55.24%) of the area has < 1500m, > 3300m altitude which was currently not suitable for wheat production, 3.05 km² (0.25%) of the area has 3000-3300m altitude which was marginally suitable, 473.74 km² (38.49%) of the area has 1500-2000m or 2600-3000m altitude which was moderately suitable and 74.13 km² (6.02%) of the area has 2000-2600m altitude which was highly suitable for wheat production.

Based on the analysis done on rainfall distribution of the area 1.5 km² (0.12%) of the area got < 700mm and > 1750mm annual rainfall which was permanently not suitable for wheat production, 386 km² (31.4%) of the study area got 1000-1250mm annual rainfall which was moderately

suitable for intended land use and 842.5 km² (68.48%) of the study area got 700-1000mm annual rainfall which was highly suitable for wheat production. According to the analysis done on temperature distribution of the study area 1028.7 km² (83%) of the study area has got < 12.4 and >21.3^oc average temperature which was permanently not suitable for wheat production, 49.9 km² (4%) of the study area has got 12.4-13.4 or 20.8-21.3^oc average temperature which was currently not suitable for wheat production and 116.9 km² (10%) of the study area has got 13.4-14.4 or 19.4-20.8^oc average temperature which was marginally suitable for wheat production while 34.2 km² (3%) of the study area has got 14.4-14.9 or 18.4-19.4^oc average temperature which was moderately suitable for wheat production.

Soil depth was one of soil factor taken into this study as a result 0.17 km² (0.02%) of the study area has 50–90cm depth which was moderately suitable for wheat production and 1229.49 km² (99.98%) of the study area has >90cm depth which was highly suitable for wheat production. Soil texture of the study area was characterized as clay, sand clay, clay loam sandy clay loam, loam and sandy loam. Based on the analysis done on soil texture of the area 0.13 km² (0.01%) of the study area soil texture was sandy loam which was currently not suitable for wheat production, 246.5 km² (20.05%) of the study area was sandy clay loam which was marginally suitable and 623.1 km² (50.68%) of the study area soil texture was loam and clay loam which was moderately suitable while 359.69 km² (29.26%) of the study area soil texture was clay and sandy clay which was highly suitable for wheat production.

Soil drainage type of the area is poor and moderately soil drainage type. 572.92 km² (46.8%) of study area soil drainage was poor soil drainage type which was currently not suitable for wheat production and 651.31 km² (53.2%) of the study area soil drainage was moderate soil drainage type which was moderately suitable for wheat production. Soil pH content of the area is classified into three suitability class for wheat production, as a result 443.8 km² (36.27%) soil pH of the study area was <5.2 which was currently not suitable, 526.24 km² (43.01%) was 5.6-6.5 or 7.5-8.2 which was moderately suitable and 253.6 km² (20.73%) of the study area pH contain was highly suitable for wheat production. 460.3 km² (37.6%) of study area soil organic carbon content was <0.5 which was currently not suitable and 769.7 km² (62.4%) of study area soil organic carbon content was in between 0.5 and 1.0% which was marginally suitable for wheat production.

Each parameter has its own effect in minimizing suitability level of the study for intended land use even if it has small influence while comparing to other factors and control the result to be moderately, marginally suitable and currently not suitable for wheat production including protected area. As a result the overall land suitability analysis implies the study area is suitable but not highly suitable for producing wheat crop due to limiting factors which seem to agree with the realities of the study area. All suitability classes have their own limiting conditions but also all suitability classes have a probability of improvement and correcting of their suitability level through production management.

Moreover elevation, temperature and LULC of the area have a major limitation for wheat production. Vast part of study area temperature is too high beyond the requirements and almost half of the area elevation is too low below the requirements for wheat production. If production management is not taken place both have major effect on suitability level of the area in production of wheat. Since the area has forest and settlement coverage which cannot allow for production activity, LULC of the area stay as limiting factor for wheat production which cannot be modified currently.

Soil pH and organic matter content of the area is also identified as a limiting factor for wheat production. 36% of the areas characterized as strongly acidic such areas have claimed to have low calcium, magnesium and phosphorus which is not favorable for wheat production and affect suitability level of the area for wheat production. The area has very low soil organic matters which affect supplies of all minor and micronutrients to crops and affect soil water holding capacity. If production management is not taken place both the above pedological limitation of the area has a sound effect on wheat production.

Beyond the fact that areas have limitation for wheat production slope, rainfall, soil depth and texture of the area made the area suitable for wheat production. As a result suitability of the area is found to be moderately suitable which is areas having minor limitation for wheat production. Marginally suitable which are areas having severed limitation and currently not suitable areas having severe limitations that preclude wheat production, but it can be improved by specific production management. The result also includes protected area as a constraint, area which is not allowed for production.

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATIONS

5.1. CONCLUSION

Land suitability analysis is a complex process and includes various domains of knowledge. In doing so soil depth, drainage, texture, pH, SOC, temperature, rainfall, slope, altitude, LULC were used as factors of analysis and protected area was considered as constraint. FAO land evaluation method is used in evaluating suitability of the area for wheat production.

Elevation, temperature and LULC of the area were identified as major limitation variables for wheat production in the area. Soil pH and organic matter content of the area is identified as a minor limiting factor for wheat production while slope, rainfall, soil depth and texture of the area made a good opportunity for wheat production. As a result most of the area is marginally suitable for wheat production. In general, the area comprises moderately suitable (S2), marginally suitable (S3) and currently not suitable (N1) areas for wheat production. Which implies the area have minor, major and sever limitation for wheat production but that can be modified through specific production management. The area also includes protected area which could not be possible to use for wheat production with the current land use policy of the country.

Moderately suitable area coverage's 326.3 Km² (26.5%), followed by marginally suitable area which covers 736.4 Km² (60%), while currently not suitable area accounts 10.3 Km² (0.8%). Protected land covers around 157 Km² (12.7%) of the area. Since this land cover is set as protected, is assumed permanently not suitable areas for wheat production.

Generally, the district agricultural authorities targeted in making wheat as an alternative cereal crop, this study can be used as a primary instrument for better planning and allocation of land for wheat production as well as for deciding agricultural incentives in the study area. However the factors used are not the only criteria for making decision inclusion of socioeconomic issue may complement for better suitability analysis of wheat in the study area.

5.2. RECOMMENDATIONS

Based on the findings the following recommendations are forwarded.

- ✚ As the evaluation indicated, the area has a potential for wheat production. But it is highly recommended that agricultural practice need to modify and follow strict production management system to get better yield and to correcting suitability level of the areas for wheat crop production, to achieve successful land management, familiarizing alternative crop and income generation method. In revers which can help farmers and reduce pressure on land resources.
- ✚ As the area has limiting factor for wheat production, wheat species that tolerate those limiting factor have to be selected. According to Agricultural Transformation Agency (ATA) wheat production manual based on elevation and climatic factor of the area kingbird, Paven-76 (ፓሽጉ-76) and lemu bread wheat species is recommended for the area.
- ✚ Soil of the area suffers from acidity to obtain optimum crop yields addition amendments such as liming is recommended to correct the acidity.
- ✚ Soil organic carbon of the area is also a limiting factor for wheat production. So to increase production yield soil organic carbon has to be treated by adding organic amendment like animal manure and biosolids, adding fertilizer, growing cereal crop, improving crop rotation and doing land conservation can treat soil organic carbon.
- ✚ Protected area should be strictly considered while using the result.
- ✚ While using the result including all above mentioned recommendation, social and economic factor towards of wheat production have to be considered.
- ✚ Finally further studies should be continued for the different crops to increase alternative crop and identify the best alternative land use by containing different factors including factors which are not included in this study.

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