

ABSTRACT

Physical Land Suitability Analysis for Wheat and Sorghum crops using GIS and Maximum Square Root Test method: in case of Wogdie Woreda, South Wollo, Ethiopia

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Land suitability analysis is the evaluation of specific area of land in terms of their suitability for a defined use. Land suitability analysis for agricultural crops is an important step for sustainable land use in order to get the optimum benefit out of the land. In this study, physical land suitability analysis for wheat and sorghum crops in Wogdie Woreda, South Wollo, Ethiopia was made using GIS technology. The parametric square root test mathematical formula and FAO methodology were applied to identify suitability level of the land for these crops. Factors considered in the evaluation of the land suitability analysis for wheat and sorghum crop were soil (depth, texture, organic carbon, drainage and type), slope, temperature and rainfall. As the result showed 20.5 % and 79.5% of the study area were classified as moderately suitable and marginally suitable, respectively, for wheat crop production. Similarly, 3.3%, 93% and 3.7% of the study area were classified as moderately suitable, marginally suitable and currently not suitable, respectively, for sorghum crop production. The result showed that, there is no land classified as highly suitable, currently and permanently not suitable for wheat crop production, and there is no land, which is classified as highly suitable and permanently not suitable for sorghum crop. Therefore, integrating parametric square root test method with GIS in land suitability analysis for agricultural crops is a meaningful technique. Hence, to increase the choice of land for different crop production, further study for different land utilization types including other factors are necessary.

Key words: GIS, Land Suitability Analysis, Land Utilization Type, Wogdie Woreda, Parametric Method,

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Acronyms

AHP- Analytical Hierarchy Process

CSA- Central Statistical Agency

DEM- Digital Elevation Model

EAFF- East Africa Farmers Federation

EGTE- Ethiopian Grain Trade Enterprise

FAO- Food and Agricultural Organization

GDP- Gross Domestic Product

GIS – Geographic Information System

HH- House hold

LSA- Land Suitability Analysis

LUT- Land Utilization Type

MoA- Ministry of Agriculture

N- Not Suitable

NMSA- National Meteorological Service Agency

RBOARD- Regional Bureaus of Agricultural and Rural Development

S- Suitable

SI- Suitability Index

USDA- United State Department of Agriculture

UTM- Universal Transverse Mercator

WARDO- Woreda Agricultural and Rural Development Office

WGS- World Geodetic System

WRSI- Water Requirement Satisfaction Index

CHAPTER ONE

1. INTRODUCTION

1.1. Background of the Study and Justification

Agriculture is the practice and occupation of growing crops and raising livestock. It is the basis for the development of civilization by way of settled life and it includes the source of food we eat, the clothing we wear, the material of our homes, the gardens around us and many of our traditions and values. Many of the products used by human beings for food and fiber come from plant and animal by-products through farming and ranching activities. With the advancement in civilization, man came to know about more crops and started to cultivate. Population growth and advancement made man to settle at one place and to cultivate the area year to year. Now, agriculture is developed as a science that deals with crops and given a profession name such as commercial agriculture, precision agriculture and sustainable agriculture for the subsistence and sustains of human beings (Goswamin et al., 2012).

The human population of the planet earth is growing dramatically. In order to meet the increasing demands for food, this farming community has to produce more and more food. Under the present situation, where the land is a limiting factor, it is impossible to bring more area under cultivation (extensive farming), so farming community should tackle this challenge of producing more food with the available land only (intensive farming) using the current technologies having the potentiality to increase food production. Higher productivity, profitability and health of humankind as well as environment are the concerns of the present day agriculture. To overcome this concern, in addition to produce more high quality food using eco-friendly practices. The need for eco-friendly practices has paved the way for the concepts like precision farming, sustainable farming and organic farming. One of the most important techniques for sustainable agricultural development was comparison of land use type with land quality (suitability analysis). Hence, in case of crop agriculture much attention was shifted on selection of crops, with the best land quality for the selected crop (Joshua et al., 2013).

The suitability analysis of an area is a function of comparison of crops with their requirements or land characteristics. Therefore, Suitability is a measure of how well the

qualities of a land unit match with the requirements of a particular form of land use type. In Ethiopia, land resource degradation is major threat that affects the existence and livelihood of the community. The degradation of land resources due to overexploitation and misuse and consequent economic, social and environmental impacts has intensified the pressure on the land resources of the country. Suitability mainly based on the land qualities, which derives from land characteristics that can be quantified. The land characteristics that used for physical land suitability analysis are slope, physical and chemical properties of the soil (FAO, 1976).

The common way of determination of land qualities from land characteristics is mainly by assessing and grouping the land types and classes according to their capacity. The order of suitability ranges from suitable (S), that characterizes a land in suitable for sustainable use and can give good benefits and to not suitable (N) which indicates that the land qualities do not allow the considered type of use, or are not enough for sustainable outcome (FAO, 2006).

To incorporate the different land attributes that differ spatially and to identify the best suitable land use, GIS has proved to be the most suitable tool. Geographical Information System is a tool that incorporates database for spatial data designing and developing to enable data acquisition, compiling, analyzing and displaying topological interrelations of different spatial information. Moreover, the surface and overlay analysis capabilities in GIS can effectively facilitate in handling vast amount of spatial information (Halder, 2013).

The land suitability analysis requires the use of different kinds of data and information; the important once are soil, climatic and topographic factors. The GIS offers a flexible and powerful tool than convectional data processing systems, as it provides a means of taking large volumes of data sets then manipulating and combining these data sets in to new data sets, which is displayed in the form of thematic maps. Topographic characteristics, climatic condition, and soil quality of an area are the most important factors for land suitability evaluation (Almashereki et al., 2011).

Ethiopian agriculture is mostly rain fed, in which inter-annual and seasonal rainfall variability is high and drought are frequent in many parts of the country. Rainfall variability has historically a major cause of food insecurity and famines in the country. However, the relationships between rainfall variability and fluctuations with land quality in agricultural production at regional and sub-regional scales have not been studied in detail (Woldeamlak Bewketu, 2009).

Land Suitability Analysis (LSA) is a GIS-based process applied to determine the suitability of a specific area for a considered use, i. e. it reveals the suitability of an area regarding its intrinsic characteristics (suitable or unsuitable) for a specific purpose. In addition, this analysis is involved with wide ranges of criteria including environmental, social and economic factors. In the present study, only the physical land suitability parameters were considered. In the study area, there are different crop types such as wheat, sorghum, teff, maize and different oil seeds that have grown. Those crops are being cultivated traditionally in the area since there is no suitability identification. Due to this reason in the study area, there is a variation in the yield of different family in the same climatic region from similar crops. This is due to the existing variations in the land qualities. Analyzing the suitable area for specified crops and the productivity will increase in the area and food insecurity problem minimized. In order to utilize the land resources in a sustainable and optimum way, a land use with land quality identification is a supreme importance. In this study, an effort is made to identify a suitable class for all land units in terms of crop requirement standard and by incorporating different suitability parameters of the crops in Wegdie Woreda, South Wollo, Ethiopia using GIS technology and square root test mathematical formula.

1.2. Statement of the Problem

Physical land suitability analysis is needed for various purposes in Wogdie Woreda, since the livelihood of the people was highly dependent on rain fed agriculture with small extent of land. The cropland suitability analysis is a prerequisite to achieve optimum utilization of the available land resources for sustainable agricultural production and to produce the essential livelihood food and other resources for the people.

Agriculture is the main source of income and form of survival of peoples in the study area and cereal crops are the major crops used for food. The cereal production of the study area does not meet the local demands due to its rapidly growing population. Pressure on land resource has continuously increased due to the population growth. Improper land use results in land degradation and decline in agricultural productivity. These further exacerbates food insecurity of the place, which further leads to expansion farming to nearby lands. To serve the increasing demands, it is necessary to struggle for sustainable land use. Land suitability evaluation for agricultural crops are an important step for sustainable land use and to increase agricultural productivity by matching of crop requirement to land quality.

It is obvious that land crop type should be suitable for the area with good yield after suitability of the area were identified. Therefore, it becomes clear that in determining the best modes of sustainable land in land suitability assessment for a particular purpose has an important role for sustainable development to fill the demand. Hence, in order to get the optimum benefit out of the land, proper utilization of its resource is to be anticipated. As a result, a land use plan, which incorporates different land characteristics, has a paramount importance. GIS and remote sensing is convenient and powerful platform to integrate spatially complex and different land attributes for performing land suitability analysis.

In Ethiopia, most of the studies conducted suitability analysis by using weighted overlay. Weighted overlay is one of the tools of spatial analysis, which is important to overlay different raster layers. However, in weighted overlay the weight giving for each parameter is estimated by the expert opinion and it is highly subjective. Therefore, in the present study the square root test parametric method was used to avoid this subjectivity and expert opinion.

Kassa Teka and Mulu Haftu (2012) conducted land suitability characterization for crop and fruit production in midlands of Tigray, Ethiopia. The aim of the evaluation was to find out which parcel of land may best support for growing of different crops and fruits by local farmers. The researcher evaluates the land suitability analysis using physical and

chemical properties of soil and slope criteria with the help of GIS and remote sensing. In the present study, the climatic criteria was added to the criteria used by aforementioned researcher since climatic factors also an important factors which determine the productivity of rain fed crop production.

Yitbarek et al. (2013) conducted physical land suitability evaluation for rain fed crop production of cotton, maize, rice and sorghum crop in Abobo, western Ethiopia. The land suitability of the area for those crops is evaluated using soil, slope and climate factors. In this research, no evaluation was made of the area using all these parameters together. Therefore, in the present study the gab of using parameters separately is filled by using the parameters together by the help of GIS technology and square root test method.

1.3. Objective of the Study

1.3.1. General Objectives

- ❖ To evaluate the potential of the physical land suitability analysis of the study area for wheat and sorghum crops using GIS technology and maximum square root test method

1.3.2. Specific Objectives

- ❖ To identify key factors for selecting appropriate site for wheat and sorghum crops
- ❖ To assess the suitability of the identified parameters for wheat and sorghum crops
- ❖ To develop and evaluate the overall suitability classes of the area for wheat and sorghum crops

1.4. Significance of the Study

The physical land suitability evaluation is a prerequisite for land use planning and development. It provides information on the constraints and opportunities for the use of the land and guides a decision on optimal utilization of land resources. Land suitability is the most important factor in order to make the area more profitable. Almost all Ethiopian farmers are highly dependent on agriculture with small extent of land. As a result, production of crops does not match with the growth of population of the area as well as of the country. Therefore, land suitability analysis is an important technique for sustainable agriculture as suitability analysis is the system of comparing land use type

with the land quality or crop requirement standard to maximize productivity of the area and to trim down under and over utilization of the land.

Generally, the study was important to show:

1. The physical land suitability analysis for sorghum and wheat crops in the study area
2. The soil physical characteristics of the area with its significance
3. Topographic suitability of the area for crop production and
4. To show the climatic condition of the area and to produce its suitability classes of the area for the crops

1.5. Scope of the Study

This study is limited to Wogdie Woreda, South Wollo of Amhara Regional State. It covers a total area of about 1101 km² with different Kebeles. The study is only concentrated on the physical land suitability analysis for wheat and sorghum crops using GIS and parametric methods. Moreover, this research was employed the climatic, slope and physical and chemical properties of soil factors for the suitability analysis of the crops in the area.

CHAPTER TWO

2. REVIEW OF RELATED LITERATURE

2.1. Agriculture in Ethiopia

Agriculture is one of the oldest, but still prospective economic practices of human civilization. It is a basic instrument for sustainable development and poverty reduction, especially in developing countries as they have significant agrarian components in their economies (Goswamin et al., 2012).

Ethiopian agriculture is complex with a variety of crops grown across the country's different climatic regions. The cereal crops like teff, wheat, maize, sorghum and barley are the core agriculture and food economy of the community that accounted for about 29% of agricultural gross domestic product (GDP) in 2005/06. In terms of the extent of area cultivated, yield and production, there has been a substantial growth in cereal crops in 2000, but there is low yield by international standards and the production is highly susceptible to whether conditions, particularly drought. Thus, both raising production levels and reducing variability are essential for improving food security in Ethiopia (Hamza Mohammed and Anderson, 2005; Tadesse Geletaw, 2001 as cited in Alemayehu Seyoum et al., 2011). However, agriculture contributes for 41.8% of the GDP in 2011, 42% in 2012 and 46.8% in 2013 (CSA, 2013).

According to FAO (2011) under all African, Asian and Pacific Program of Work, a series of regional capacity building workshops held in collaboration with East African Farmers Federation (EAFF) for the representatives of national apex and district organizations from eight countries in the east Africa region. Ethiopia is part of this project to improve its food security through increasing crop diversification and appropriate use of inputs and technologies in their regions. Seed grower farmers, cooperatives and the surrounding farming communities developed awareness on the importance of using good quality seeds, and the techniques and management of seed production and distribution. The capacity of the government to implement the project, particularly the regional bureaus of agriculture development (RBOARD) and the Woreda Agricultural and Rural Development Offices (WARDO) were also improved by providing farm technology that

has a potential to increase production and productivity as well as quality standards, through a community driven development approach.

According to Woldeamlak Bewketu (2009) agriculture is the source of livelihood of the majority of Ethiopian population. It employs over 80% of the labour force and contributes ~45% to the national GDP, on an average. The Ethiopian agriculture was characterized by extreme dependence on rainfall, low use of modern agricultural inputs and low output levels. For instance, the use of chemical fertilizers on average in 1999/2000 was only ~35 kg ha⁻¹, irrigated land accounts for < 2% of the total cultivated land of the country and crop yields oscillate around 1.2 t ha⁻¹. The amount and temporal distribution of rainfall as generally the single most important determinant of inter annual fluctuations in national crop production levels.

According to FAO (2011) at the beginning of the collection of national agricultural statistics in the 1960s, teff has always been accounted for the largest share of cereal crop cultivated in an area. However, over the past five decades, the share of teff has decreased by 5.8% while the share of maize has increased by 7.8% from the 1960s to the first decade of the 2000s. Compared to teff and maize, the share of other cereals stayed relatively stable over time. During the first decade of the 2000s, production of all the major cereals increased with teff 8.9%, sorghum 8.6% and wheat 8.3% having the fastest annual growth rates. Growth in maize production was slowed to 4.2% in the early of 2000s. This reduced growth figure was caused in part by a collapse in domestic maize prices and slow adoption of hybrid maize technology.

Ethiopia has an agrarian economy, with mainly rain fed agricultural system. The major grain crops grown in the country are teff, wheat, corn, barley, sorghum, and millet. Cereal crops are predominantly produced by small landholders and consumed by human and livestock. Due to a good rainfall in 2012, production of all grains during the Marketing Year 2012/13 the price was better compared to the previous years. In the marketing year 2013/14, the forecast of wheat production is to be slightly higher than in 2012/13 due to improvement in seed supply. Wheat imports were made only through the government

owned enterprise Ethiopia Grain Trade Enterprise (EGTE) and through food aid, no other grains were traded (Abu Tefera, 2013).

2.1.1. Production and Importance of Sorghum Crop

Depending on the varieties of sorghum (*sorghum bicolor*), the crops can be used for multiple functions. Sorghum is used as forage or silage crop to feed livestock and as a grain crop for human. Sorghum grain is used as a substitute to maize and wheat meals and supplement feed poultry, horses and swine. It can be processed in to flour to substitute wheat. The flour is used in the bakery industry to produce cakes, bread, and biscuit flakes (Chandiposha et al., 2013).

Sorghum is one of the most widely grown cereal crops in Ethiopia. The lives of millions of rural Ethiopians depend on sorghum as a staple food crop. It has tremendous uses for the Ethiopians; and no part of this plant was ignored. Sorghum grows in a wide range of agro ecological zones, mostly in the moisture stressed parts where other crops can least survive and food insecurity is extensive. However, in recent years, the variability is becoming less in the lowlands, where vulnerability due to recurrent drought and incidence of pests is very high. The local cultivars in these areas are facing late-maturing resulting of crop failure as the rains end early in the season before or at the time of flowering. For these areas, it is indispensable to introduce early-maturing germplasm that can mature within the range of the rainy season. A large number of early-maturing sorghum and millet varieties and hybrids that are compatible with the quality of the land should be introduced and evaluated for the population (Alemayehu Seyoum et al., 2011).

Sorghum is the fourth important cereal crop in Ethiopia, and is produced in most parts of the country. Due to its versatility, diversity and tolerability to pests and drought relative to other major cereal crops, it is produced over a wide range of agro-ecological zones. It is primarily a crop of resource-poor and is typically produced under adverse conditions such as low input use and marginal lands. Farmers prefer to plant indigenous sorghum varieties rather than improved varieties as indigenous varieties produce larger volumes of biomass, which can be used as animal fodder, fuel, and construction materials. Areas of greater concentration of sorghum production include much of the northwestern and eastern parts of Ethiopia. In 2011/12, the rainfall distribution was good and resulted in

good yields. In 2012/13, due to the late start of the short rainy season, the performance of the crop was negatively affected in low land areas of the country. The late rains did not decrease the quantity of production, but negatively impacted on the quality of the grain. The main use of sorghum in Ethiopia is for making traditional bread, injera by mixing with teff for human consumption and used for local beer production in some parts of the country. It accounts for an average of ten percent of daily caloric intake of households living in the eastern and northwest areas of the country. Lower quality sorghum grain is used for animal feed. The stalks are an important product, used as fire fuel, fodder and as construction material for rural houses. Sorghum consumption is increasing in the middle and below average class communities due to adulteration of sorghum with teff to make injera and the higher price of teff (Abu Tefera, 2013).

2.1.2. Production and Importance of Wheat

Flour milling takes the major share of wheat processing in which the main product is sold to grain based food manufacturers and some of them are sold to ingredient distributors. Apart from milling wheat in to flour, the crop product can be used to produce livestock feed, starch and ethanol. Another potential use of wheat bran is in bio ethanol production as an alternative to fossil fuel that is facing depletion. Bran of wheat can be used to supplement wheat flour and baked products with cheap vitamin and other nutrients. Apart from that, wheat bran can be used to make livestock feed formulations and to improve daily milk yields (Chandiposha et al., 2013).

The use of wheat consumption is gradually increasing in Ethiopia particularly in urban areas due to high population growth (immigration of people in to urban areas) and changes in life styles. In most parts of the country, families prefer to use teff to make injera and sometimes to make porridge. Teff straw is an important source of animal fodder and has been shown to be more nutritious as animal feed than other grain by-products. Because of the price escalation of teff compared to wheat most middle and lower class families are shifting to wheat consumption. Ethiopia is the second largest wheat producing country in Africa next to South Africa. Wheat is mainly grown in the central and south eastern highlands of the country during the longer rainy season (June to September) and harvested in October-November. Arsi, Bale, and parts of Shoa are

considered the wheat growing belt of the country. Wheat was produced in large state-owned farms covering around 124,000 ha of land in Arsi and Bale zones. The Federal Government of Ethiopia is in the process to privatizing these farms. The remaining 92% (1,390,000 ha) of production of wheat is from small farms (Abu Tefera, 2013).

2.2. Land Suitability Analysis

According to FAO (1976) land suitability is the way of dividing land in to different suitability classes for the production of crops in a sustainable manner. The suitability analysis enables identifying the main factors of a particular crop production and allows decision makers to develop a crop management system for increasing the land productivity. To achieve the optimum utilization of the available land resource for agricultural production in a sustainable manner, the cropland suitability analysis is a prerequisite. Land suitability evaluation is a classification of lands in terms of their suitability for a 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).

Appropriate land use decisions are vital to achieve optimum productivity of the land and to ensure environmental sustainability. This requires effective management of land information on which decisions should be based. Land suitability evaluation is one of the effective tools for such purpose. There are two general kinds of land suitability evaluation approaches, which are qualitative and quantitative methods. Qualitative approach used to assess land potential at a broad scale or employed as a preliminary to more detailed investigations. The results of classification are generally given in qualitative terms such as highly suitable, moderately suitable and not suitable. The second approach is that using parametric techniques involving land that is more detailed attributes, which allow various statistical analyses to be performed. Land evaluation is a tool to predict land performance in terms of both the expected benefits and constraints to productive land use as well as expected environmental degradation (Feizazadeh and Blaschek, 2012).

Land suitability analysis is a GIS based process used to determine the suitability of a specific area for specific use to show the suitability of an area regarding its intrinsic

characteristic (suitable or unsuitable) for a particular purpose. This analysis considers criteria including biophysical, environmental, social and economic factors (Jafari and Zaredar, 2010).

According to FAO (1976) land suitability classification system has four different categories with orders, classes, subclasses and units. There are two Orders (S and N), which reflect the kinds of suitability (S for suitable and N for unsuitable land). However, it has been recommended to use only three classes within the order S and two classes within the order N. The classes were indicated by an Arabic number in a sequence of decreasing degrees of suitability within the orders and shown in Table 1.

Table 1. FAO land suitability classification standard.

Order	Classes	Description
Suitable	S1 (very highly and highly suitable)	Land have no limitation to the given type of use and land has very minor limitation
	S2(moderately suitable)	Land having minor limitation to the given type of use
	S3(marginally suitable)	Land having moderate limitation to the given type of use
Not suitable	N1(currently not suitable)	Land having sever limitation that preclude the given type of use and improved by specific management
	N2(permanently not suitable)	Land having so sever limitation that are very difficult to be over come

Source: (FAO, 1976)

Land suitability classification was developed by considering different land characteristic factors. The suitability class value of each factor was reclassified for each crop based on their crop requirement standard and this reclassified suitability class values were given from very highly suitable to permanently not suitable. This is after the suitability ranking of each land characteristic factors by adding and taking their average value to determine the suitability of the land for each land use type.

2.3. Identifying the Most Suitable Land use

According to FAO (1976) framework for land evaluation and development, land units are rated according to their suitability for a range of uses, including the production of individual crops. This matching process provides a measure of how successful any crops would be on a specific land unit. The land use normally involves the production of crops for consumption or sale by matching the soil, topographic and climatic factors with the crops. However, the suitability matching process did not take in to account a potential market exists and transport. It is, as far as possible, a technical process, which did not include off farm or non-production factors such as the availability of credit and did not make value judgments on the potential uses of the land. The environmental, social and economic issues are taken in to account at separate and subsequent stage. Furthermore, the evaluation process is carried out separately for each individual crops and results in an individual suitability rating.

There are various ways to estimate the extent of land with cultivation potential. Any quantification would depend up on a variety of assumptions. Since land suitability analysis requires the use of different kinds of data and information. The slope, climate and soil characteristics of an area are the most important determinant parameters of the physical land suitability evaluations and the use of GIS allows the construction of land suitability models from their set of thematic maps (Harasheh, 1994, Marble et al., 1994 and Foote and Lynch, 1996; as cited in Bhagat et al., 2009).

Studies on the soil factors in relation to different plant species illustrate how far soil depth, soil texture, soil organic matter and soil drainage conditions are linked to soil site quality. The objectives of various soil site evaluation studies have been to predict and classify land suitability for plant growth. Soil resource maps based on several parameters, can aid in predicting the behavior and suitability of soils for growing field crops once the suitability criteria are established (Sehgal 1996, as cited in Mishra, 2007).

2.4. Parametric Properties used for Crop Suitability Analysis

Even if studying rainfall variability is important for crop production temperature, slope and soil factors made one study more reliable and acceptable. Temperature requirement for optimal growth of sorghum crop is from 21-32°C. Sorghum crop can tolerate hot and

dry environmental conditions than other cereal crops. Even if it resist drought, it requires at least 150 mm rainfall during the growing stage and from 400 to 900 mm of rainfall as optimal water supply. It grows particularly well on heavy soils, especially on the deep cracking valley bottoms of the tropics (soil with cambisols and arenosols properties). The maximum crop rooting depth is 1-2 m. The root and stubble residues of sorghum leave an excess amount of sugar in the soil by causing multiplication of the soil microorganisms. This locks up the available N for some time (N- immobilization), stir up N deficiency in the succeeding crop. Droughted and freshly ratooned plants are dangerous sources of poisoning (Sys et al., 1993).

The factors that determine wheat production are physical and chemical characteristics of soil, temperature, rainfall and slope of the area. For growth of wheat 10-25°C of temperature and monthly 200 mm with a mean annual rainfall of 350-1250 mm were required. Low temperature encourage tillering. It grows in soils with sandy loam to clay texture. The minimum soil depth of grain crop is 0.1m. Optimal conditions are meeting in soil with a depth of greater than 0.9 m. The maximum rooting depth of spring wheat is 1.2 m-1.5 m and winter wheat is 1.5 m-2 m. It performs best on moderately well-to-well drained soils (Sys et al., 1993).

The topographic characteristics, climatic conditions and soil quality of an area are the most important determinant parameters of the land suitability evaluations (Bhagat et al., 2009 and Elaalem, 2012).

According Keshavarzi et al. (2011) to and Joshua et al. (2013) organic carbon, soil pH, soil texture, soil depth, slope, temperature and rainfall are the major factors of land suitability analysis for wheat and sorghum crops.

2.4.1. Chemical and Physical Characteristics of Soil

Soil is the natural body consisting of layers or horizons of mineral or organic constituents of variable thickness, which differ from the parent material in their morphological, physical and chemical properties and their biological characteristics. It was the supportive layers that encourage the middling through which water and nutrients are made and

readily available for the growth of plants. For any agricultural land use, soil suitability analysis has major importance (Joshua et al., 2013).

2.4.1.1. Soil Texture

Soil texture is one of the most important parameters of soils in which most of the physical characteristics of the soils depend up on. Soils that are high in sand content tend to have a lower available water holding capacity and soils that are high in clay content tend to have a higher water holding capacity (Halder, 2013). The different soil texture classes accompanied with their descriptions are given in Table 2.

Table 2. Soil texture classes and their description.

No	Texture class	Description
1	Sand	Very coarse, cannot form clods/ balls, no stickiness
2	LoamySand	Very coarse, can form ball but easily collapsed
3	Sand Loamy	Somewhat coarse, form balls easily collapse, has Some stickiness
4	Loam	Not coarse and slippery, can form balls; can be rolled with shiny surface and somewhat sticky
5	Silt Loam	Slippery, can form strong clods/balls, can be rolled with shiny surface, and rather sticky
6	Silt	Very slippery, can be rolled with shiny surface, and rather sticky
7	Clay Loam	Some rough/ coarse materials; can form rather firm balls when moist, can be rolled but easily broken, somewhat sticky
8	Sandy Clay Loam	The coarse materials can be easily recognized, can form a rather firm balls, can be rolled but easily broken, sticky
9	Silt Clay Loam	Slippery, can form firm balls, can easily form shiny rolls & sticky
10	Sandy Clay	Slippery but rather coarse, can easily form shiny rolls but cannot easily bent, and sticky
11	Silt Clay	Slippery, can form balls, can easily be rolled, and sticky
12	Clay	Heavily sticky, can form very rounded and good balls, hard when dry, sticky when wet

Source: (Ritung et al., 2007)

2.4.1.2. Organic Carbon (OC)

Organic carbon of soil indicates the organic matter content in the soil, which often creates the basis for the successful use of mineral fertilizer. Organic matter, slope and soil physical characteristics are found to be the limiting factors for wheat production in the study area. The combination of organic matter and mineral fertilizers provides suitable

environmental conditions for crops as the organic matter improves soil properties and mineral fertilizer supplied to the plants. Soil organic carbon content in the soil, which has many benefits such as reservoirs of plant nutrients especially nitrogen, phosphorus and sulfur, and it is important for maintaining micro nutrient cautions available from and completing aluminum in less phyto-toxic form. In addition, it has a high water holding capacity and hence minimizing the effects of moisture stress (Mustafa et al., 2011 and Halder, 2013).

2.4.1.3. Soil Depth

Soil depth is an important physical property of soil through matching the land use type with their requirement depth level. It determines how far the roots can grow and how much the soil can hold water. It is measured to the shallowest root-limiting layer. The presence of a root-restricting layer reduces the available water capacity of the soil, as it reduces the amount of soil that is available for plant roots. Soil depth is divided as very shallow, shallow, moderately deep and deep. Therefore, a very shallow soil depth is not good for crop production whereas moderately deep and deep soils are good for crop production (Ritung et al., 2007).

2.4.1.4. Soil Type

The wide ranges of topographic factors, climatic factors, parent material and land use types changes have resulted in extreme variability of soil types. In different parts of the country, different soil forming factors have taken place. The big proportion of the country's landmass is covered by nitosols, cambisols, lithosols and regosols soil unit in order of their importance (MoA, 2000). The existing Soil type was shown the soil depth and nutrient content of an area. For instance, nitosols and cambisols are associated with moderately deep soil, and regosols and leptosols with shallow depth (Woubet Gebre et al., 2013).

Leptosols are soil unit with a very shallow profile depth indicating little influence of soil forming processes and they often contain large amount of gravel that does not yield deep soil and are unattractive soils for rain fed agriculture. Lixisols are soil with sub surface accumulation of low activity clays and high base saturation. In Oxisols, their age and mineralogy have led to low levels of plant nutrient availability and high erodibility. It is

more suitable for perennial crops than root or tuber crops. Arenosols consists of sandy and loamy soil that developed in residual sands after weathering of old quartz-rich rock and soils developed in recently deposited materials. Haplic nitosols and vertic cambisols are associated with moderately deep soil and moderately suitable for crop agriculture where as leptosols are also associated with a very shallow soil depth profile and has low suitability for crop (Joshua et al., 2013).

2.4.1.5. Slope

The slope capability describes the suitability of the topography of the area for croplands. This capability is not only based on the risk of erosion, but also on soil depth, which is an important characteristic for vegetation and crop production (Joshua et al., 2013). Low slope area is more important for crop production, medium slope has moderate importance and very sloppy area is not good for crop production. According to FAO (1997) slope classification from 0-8% is low slope, 8-16% moderate slope and 16-30% is high slope and 30+% is very high sloppy.

2.4.1.6. Soil Drainage

According to FAO (1976) standard guidelines soil drainage of a specified area can be divided in to five classes. These are well drained, moderately drained, imperfectly drained, poorly drained, and very poorly drained. Soil drainage or drainage classes are a way of expressing the frequency and duration of periods in which the soil is saturated having free water in excess of field capacity. The excess free water in the root zone can kill plants or keep them from becoming established. In well-drained areas water is removed from the soil readily but not rapidly. The internal free water occurrence is commonly deep or very deep and its annual duration is not specified. Water is available to plants throughout most of the growing season in humid regions. In moderately drained area, water is removed from the soil somewhat slowly during some periods of the year. Commonly the internal free water occurrence was moderately deep and transitory through permanent. The soils are wet for only a short time with in the rooting depth during the growing season. In imperfectly drained area, water is removed slowly so that the soil is wet at a shallow depth for significant periods during the growing season. Commonly, the occurrence of internal free water is shallow to moderately deep and

transitory to permanent. In poorly drained areas unless the soil is artificially drained, most mesophytic crops cannot be grown.

2.4.2. Climatic Factors

Climate is one of the most important factors for land suitability analysis. The majority of the land uses are sustainably affected by rainfall, temperature and humidity of the area. For some land evaluation studies, the actual weather data are not needed and the area is defined with the regions with a similar climate. The two major climatic variables are precipitation and temperature (FAO, 2007).

Climate plays a fundamental role for agricultural activities. Agro climatic or agro meteorological indices have great potential to quantify and communicate the impacts of climate changes on agricultural production. Frost and heat stress can be quantified through relatively simple indices such as number of frost days (days with temperature $< 0^{\circ}\text{C}$) or number of heat stress days (days with temperature $> 35^{\circ}\text{C}$). Excess rain can be quantified in relation to precipitation percentiles or as daily rainfall exceeding a crop specific threshold. Drought indices have been quantified the lack of water during plant growth (Holzkamper et al., 2010).

2.4.2.1. Temperature

Sorghum and wheat seeds germinate and grow in places having a temperature of above 10°C . The optimum temperature for the growth of sorghum is $21\text{-}32^{\circ}\text{C}$. Whereas the temperature range for the growth of wheat is $10\text{-}25^{\circ}\text{C}$. The optimal temperatures for wheat crop growth are between $12\text{-}23^{\circ}\text{C}$. The temperature has marked effect on the length of time to maturity. The night temperatures of below 15°C for 5-night days completely inhibited and killed the crop by frost (Sys et al., 1993).

2.4.2.2. Rainfall

Wheat growing areas need to receive a precipitation that exceeds 200 mm per growing cycle. The mean annual rainfall required for the crop should be around 450 mm and above. A dry period is necessary at the maturing stage. Sorghum requires rainfall in the growing cycle guaranties an optimal water supply. Sorghum is grown in areas having at

least 150 mm of rainfall in the growing cycle and for good yield more than 500 mm is required (Sys et al., 1993).

2.5. Application of GIS and Remote Sensing for Sustainable Agriculture

To achieve sustainable agricultural development, the following agricultural technologies are important:

- Improved cropping management technology by analyzing the soil, climate and biotic stresses
- Selecting suitable cropping system for different agro-ecological regions using soil, terrain and climatic suitability
- Improving soil productivity through nutrient management and minimization of the risk of pollution of soil, water and environment by conducting different indices
- Evaluate the past and present natural resource of an area and made soil and water conservation and improving moisture availability
- For sustainable agricultural development through cropping system analysis, agro economic zonation, quantitative assessment of soil carbon dynamics and land productivity, soil erosion inventory and integrated agricultural drought assessment.

Areal extent of crops and yield are important to find out agricultural area with low to medium crop productivity. Sustainable crop production was achieved by adaptation of suitable agronomic management packages by introducing of new crops (Rundquest et al., 2009).

2.5.1. Role of Geographic Information System

Land suitability analysis database can be developed in two GIS formats such as vector and raster format. The vector format was mainly used for data management and querying, where as the raster format was used for most spatial analysis. Raster based GIS is organized as a set of partially independent modules. A macro language allows successive calls to these modules in order to realize the procedures used to compute the suitability analysis map (Joerin et al., 2001).

Geographic Information System has emerged as a powerful tool in the management and analysis of large amount of basic data and information. Statistical, spatial and temporal data sets needs to generate information products in the form of maps as well as tabular

and textural reports for land use decisions. In recent years, GIS has been developed in linkage with agro-ecological zoning and similar models, to tackle issues of land use at regional levels. It is a very useful tool for automated logical integration of bioclimatic, terrain and soil resources information, which are required for land use planning. Generation of spatial database from point database using various geo-statistical techniques is an important part of GIS application, which aids for the integrated analysis. The system is capable of containing all data required to solve resource management problems. The topographic, land resource and contour maps having physiographic, geographic and bioclimatic information forms primary input of GIS for land use planning. It is a vital tool to analyze a multilayered database. Its capability to process various data in spatial domain make the planning process easier. This technology is the most useful in spatial planning processes that follow land evaluation, as its application is most useful for resource analysis and conservation activities. Therefore, the information obtained through GIS techniques can be used to model yield production factor relationships and to apply in land suitability evaluation studies (Bhagat et al., 2009).

2.6. Parametric Methods for Physical Land Suitability Evaluation

Physical land suitability evaluation is a prerequisite for land use planning and development. It provides information on the constraints and opportunities for the use of the land and guides decisions on optimal utilization of land resources. The physical land suitability evaluation indicates the degree of suitability for land use without respect to socioeconomic conditions. This means when the land use is at risk or physically impossible, no economic analysis can justify it. Therefore, for physical land suitability soil, climate and slope were preferable than other economic, social and political factors for agricultural suitability analysis (Bagherzadeh and Daneshvar, 2011).

There are two land evaluation approaches based on the method of data analysis, namely non-parametric method that evaluate the physical land suitability analysis based on expert judgment and described in terms highly suitable, marginally suitable and not suitable and it is highly subjective. The parametric method is another method in which assessment of land suitability is based on a continuous scale using multiplicative or additive models without subjectivity. It is an important process for assessing the value and proficiency of

the land and helps in planning for future sustainability of land resources. Therefore, parametric method is an important method to analyze land suitability, which minimizes human bias to improve the pragmatic value of land evaluation results. The parametric approach has three methods storie, minimum square root test method and maximum square root test method. The storie and minimum square root method were classical methods that undermine the suitability result. Therefore, many researchers have conducted comparison studies between those methods. The result of the different land suitability methods usually correlated to each other and the maximum square root parametric method that is adapted by Rabia and Terribile commonly gives good and more realistic result than others. For applying this parametric system the evaluator should be prepared the land unit for the area they are going to assess (Ashraf et al. 2010, and Rabia and Terribile, 2013).

CHAPTER THREE

3. METHODS AND MATERIALS

3.1. Description of the Study Area

The present study area is found in South Wollo Zone and Amhara Regional State of Ethiopia. The Woreda has 34 Kebele administrations. The study area was found 600km away from the capital city of Ethiopia, Addis Ababa. The location of the study area was found at the latitude $10^{\circ} 21' 43''$ – $10^{\circ} 44' 10''$ N and longitude $38^{\circ} 27' 50''$ – $38^{\circ} 58' 47''$ E with area coverage or extent of 1101 km² (Fig.1). The map was prepared with 1:250,000 scale.

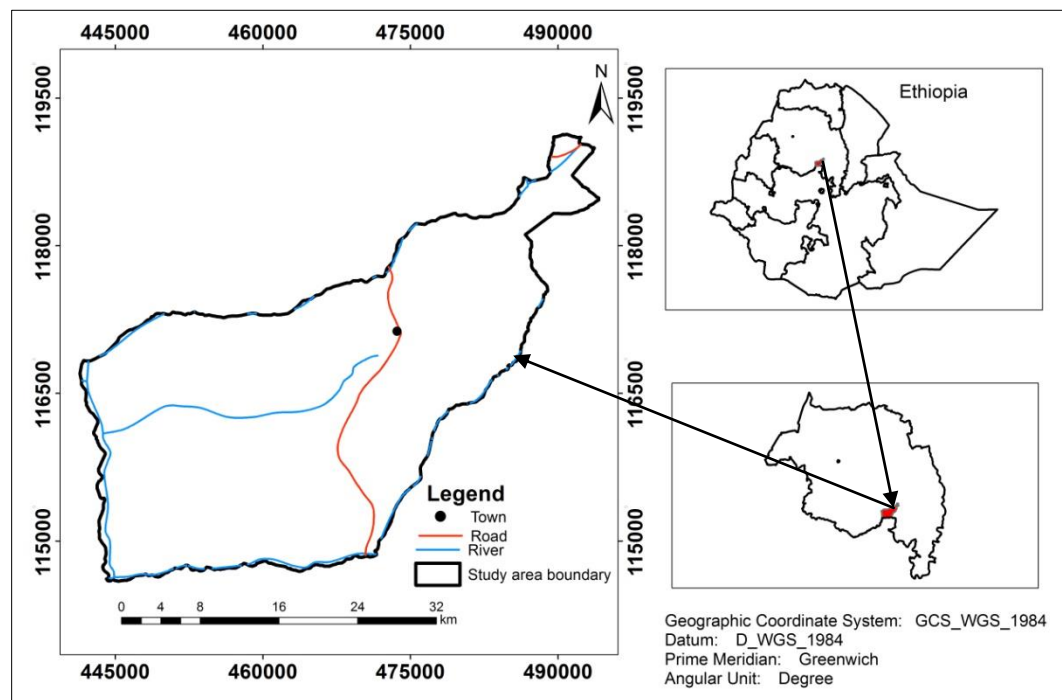


Fig. 1. Location map of the study area.

3.1.1. Population

The Woreda has 33 rural Kebele administrations and one urban Kebele. The total population of the area was 101,521 with rural population of 99,843 and urban population of 1678. The area coverage of the Woreda was 1101km². One of the most important determinants of wealth is the ownership of plough oxen in particular. The ownership of a pair of oxen allows better of households to prepare their land on time and rent in the land

of poor and very poor households on a contractual basis. The wealth breakdown of the people in the Woreda is shown in Table 3.

Table 3. Population wealth breaks down of the population in the Woreda.

People	Wealth group characteristics			
	H.H size	Land cultivated	Livestock /asset holding	Other asset
Very poor	3-5	0-1 timad	1-3 chicken	None
Poor	4-6	0-2 timad	3-5 goats, 0-2 cattle, 1-3 chicken	None
Middle	5-7	4-7 timad	6-8 goats, 1-3 oxen, 2-4cattle, 0-2 donkey, 1-3 chicken	0-2 beehives
Better off	6-8	8-10 timad	12-14 goats, 2-4 oxen, 5-7 cattle, 1-3 donkey, 1-3 chicken	2-4 beehives

Source: Agriculture and Rural Development Office of the Woreda (2014).

The wealth of the population in the area was determined by cultivated land and livestock possession (plough oxen, cattle and goats). There is a big difference in the ownership of land, with the better-off owning three times more land than the very poor. Differences in cultivated land are even greater ranging from 0-1 timad for the very poor to 8-10 timads for the better off. This reflects the fact that the poor and very poor do not have oxen and so are unable to cultivate all their own land, and rent out part of their land to the middle and better-off with an equal (half) crop sharing arrangement. Except in December and January, when both cattle and goats are sold, different types of livestock also sold at different times of the year. Goats are sold around the major Christian Festivals (New Year, Christmas and Easter) and Islamic festival (Arefa and Mewulid); cattle are sold in the months when there is no need for oxen for agricultural activities. Whilst migratory labor is not common, some people travel to Tapi, Metema, Wollega, Nazareth, Bale Goba and Humera for work after the end of December and January.

3.1.2. Topography

The Woreda is located at an elevation of 1883 m above mean sea level. The Woreda has low slope (0-8%) at the northern tip, medium slope (8-16%) at the eastern part, central and eastern part and most part of the Woreda is highly sloppy (16-30%) at the tip of the south east and west as well as at the central and northern parts. Steep slopes are vulnerable to erosion, and have shallow soil depth, which affects vegetation and farming, making agriculture impossible. Medium slopes are moderately suitable slopes for crop agriculture. Here, soil erosion is moderate with moderately shallow soil depth, making agriculture possible only with frequent fertilizer applications, minimum tillage and careful erosion control and low slope is more important for agriculture than other slope type.

3.1.3. Climate

The Woreda has a rich Variety of local climate ranging from dry woynadega, moist woynadega to wet woynadega like climate. The mean monthly rainfall amount varies between about 6 mm to 250 mm with total annual rainfall of about 964 mm, which is shown in figure 2. The mean temperature of the area is 19.8°C with minimum and maximum average annual temperature of 10°C and 29.7°C respectively and shown in figure 3.

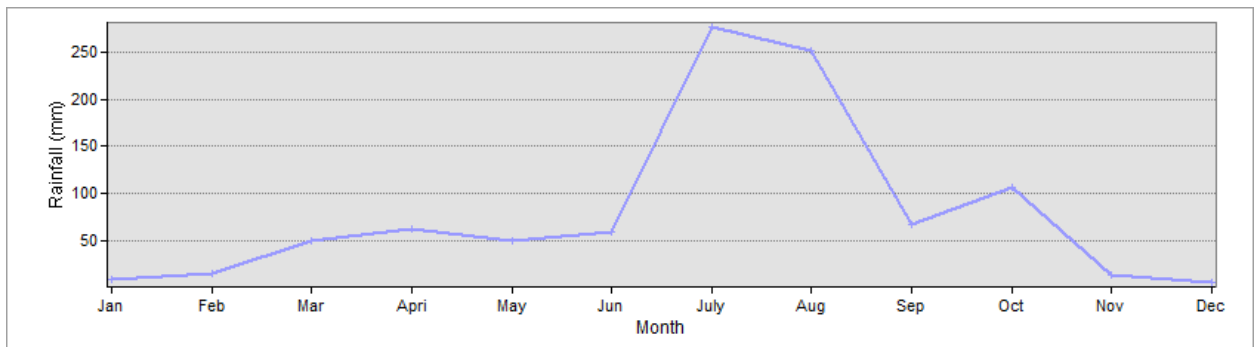


Fig. 2. Mean monthly rainfall (mm) of Wogdie Woreda.

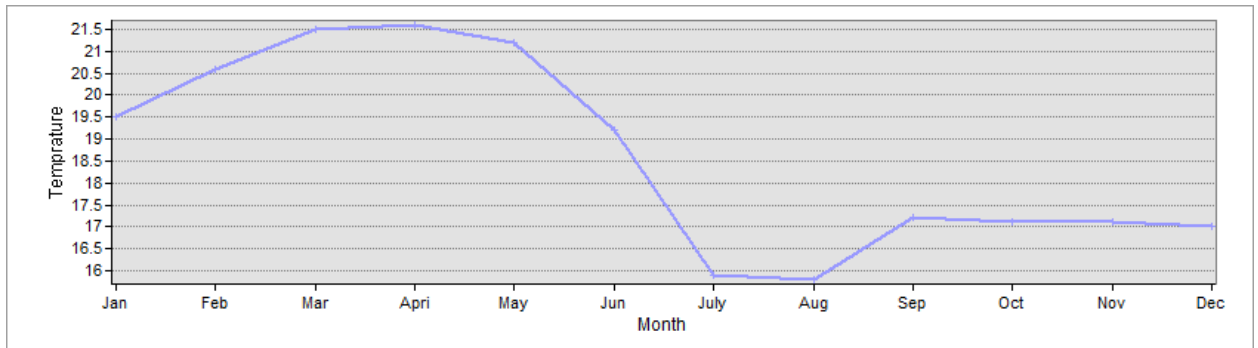


Fig. 3. Mean monthly temperature (°C) of Wogdie Woreda.

According to Ethiopian Ministry of Agriculture, there are around eight traditional ecological zone classification in Ethiopia. These ecological zones are bereha, erdeb kola, weinadega, erdeb weinadega, dega, erdeb dega and wurch zone which is illustrated in Table 4. Based on these, the present study area has an ecological zone of dry warm, sub moist and moist cool. All Ethiopian Agro-Ecological Zones are described in altitude, rainfall and temperature (MoA, 2000).

Table 4. Traditional Ecological Zone of Ethiopia.

Zone	Altitude (m)	Rainfall (mm)	Temperature (°C)
Bereha (dry-hot)	500-1500	<900	>22
Erdeb kola	500-1500	900-1000	18-24
Weinadega (dry warm)	1500-2500	<900	18-20
Weinadega (sub moist cool)	1500-2500	900-1000	18-20
Erdeb-weinadega (moist cool)	1500-2500	>1000	18-20
Dega (cold)	2500-3500	900-1000	14-18
Erdeb dega (moist cold)	2500-3500	>1000	10-14
Wurch (very cold)	>3500	>1000	<10

Source: (MoA, 2000)

The features found in these ecological zones, which are found in the present study area, are stated below. The soil type, natural vegetation, plant species, crop type and livestock that are found in wet weinadega, moist weinadega and dry weinadega are illustrated in Table 5.

Table 5. General feature of the Agro-Ecological Zones of the Woreda.

Zone	Altitude (m)	RF (mm)	Soil type	Natural vegetation	Main-plant species	Crop	Livestock
Erteb weinadega (sub moist cool)	1500-2500	>1000	Brown		Acacia, Cordia, Ficus, Arundinaria	Teff, Maize, Enset, Barely	Sheep, Cattle, Goat, Horse, Bees
Moist weinadega (moist cool)	1500-2500	900- 1000	Red brown		Acacia, Ficus, Cordia	Maize, Sorghu m, Teff, Wheat, Barely	Cattle, sheep, Goat, Horse, Donkey, Bees
Dry weinadega (dry warm)	1500-2500	<900	Light brown yellow	Savanna	Acacia	Wheat, Teff, Maize	Cattle, Goat, Donkeys, Bees

Source: (MoA, 2000)

3.1.4. Soil Type

The present study area has a soil type of Cambic Arenosols, Vertic Cambisols, Eutric Leptosols, Lithic Leptosols and Haplic Nitosols. The vertic cambisols was found in the study area where there is a medium steep slope and moderately deep soil and it covers an area of 15 km² from the total. Haplic nitosols was found in the area of gentle slopping and covers an area of 142 km² in the study area. Cambic arenosols was an attractive soil that developed from recently deposited material and very important for vegetation and covers 420 km² of the area. Lithic leptosols are soils associated with very shallow depth and contain large amount of gravel that does not yield deep soils. It covers 166 km² of the total area whereas eutric leptosols are related with shallow soil depth. It covers an area of 358 km² from the total area of the Woreda.

3.1.5. Vegetation

The vegetation of the area includes bush, shrubs, grassland and little forest. The natural resources found in this Woreda include gypsum and gum Arabic Acacia. It is a mixed production system with both crops and livestock. The dominant crops cultivated include sorghum, teff, maize, wheat and haricot beans. The crop production is entirely rain feed, except in small number of localities where small scale water harvesting practices have been recently introduced by the office of agriculture and rural development.

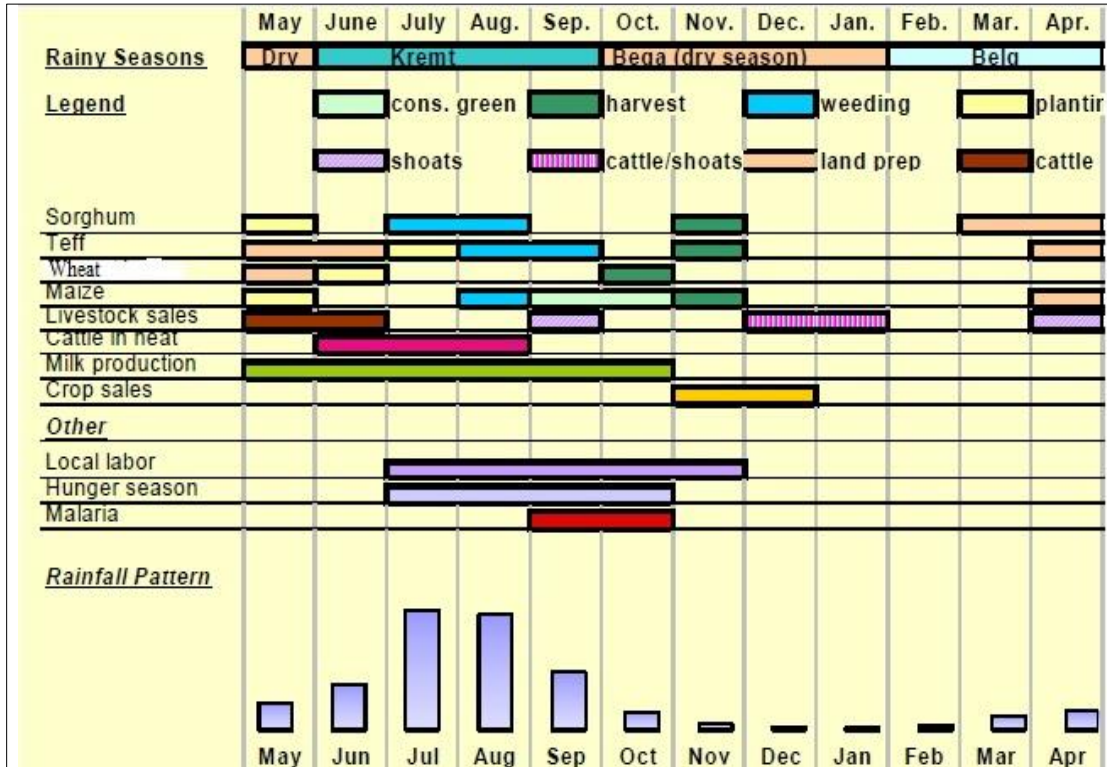
3.1.6. Livelihood Profile and Seasonal Calendar of the Woreda

This Woreda is a chronically food deficient area. The main economic livelihood of the population is crop production (wheat, teff, sorghum, barely and pulses) supplemented by livestock rearing (sheep, goat and cattle). The main source of cash for the middle and better off are sale of crops, livestock and eucalyptus trees. Local or urban labor and the selling of eucalyptus tree are the major economic activities of the poor and very poor people in the Woreda. There is only one rainy season that is long rainy season (kremt) and it is important for the cultivation of both long and short cycle crops. As the crop production is very small, almost all agricultural products are consumed locally and whatever is supplied to the local market does not exceed the local demand. Haricot beans are the only crop supplied to external markets in urban areas of Mota, Dessie and Addis Ababa. Livestock and livestock products are sold in the major towns within the livelihood zone. The only opportunity in terms of employment is the local agricultural labor.

3.1.7. Seasonal Calendar

Of all agricultural activities, land preparation (March-June) and weeding (July-September) are the most laborious and time-consuming activities which is shown in Table 6. Agriculture is entirely dependent on long rain season that last from June to September. Maize is harvested green from September to October and the main food crops sorghum and teff are harvested in November- January. Local employment opportunities are available for a relatively longer period of time starting with weeding in July to harvesting in November-January. The food insecure season and the period of highest dependence on market for food purchase lasts for about two months in September and October.

Table 6. The seasonal calendar of the Woreda for crops.



Source: Agricultural Office of Amhara Region Livelihood Zone Report, (2007).

3.2. Methods

3.2.1. Materials and Data Source

The following software's were used in the present study for data collection, acquisition, design, analysis and presentation of the final research results: Arc GIS 10, Microsoft word, Microsoft excel, and Microsoft access. Several reports, journal articles and books were used to do the literature review of the topic. The following digital data merged in to a GIS platform and have been used: DEM (Digital Elevation Model), Soil and Climate data under this study. The material and their source was shown in Table7 below.

Table 7. The source and purpose of the data used for the present study.

No	Data used	Purpose of the data	Source
1	DEM	To generate slope	WWW.DEM (30m)
2	Soil data	To generate the physical and chemical properties of soil	FAO (1997)
3	Satellite climate data	To interpolate temperature and rainfall data	NMSA
4	Ethiopian shape file	To clip the study area boundary	CSA
5	Yield data	For result validation	WARDO

The success of any GIS application was depended on the quality of the geographic data used. The collection of high quality geographic data as an input data for GIS was marked as a critical stage. Data collection is one of the most time-consuming and expensive, yet important for GIS based studies. Geographic Information System can contain a wide variety of geographic data types originating from many diverse sources. To achieve the objectives of this study, secondary data, i.e. raster and vector data were used. In the present study, the data that were used to evaluate land suitability for different Land Utilization Types (LUTs) was based on FAO guidelines of crop requirement. This guideline was accepted by many researchers and used as a standard for the crop suitability analysis in Ethiopia and other countries. It has a procedure to evaluate the suitability of the land for intended land use. The physical and chemical properties of soil data like depth, drainage, texture, organic matter, and soil type used for analysis was obtained from FAO and the climatic data used for analysis were collected from National Meteorological Service Agency (NMSA).

The attribute table of FAO data used for the present study was prepared in code for each physical and chemical properties of soil. By the help of the legend that was taken from the organization, the code was renamed and identified easily for the analysis. Some of the attribute table codes of the data used for the present study is given in Table 8.

Table 8. The code and description of soil data of the study area.

Soil parameters	FAO code	Description
Texture	3	Loam
	4	Clay loam
	5	Clay
Organic carbon (%)	B	0.8-1.5
	C	1.5-2.5
	D	2.5-3
Soil depth (cm)	A	0-10
	B	10-50
	C	50-100
	D	100-150
Soil type	ARb	Cambic Arenosols
	CMv	Vertic Cambisols
	LPe	Eutric Leptosols
	LPq	Lithic Leptosols
	NTh	Haplic Nitosols
Soil drainage	W	Well
	M	Moderate
	IP	Imperfect

Source: FAO (1997)

3.2.2. Ancillary Data

The ancillary data that were utilized during the data analysis includes soil data, climate data, slope data and other study area description thematic layers like road, rivers, towns, kebele, and Woreda were also used. All data were projected to the Universal transverse Mercator (UTM) projection system Zone 37 N and datum of World Geodetic System 84 (WGS 84) ensuring consistency between datasets.

3.2.3. Selection of Parameters and Crops (Land Use Types)

The nature of the criteria used for physical land suitability analysis was physical and chemical properties of soil, climate and slope. However, it did not include the socio-economic and political factor for the analysis. In the present study, the criteria were considered by using the literature review of internal and external references, interviewing with experts and availability of data. As stated in review of literature the criteria like climate, slope and physical and chemical properties of soil were the dominant factors that determine cereal crop production. Therefore, the parameters like climatic factors (rainfall and temperature), slope and physical and chemical properties of soil (soil type, soil texture, soil drainage, soil depth and soil organic carbon) were taken in to account. For

the present study, the crop types that were considered for evaluation were sorghum and wheat, as the population of the area preferred these crops more than other crops for cultivation and consumption. The people in the study area commonly use sorghum and wheat for subsistence and use the debris of these crops for their livestock. As those crops are low in price to purchase by low income group people for consumption when compare with teff and other cereal crop.

3.2.4. Wheat and Sorghum Crops Requirement Standard for Suitability Reclassification of Each Parameter

The criteria used for the land suitability evaluation for the selected crop were reclassified based on Sys et al. (1993) and FAO (1976) crop requirement standards. First, clipping and masking the data from the whole data only the present study area by using study area shapefile. The clipped and masked data by using the study area shapefile has its own classes. These classes of the data were reclassified based on the crop requirement standard to prepare the rating class of the parameter for the index calculation and to show the suitability of each parameter and this standard were shown in detail in Table 9 below. Then, to reclassify and to make all data in the same format with masked data, the clipped data were converted in to raster data. The land suitability evaluation of each parameter for sorghum and wheat crop was performed based on comparison of land use type with land quality. Therefore, the suitability classes of each parameter were determined from very highly suitable to not permanently suitable based on this crop requirement standard. Since matching land use requirement with natural resources is an essential part of land suitability classification and express the result qualitatively. Finally, the suitability indices procedure have the following key steps: step1 was identifying land unit with a similar land provinces. Step 2 was producing the suitability of each parameter for the land use using crop requirement standard and masking this suitability map by each land unit with crop requirement. Step 3 calculate the rating value of each parameter for all land units and using this rating value compute the suitability of the land unit by a mathematical formula of maximum square root test method. Then, after calculated the suitability index of all land units by the given formula, the land unit that have the same and different suitability class was identified and mapped using GIS technology.

Table 9. Sorghum and Wheat crops requirement standard by Sys et al. (1993).

Suitability Class and Degree of Limitation for Sorghum Crop						
	S1		S2	S3	N1	N2
Factors	100-95	95-85	85-60	60-40	40-25	25-0
Rainfall(mm)	500-950	450-500 &950-1200	300-400 & 1200-1400	150-300	-	<150 & >1400
Temperature (°C)	24-26	21-24 & 26-32	18-21 & >32	15-18	-	<15
Slope (%)	0-4	4-8	8-16	16-30	30-50	>50
Soil texture	SiL, L	CL, SiCL	SiC, C	LS	-	S
Soil depth(cm)	>100	50-100	20-50	20-10	-	0-10
Soil type	ARb, RG, CMmo, CMvreuh	PH, NTh, FL, CMcr, CMeou	CMv, VR	Lpe	Lpli	-
Soil OC (%)	>1.5	0.8-1.5	<0.8	-	-	-
Soil drainage	Well	Moderate	Imperfect	Poor	Very poor	-
For Wheat Crop						
Rainfall (mm)	450-1000	350-450 & 1000-1200	250-350 & 1200-1500	200-250 & 1500- 1700	-	<200 & >1750
Temperature (°C)	15-20	20-23 & 12-15	23-25 & 10- 12	25-30 & 8-10	-	<8 & >30
Slope (%)	0-4	4-8	8-16	16-30	-	>30
Soil depth(cm)	>100	50-100	20-50	10-20	-	0-10
Soil texture	SiL, L	CL, SiCL,	SiC, C	LS	-	S
Soil type	ARb, CMVreou, CMmo	RG, PH, FL, NTh, CMcr,	VR, CMv	Lpe	Lpli	-
Soil OC (%)	>2.5	2.5-1.5	1-1.5	<1	-	-
Soil drainage	Well	Moderate	Imperfect	Poor	Very poor	-

ARb= cambic arenosols, NTh=haplic nitosols, Lpe=eutric leptosols, Lpli=lithic leptosols, CMv=vertic cambisols, RG=humic regosols, PH=pachic paeozem, CMcr= vertic cromatic cambisols, VR=, CMcr=, CMeou =Fluvic Orthieutric Cambisols, FLh=humic fluvisols, CMVreouh=hypereutric vertic cambisols,CMmo=mollic cambisols,CMVreuh=Hypereutric Vertic Cambisols, L=loam, SiL=siltloam,CL=clayloam, SiCL=siltclayloam, LS=loamsandy, ,SiC=silt clay,C=clay, S=sand

A crop requirement in Table 9 for wheat and sorghum were established using the structure of the FAO framework for land evaluation by (Sys et al., 1991 and 1993). Many Ethiopians used this crop requirement standard for crop suitability analysis in different areas. Teshome and Verheye (1993) used this crop requirement standard in Hossaina,

Debrezeyer and Ambo in Ethiopia for Barly and Teff crop suitability analysis. Similarly, Kassa Teka and Mulu Haftu (2012) used this standard for land suitability characterization of crop and fruit production in mid lands of Tigray, Ethiopia. These showed that applying this standard in Ethiopia, which is adapted from FAO, was possible or applicable for different crop suitability analysis. Due to this reason, in the present study this crop requirement standard was used for wheat and sorghum physical land suitability analysis.

3.2.5. Land Suitability Factor Rating and Index Calculation Method

According to Bagherzadeh and Daneshvar (2011) the physical land suitability evaluation consists a model that assigns a score to every land quality and characteristics. Land quality is a complex attributes of land, which distinctly influences its suitability for a specific kind of use, while land characteristics are any measurable features of land that can be used to characterize a land for different purpose. The suitability classes in terms of degree of limitation were adapted from FAO for any suitability analysis classification by different researchers. This degree of limitation was used only for individual parameters. For instance, for soil texture parameter loam soil is very highly suitable for crop agriculture and rated from 95-100 whereas sandy soil is not permanently suitable and found in rating class of 0-25. Therefore, to calculate its index, they should take the average of the rating class. The suitability rating class used for rating each parameter based on their degree of limitation was given in Table 10.

Table 10. Land suitability rating according to degree of limitations.

Suitability class	Intensity limitation	Degree of limitation
S1	Without limitation	95-100
S1	Slight limitation	85-95
S2	Moderate limitation	60-85
S3	Sever limitation	40-60
N1	Very sever (modified)	25-40
N2	Very sever (non modified)	0-25

Source: Sys et al., (1991)

In order to decide the appropriate land suitability classes, combining the factor rating of all individual factors was important. The suitability class of each parameter was

determined using crop requirement standard and their rating classes by using degree of limitation for the parameter. Then, the individual parameter, which has an identified suitability level and rating class has masked by all land units. Finally, the suitability index was calculated by maximum square root test formula for each land unit. The value of calculated suitability land index for the land unit was matched with Table 11 given below and determined their suitability class for the identified land use type. Therefore, the overall value of each land units together gives the total suitability of the study area for those land use type.

Table 11. Land suitability classes according to land index.

Suitability class	Intensity of limitation	Land index
S1	Highly suitable	75-100
S2	Moderately suitable	50-75
S3	Marginally suitable	25-50
N1	Currently suitable	12.5-25
N2	Permanently not suitable	0-12.5

Source: Sys et al., (1991)

3.2.6. Method of Data Processing

The first parameter used for the analysis was slope. The format and nature of the slope data was raster and generated from the DEM of the study area in percentage, which was masked by the study area shape file, and it was reclassified in to different slope suitability classes based on slope crop requirement standards. The reclassified slope data based on crop requirement showed the hierarchical suitability of the slope classes for the specified crops.

Likewise, soil data was the other identified parameter for the analysis. From soil data the soil type, soil depth, soil texture, soil drainage and soil organic carbon content of the area were selected to use for the analysis and those data was obtained from FAO. The collected data from FAO (1997) soil classification was clipped by the study area shapefile. The format of the data was feature data and changing this feature data to raster format to assess the suitability classes of each soil property for the land use type by reclassifying the raster data based on the comparison of crops with their requirement and

assigning the result from very highly suitable up to not permanently suitable for the crops. Therefore, the reclassification of all the physical and chemical property of soil was done, and their level of suitability for the specified land use was identified and illustrated.

The other data used for the present study was climatic data. The rainfall and temperature were the dominant climatic factors, which was used for crop suitability analysis. According to Adab et al. (2013) satellite data is covering the earth so it offers a great environmental data. The satellite climatic data are needed to be initially calibrated with the data of the weather stations. The advantage of using this modified satellite data was to restructure and complete the existence of error in the data using statistical methods. Therefore, the calibrated satellite data of rainfall and temperature was obtained from National Meteorological Service Agency. In this study, 34 gridded sample points in every 10 km for 20 years were taken for interpolation that is shown in appendix 3. According to Sys et al. (1993) for crop suitability analysis a 6 month rainfall and temperature were required. Then, for these 34 sample points their 6 month mean of 20 years (1993-2013) were prepared in excel and interpolated. According to Mair et al. (2011) in the rainfall interpolation, the Thiessen polygon method produced the highest error, whereas the kriging method produced the lowest error. The disadvantage of Thiessen method is obvious that its interpolation is based on only one measurement and the information on neighboring point is ignored. Therefore, the kriging method is better than other methods of interpolation. Then, the prepared climatic data in excel were interpolated using kriging method of spatial analyst tools. The interpolated data was reclassified in to different suitability classes based on their climatic crop requirement standard to show climate suitability classes for the crops. The area coverage of each reclassified parameter was calculated to specify how much area was highly suitable, moderately, marginally suitable and not suitable for the given land use per each of the parameters.

Finally, the overall physical land suitability analysis for wheat and sorghum crops was produced by using created land unit on the bases of land province. The suitability class value of all parameters for each land unit was calculated by parametric square root test method rather than overlaying all parameters by giving weight for each criteria.

According to FAO (2007) land unit is an area of land defined in terms of land qualities and characteristics that was demarcated on a map. A hierarchy of land units was prepared based on land provinces, land system, landforms and terrain units. Therefore, the present study was classified in to different land units based on land provinces and produced 33 land units. To calculate the suitability index of each land unit first exported all 33 land units and then, masked all reclassified parameters by each land unit. The rating class of each parameter was defined by degree of limitation standards. After all the parameters rating class was determined the suitability of each land unit is computed by the formula of $S_i = R_{max} \times \sqrt{\frac{A}{100} \times \frac{B}{100} \times \dots}$, where S_i is the suitability index of an area, R_{max} is the maximum rating class of the parameter in the area, A, B and C.... are the rating classes of parameter A, B and C... in the study. Therefore, after computing the suitability index of each land unit by the given formula they were classified or grouped the calculated suitability index value of each land unit in to suitability class value based on FAO land index standard. In parametric method even if certain land unit was found in the same suitability class their level of suitability for the crop was different. Therefore, due to this and other importance, the square root test mathematical method was used to compute sorghum and wheat suitability of the present study. The overall procedure of wheat and sorghum crops suitability analysis in the present study was illustrated in figure 4.

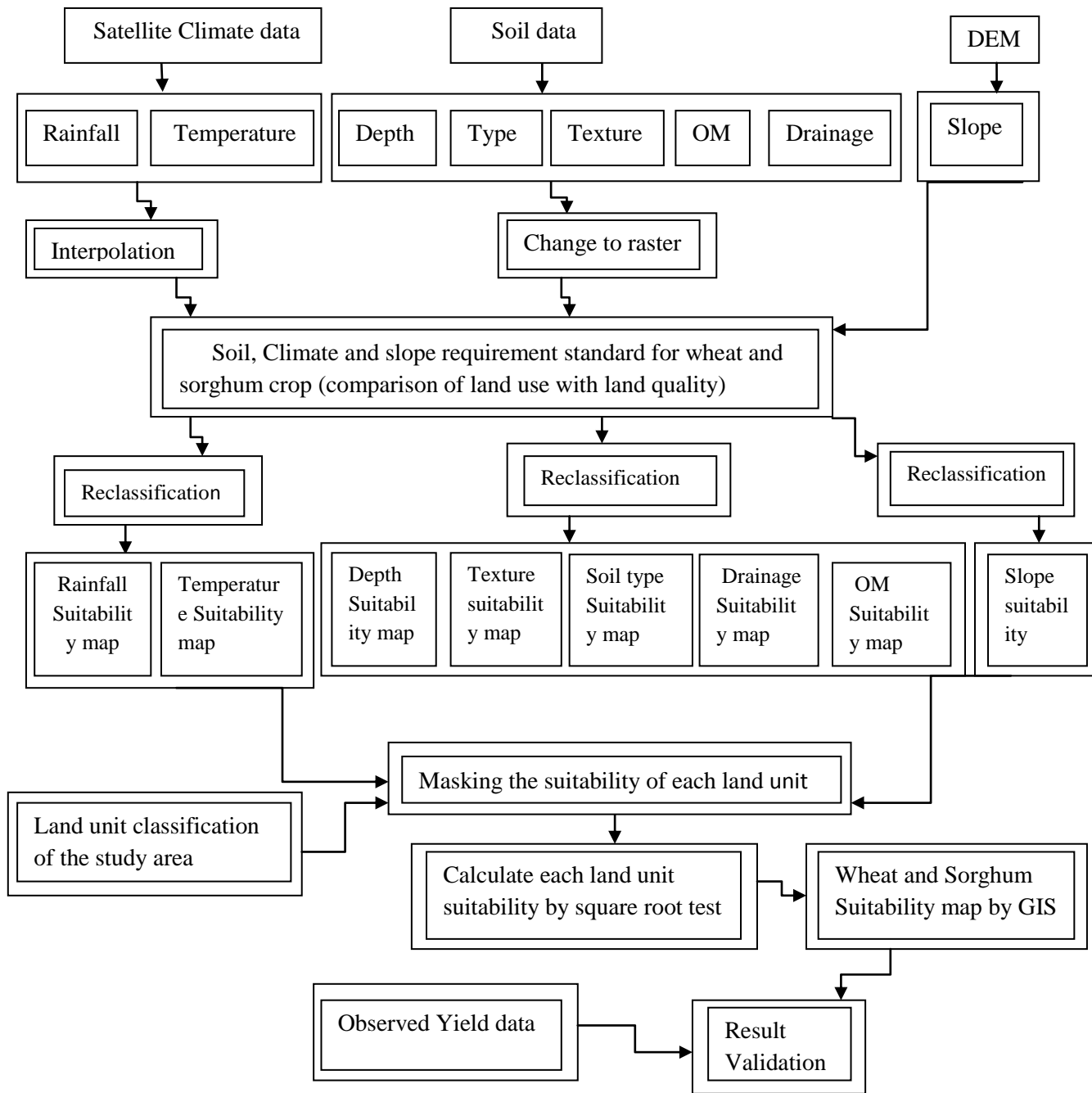


Fig. 4. Flow chart showing of land suitability analysis for Wheat and Sorghum.

CHAPTER FOUR

4. RESULT

4.1. Results of Parametric suitability Analysis

Before the suitability result of the parameters were calculated by parametric square root test mathematical formula the vector input parameters were converted in to a raster data model. The conversion of the vector data in to a raster data were done to make the data layers compatible with other raster data. On the bases of crop requirement standard and the six-suitability degree of limitation classes, which ranges from 0-100 each parameter was reclassified. During the reclassification result in the data analysis process, the reclassification classes were represented by 1-6 Arabic numbers. Where 1 represent very highly suitable, 2 represent highly suitable, 3 represent moderately suitable, 4 represent marginally suitable, 5 represent currently not suitable and 6 represents permanently not suitable based on their suitability standard classes for wheat and sorghum. After each model parameter was reclassified in to a similar scale value, the study area was classified in to different land unit based on researcher criteria. Finally, the suitability index of each Kebele in the study area was calculated using maximum square root test method.

4.1.1. Soil Depth

A soil depth variation from place to place determines the growth of plants through affecting the growing of plant roots. The soil depth of the study area was grouped in to four classes. These were 0-10 cm which is low depth and low importance for agricultural production, 10-50 cm which is medium depth, 50-100 cm which is high depth and 100-150 cm which is very high depth and shown in figure 5.

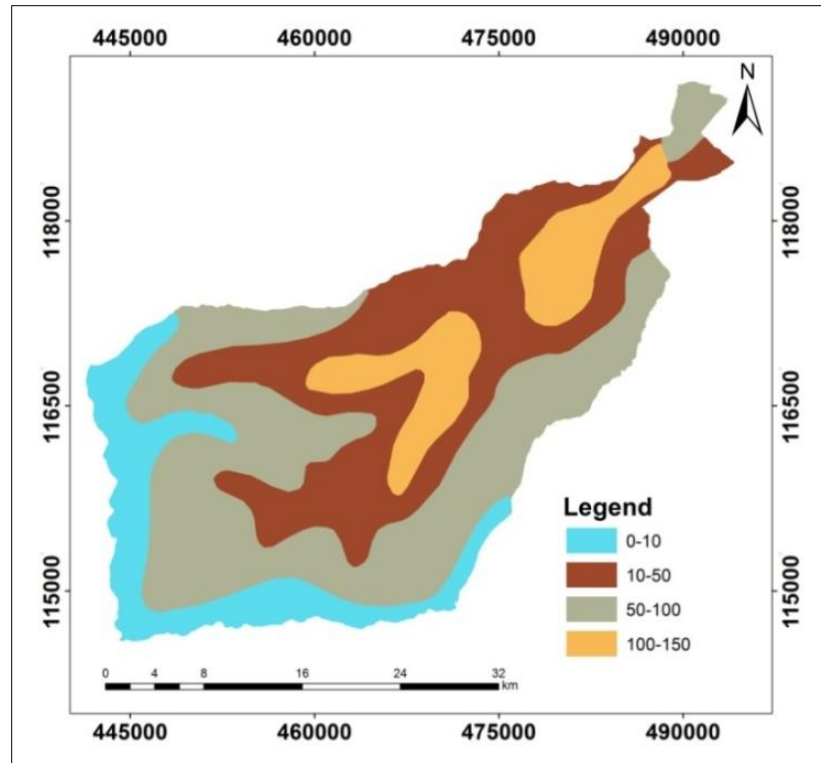


Fig. 5. Soil depth map of the study area in (cm).

The soil depth suitability of these crops were done to identify the suitability level of an area for the crops. From 0-10 cm depth is not good for crop production, 10-50 cm depth has moderate importance for crop production, 50-100 cm depth is good for crop production and 100-150 cm depth is very good for sorghum and wheat crops production. These soil depth classes of the study area, which was used as an input data has been reclassified in to four suitability classes for both wheat and sorghum crop to illustrate the suitability level of soil depth for these crops and shown in figure 6.

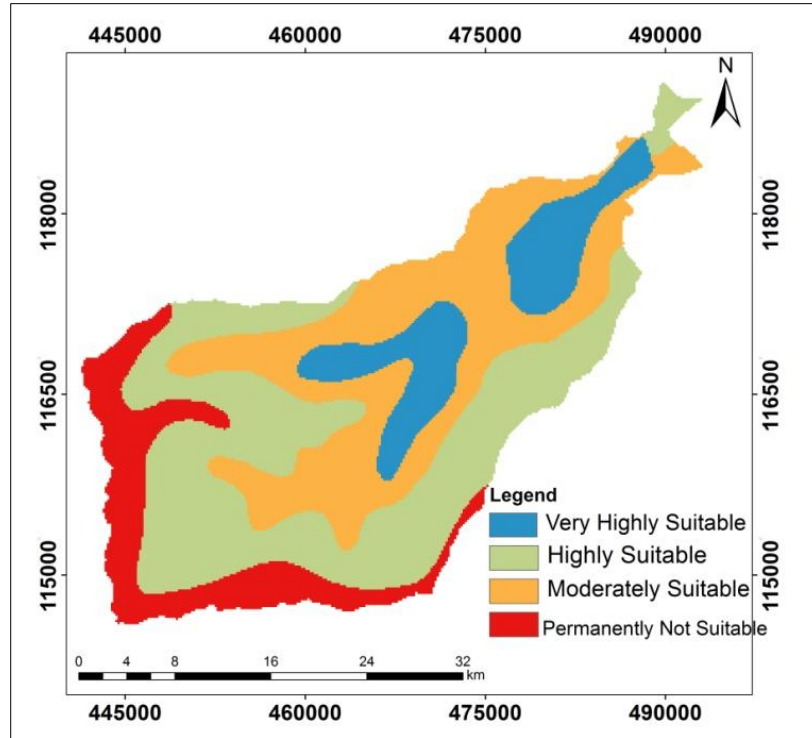


Fig. 6. Soil depth suitability map of study area.

In this result, the very highly suitable soil depth values are those that represent a highly crop production potential area and small area coverage. Most of the study area has high soil depth and medium soil depth, which was highly suitable and moderately for the crops. The study area also has small area coverage of low soil depth, which was permanently not suitable for these crops. The area coverage and its suitability classes were shown in Table 12 below.

Table 12. Soil depth suitability classes and its area coverage.

Soil depth classes (cm)	Suitability class	Area coverage (km ²)
0-10	Permanently not suitable	166
10-50	Moderately suitable	420
50-100	Highly suitable	373
100-150	Very highly suitable	142
Total		1101

As the result of soil depth suitability showed that a very highly soil depth covers an area of 142 km² (12.9%) which is very highly suitable and highly soil depth covers an area of

373 km² (33.9%) which is highly suitable for these crops production. The medium soil depth covers an area of 420 km² (38.1%) which is moderately suitable and the low soil depth covers an area of 166 km² (15.1%) from the total area that is permanently not suitable for these crop production. While running the overall suitability of the study the permanently not suitable soil depth and other lower suitability classes were reduced the overall suitability result of wheat and sorghum crop in the area and determined the classes in to moderately and marginally suitable. Since 53.2% of the area has a moderately and permanently not suitable soil depth class for these crops.

4.1.2. Soil Texture

The soil texture of the study area was classified in to three textural groups based on the FAO guidelines these are clay, clay loam, and loam soil as illustrated in figure 7. Loam soil was very importance for sorghum and wheat agriculture. Clay loam soil is medium textured soil, which has a high absorption capacity of water and they are intermediate importance for agricultural purposes. The clay soil is a fine textured soil that has slow water absorption capacity and low importance for crop agriculture when compared with loam and clay loam soil.

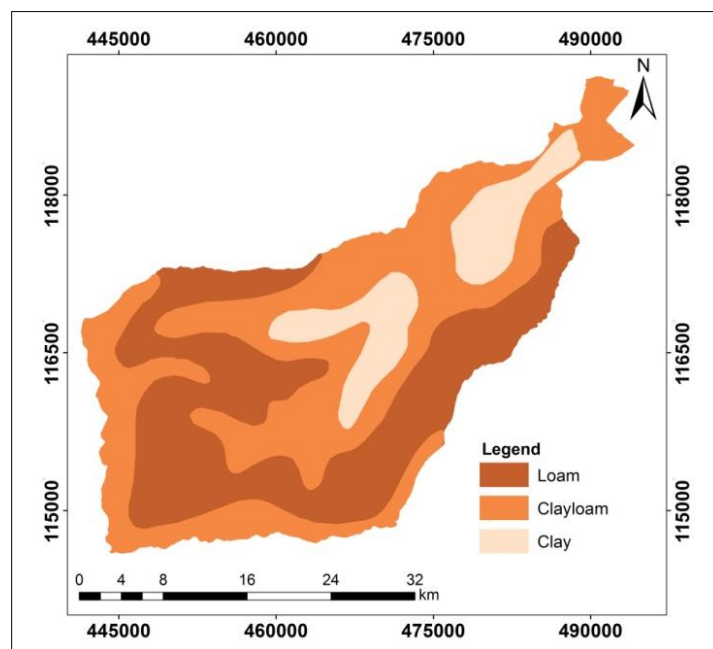


Fig.7. Soil texture map of the study area.

From the result, the loam soil was very highly suitable, clay loam soil was highly suitable and clay soil was moderately suitable for wheat and sorghum crops. This soil texture input data has been reclassified to identify soil texture suitability classes in the area for the crops and shown in figure 8.

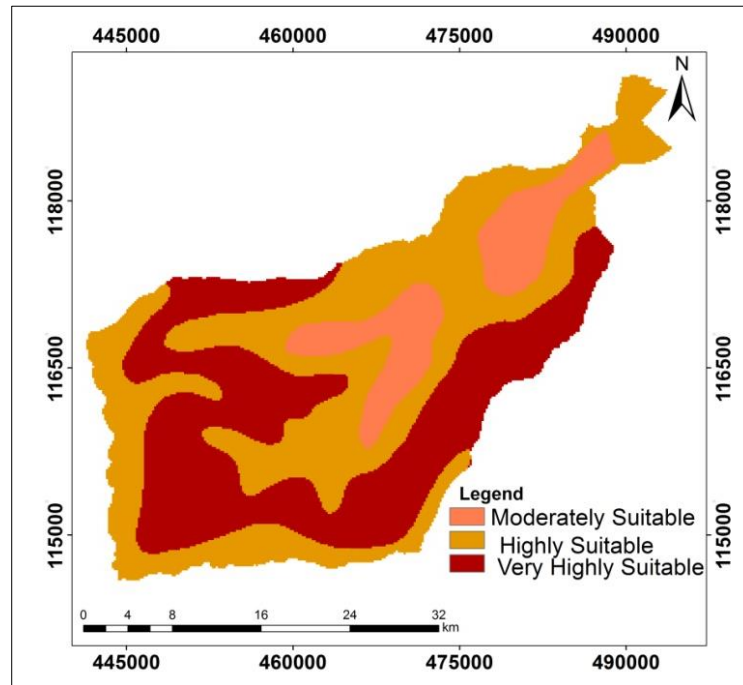


Fig. 8. Soil texture suitability map of study area.

According to this result most of the study area has been covered by clay loam, loam and clay soil texture. Therefore, the study area has good soil textural classes, which is important for these crop productions. Based on soil texture crop requirement standard the soil texture suitability classes of this study and their area coverage were identified and illustrated in Table 13 below.

Table 13. Soil texture suitability classes and its area coverage.

Soil texture classes	Suitability class	Area (km ²)
Clay	Moderate suitable	142
Clay loam	Highly suitable	601
Loam	Very high suitable	358
Total		1101

As shown from the result of soil texture suitability, the study area has been a loam soil of 358 km² (32.5%), clay loam soil of 601 km² (54.6%) and clay soil of 142 km² (12.9%) area coverage which were very highly suitable, highly suitable and moderately suitable for wheat and sorghum crop production respectively. Therefore, the area has good soil textural classes, which are important for crop production.

4.1.3. Soil Type

The soil type of the study area were cambic arenosols, vertic cambisols, Eutric leptosols, lithic leptosols and haplic nitosols which is produced and illustrated in figure 9.

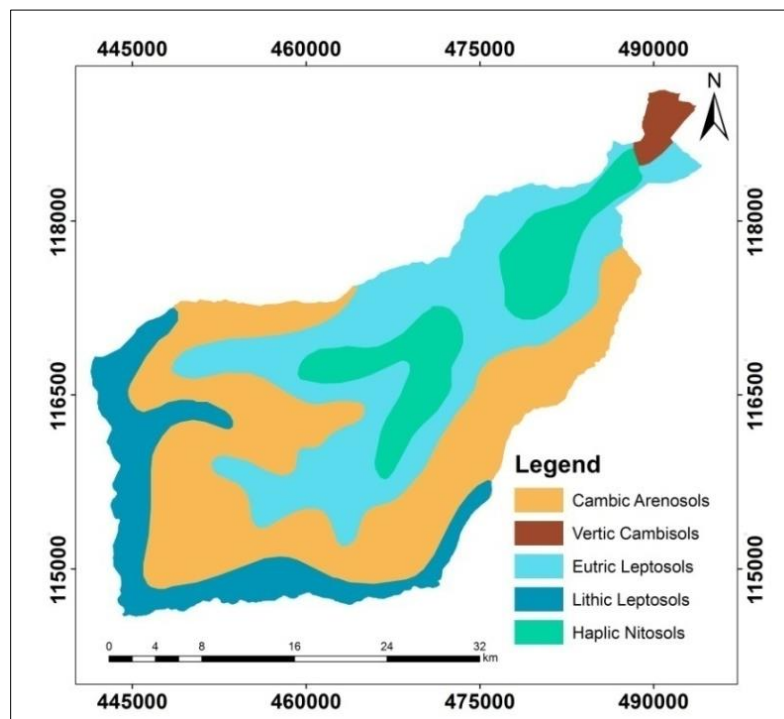


Fig. 9. Soil type of the study area.

Cambic arenosols soil type is developed from recently deposited sand and it is very highly suitable for wheat and sorghum crop. Haplic nitosols soil type is found in gentle sloping to linear land units, which is highly suitable for these crops. Vertic cambisols soil type is found in medium steep slope and has moderate depth, which has moderate importance for these crops. Lithic leptosols and Eutric leptosols soil types are an attractive soil type for wheat and sorghum crop since they are associated with very shallow depth. The soil type that is used as an input data has been reclassified to depict

the suitability class of each soil type and their degree of limitation classes and illustrated in figure 10.

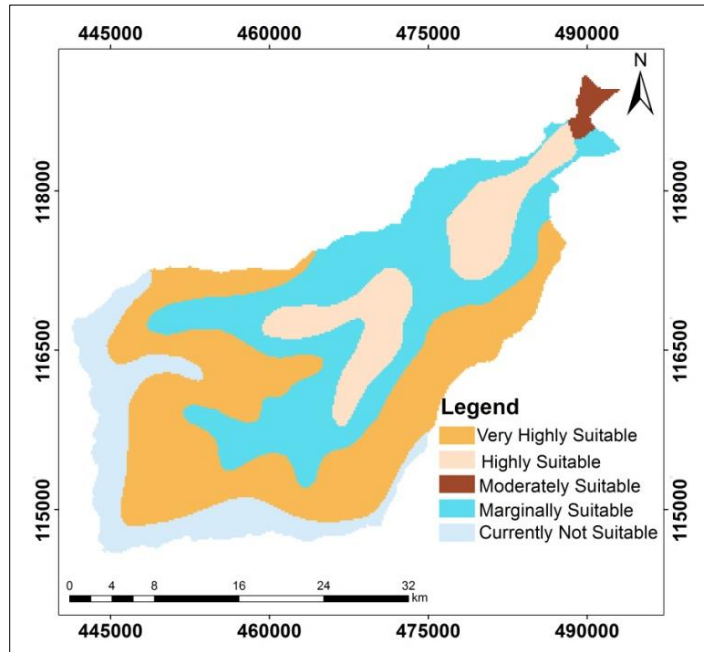


Fig. 10. Soil type suitability map of study area.

In this study, the reclassification result was drawn in by assigning the numeric number values to each soil type values based on their relative importance from 1-6 for the crop production area. Therefore, as the result showed the suitability level of cambic arenosols, haplic nitosols, vertic cambisols, eutric leptosols and lithic leptosols are very highly suitable, highly suitable, moderately suitable, marginally suitable and currently not suitable respectively with different area coverage. The suitability level of these reclassified soil type and their area coverage were illustrated in Table 14 in detail below.

Table 14. Soil type suitability classes and its area coverage.

Soil type classes	Suitability class	Area Coverage (km ²)
Cambic arenosols	Very highly suitable	358
Haplic nitosols	Highly suitable	142
Vertic cambisols	Moderately suitable	15
Eutric leptosols	Marginally suitable	420
Lithic leptosols	Not currently suitable	166
Total		1101

In this result of the study, cambic arenosols is very highly suitable soil type which covers an area of 358 km² (32.5%) for these crop production. Haplic nitosols, which is highly suitable soil type an area coverage of 142 km² (12.9%) and vertic cambisols covers an area of 15 km² (1.4%) which is a moderately suitable soil type for these crops. The soil type lithic leptosols that are currently not suitable for these crop productions cover an area of 166 km² (15.1%) and eutric leptosols, which is marginally suitable soil type for sorghum and wheat crops with an area coverage of 420 km² (38.1%). Therefore, 53.2% of the study area was marginally suitable and currently not suitable for the crops in terms of soil type and this has its own influence for the reduction of the overall suitability classes of wheat and sorghum crops in the study area.

4.1.4. Slope

The study area slope has been classified in to three classes, which are 0-8%, 8-16% and 16-30% with low, medium and high slope respectively. The steep slopes are vulnerable to erosion, and has shallow soil depth, which affects vegetation and crop production by making agriculture impossible. The medium slopes are moderately suitable slopes for agriculture. Low slope area has deep and fertile soil that was suitable for this crop agriculture. This slope of the study area was shown below in figure 11.

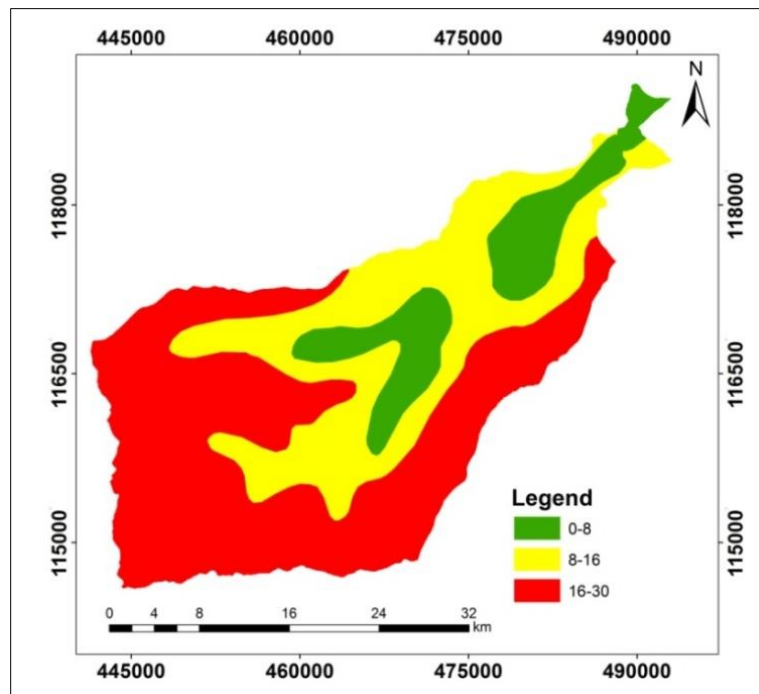


Fig. 11. Slope of the study area in (%).

Therefore, this slope input data has been reclassified to identify the suitability level of each slope classes for those crops based on their slope suitability standard and shown below in figure 12.

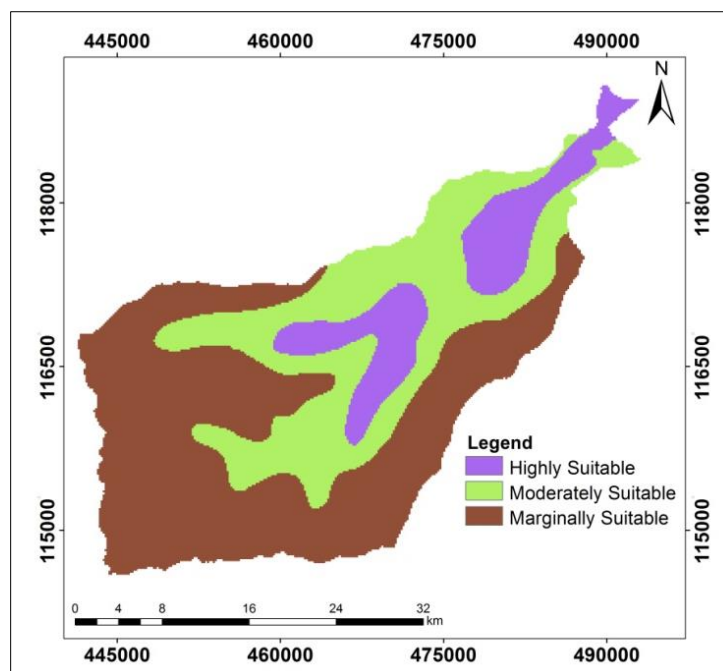


Fig.12. Slope suitability map of study area.

From the results, the slope of 0-8% is highly suitable, 8-16% moderately suitable and 16-30% marginally suitable for wheat and sorghum crop production. The suitability classes and area coverage of these slope classes was shown in Table 15 below.

Table 15. Slope suitability classes and its area coverage.

Slope classes (%)	Suitability classes	Area (km ²)
0-8	Highly suitable	157
8-16	Moderately suitable	420
16-30	Marginally suitable	524
Total		1101

From the reclassified slope suitability result, the study area has a slope of 8-16% having an area coverage of 420 km² (38.1%), slope of 16-30% with an area coverage of 524 km² (47.6%) from total area and slope of 0-8% which has 157 km² (14.3%) of area coverage.

Therefore, the result showed as 85.7% of an area from the total area were moderately and marginally suitable for wheat and sorghum crop in terms of slope and this factor dominantly reduced the overall suitability level of wheat and sorghum to marginally and moderately suitable classes.

4.1.5. Soil Drainage

The study area has been classified in to three soil drainage classes such as well drained, moderately drained and imperfectly drained and shown in figure 13. In well-drained areas, the water occurrences are very deep and available for plant throughout their growing season. In moderately drained areas, the internal free water occurrence is moderately deep and wet only for a short time of growing season. In the imperfectly drained area, water is removed slowly and the soil is wet at a shallow depth for significant periods.

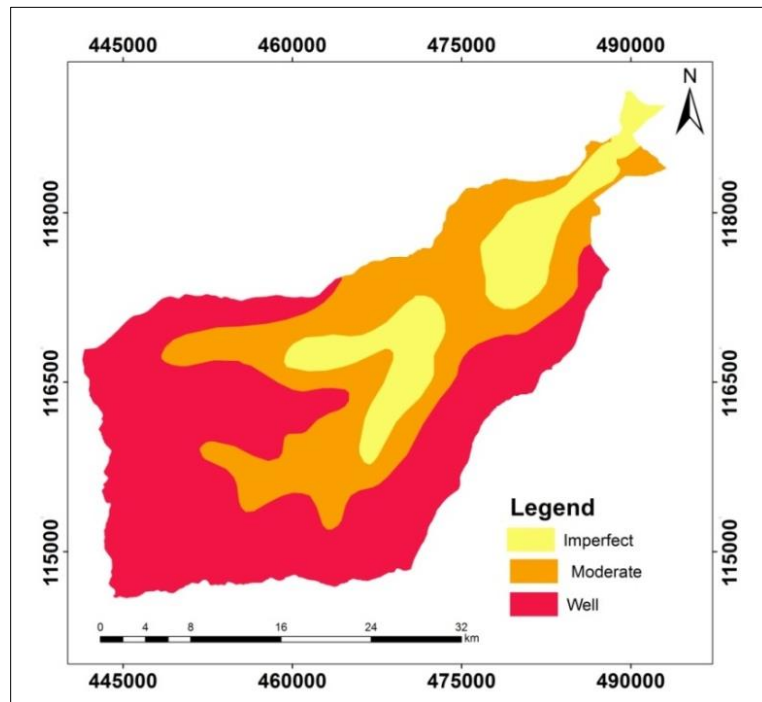


Fig.13. Soil drainage map of the study area.

Therefore, the soil drainage that is used as an input data has been reclassified to show the suitability level of each soil drainage classes for these crops and this was shown in detail in figure 14.

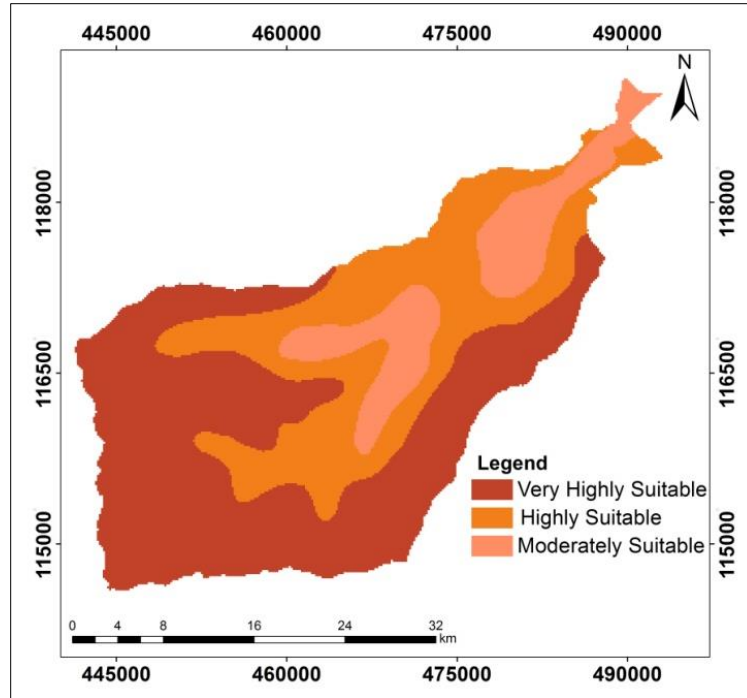


Fig.14. Soil drainage suitability map of the study area.

The well soil drainage, moderate drainage and imperfect drainage are very highly suitable, highly suitable and moderately suitable respectively for wheat and sorghum crop production based on their soil drainage requirement standard. From the reclassified soil drainage suitability result the area coverage of each soil drainage classes were calculated and shown in Table 16 below.

Table 16. Soil drainage suitability classes and its area coverage.

Soil drainage classes	Suitability classes	Area coverage (km ²)
Well soil drainage	Very highly suitable	524
Moderate soil drainage	Highly suitable	420
Imperfect soil drainage	Moderately suitable	157
Total		1101

From the soil drainage result, the study area has well soil drainage with an area coverage of 524 km² (47.6%), moderate soil drainage with an area coverage of 420 km² (38.1%) and imperfect soil drainage with the area coverage of 157 km² (14.3%) from total area of the study.

Even the crop requirement standard of Sys et al. (1991 & 1993) and FAO (1976 & 1983) were different for each crop, the physical properties of soil and slope classes that were required by wheat and sorghum crops in the present study area was found in the same degree of limitation classes. Due to this fact, the parametric characteristic like soil texture, slope, soil type, soil drainage and soil depth suitability classification results were produced together. However, the degree of limitation classes of rainfall, temperature and organic carbon content criteria for wheat and sorghum crops were different. Therefore, the suitability classes of those criteria for wheat and sorghum were analyzed and illustrated separately based on comparison of land use with its requirement standard.

4.1.6. Soil Organic Carbon Content

Soil organic carbon indicates the organic matter content in the soil. It consists of dead plant parts and animal and microbial waste products in various stages of decomposition. The organic carbon content of the study area has been classified into three classes from 0.8 – 1.5%, 1.5 – 2.5% and 2.5 – 3% as shown below in figure 15.

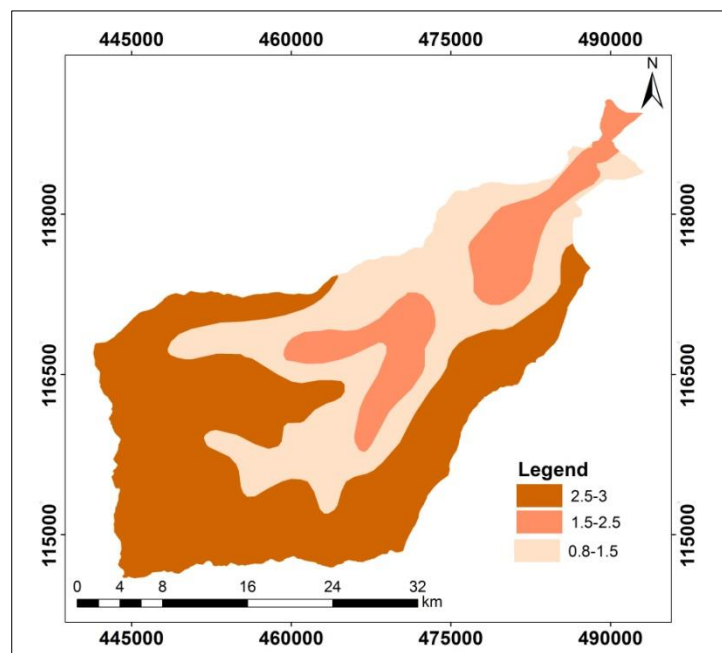


Fig.15. Organic carbon map of the study in (%).

The soil organic carbon content, which is used as an input data, has been reclassified to show the suitability classes of each organic carbon classes for wheat and sorghum crop and illustrated below in figure 16 and 17.

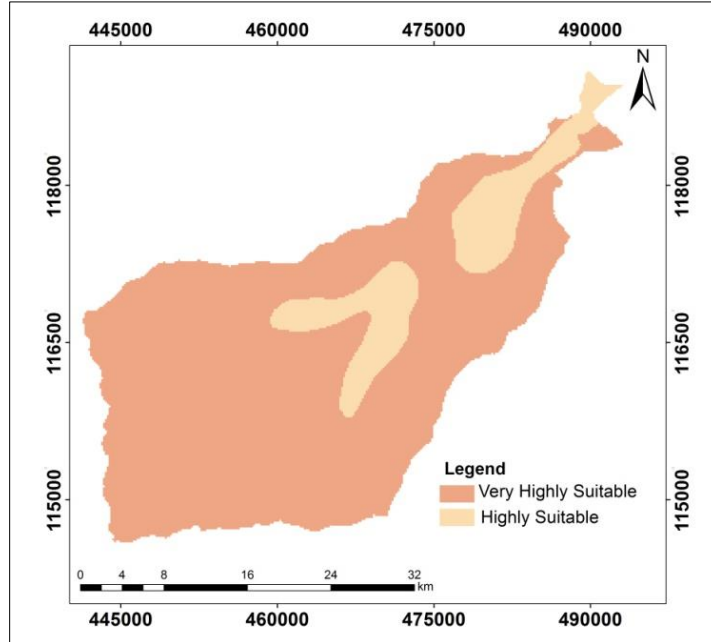


Fig.16. Soil organic carbon suitability map for Sorghum.

In the reclassified soil organic carbon content result, the study area has 0.8-1.5% organic carbon, which is highly suitable and 1.5- 3% of organic carbon content, which is very highly suitable for sorghum crop production. The present study area was very highly suitable and highly suitable for sorghum production in terms of organic carbon content. The organic carbon suitability classes and their area coverage was shown in Table 17.

Table 17. Organic carbon suitability classes and its area coverage.

Soil organic carbon (%)	Suitability class	Area Coverage (km ²)
0.8 – 1.5	Highly suitable	157
1.5 – 3	Very highly suitable	944
Total		1101

In the reclassified soil organic carbon content result, the study area has 0.8 -1.5% of organic carbon with an area coverage of 157 km² (14.3%) and 1.5 -3% of organic carbon

content with an area coverage of 944 km² (85.7%) for sorghum crop. Therefore, the organic carbon content of the area was suitable for sorghum crop production.

From the input feature data of an organic carbon content map the suitability of wheat crop in terms of organic carbon was produced by a process of reclassification based on wheat crop requirement standard to show wheat suitability classes of the area in terms of organic carbon content. This organic carbon suitability classes for wheat crop was shown below in figure 17.

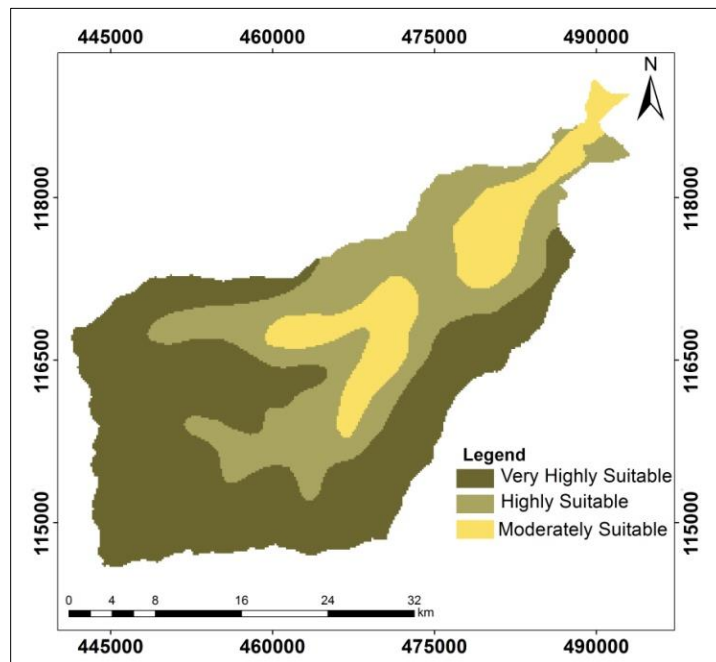


Fig.17. Soil organic carbon suitability map of Wheat.

Based on the above result the organic carbon suitability classes in the study area for wheat crop and their area coverage was calculated and shown in Table 18 below.

Table 18. Organic Carbon Suitability Classes and Their Area Coverage.

Soil organic carbon (%)	Suitability classes	Area coverage (km ²)
2.5-3	Very highly suitable	524
1.5-2.5	Highly suitable	420
0.8-1.5	Moderately suitable	157
Total		1101

According to this result, 524 km² (47.6%) of the study area was very highly suitable, 420 km² (38.1%) of the area was highly suitable and 157 km² (14.3%) of an area from the

total area was moderately suitable in terms of organic carbon content for wheat crop production in the study area. Therefore, the study area was more suitable for sorghum crop rather than wheat crop in terms of organic carbon content.

4.1.7. Rainfall

The rainfall amount of the study area that was important for crop productions in which produced through a process were classified and shown in figure 18.

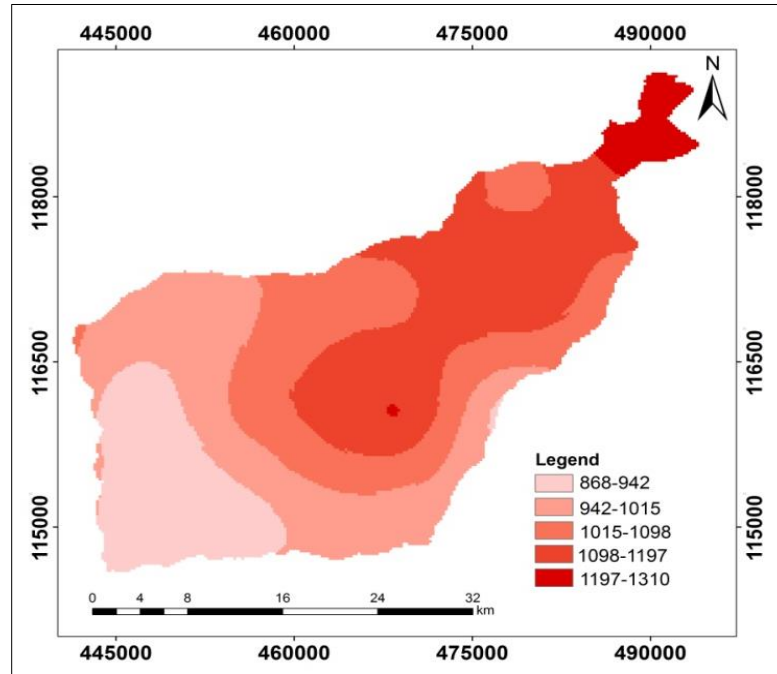


Fig. 18. Rainfall map of the study area in (mm).

The rainfall amount from 868-1015 mm was very highly suitable, 1015-1197 mm was highly suitable and rainfall amount of 1197-1310 mm moderately suitable for wheat production. Whereas for sorghum production rainfall amount from 868-942 mm highly suitable, 942-1197 mm was moderately suitable and rainfall amount from 1197-1310 mm were marginally suitable for sorghum crop production. Therefore, the rainfall that was used as an input data for the analysis of these crops has been reclassified separately according to their climatic requirement standard. The rainfall suitability classes for wheat crop was reclassified and illustrated below in figure 19 below.

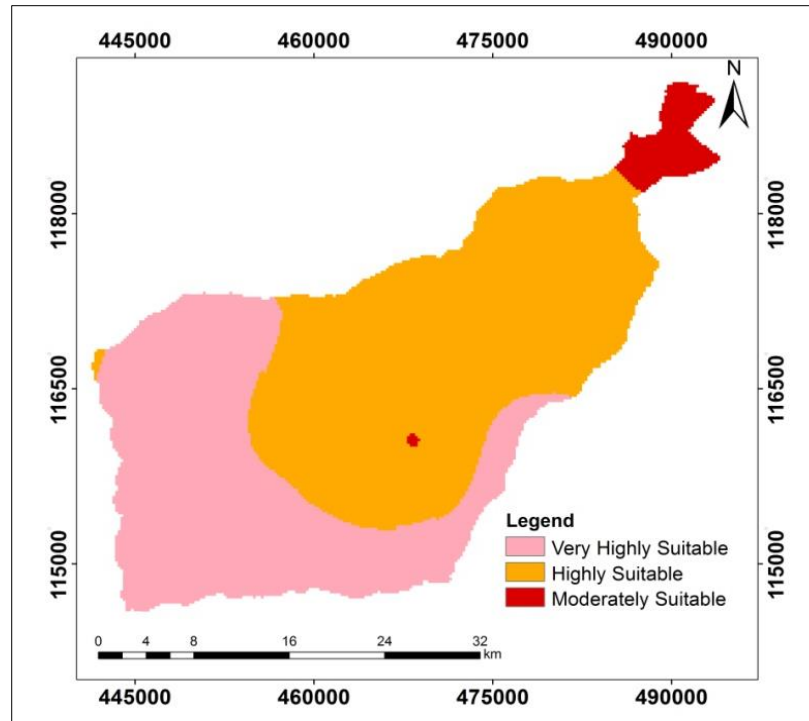


Fig.19. Rainfall suitability map for Wheat crop.

From the reclassified result each suitability classes of rainfall for wheat crop and their corresponding area coverage where described below in Table 19. Therefore, the table showed the rainfall suitability variation of the area from very highly suitable, highly suitable and moderately suitable for wheat crop production.

Table 19. Rainfall suitability class and area coverage for Wheat crop.

Rainfall (mm)	Suitability class	Area (km ²)
868-1015	Very highly suitable	390
1015-1197	Highly suitable	639
1197-1310	Moderately suitable	72
Total		1101

According to Table 19 the rainfall amounts which are very highly suitable covers an area of 390 km² (35.4%), highly suitable rainfall amount for wheat crop covers an area of 639 km² (58%) and moderately suitable rainfall covers an area of 72 km² (6.6%) for wheat crop production in the study area.

Similarly, the rainfall suitability reclassification classes for sorghum crop has been produced and shown in figure 20 below.

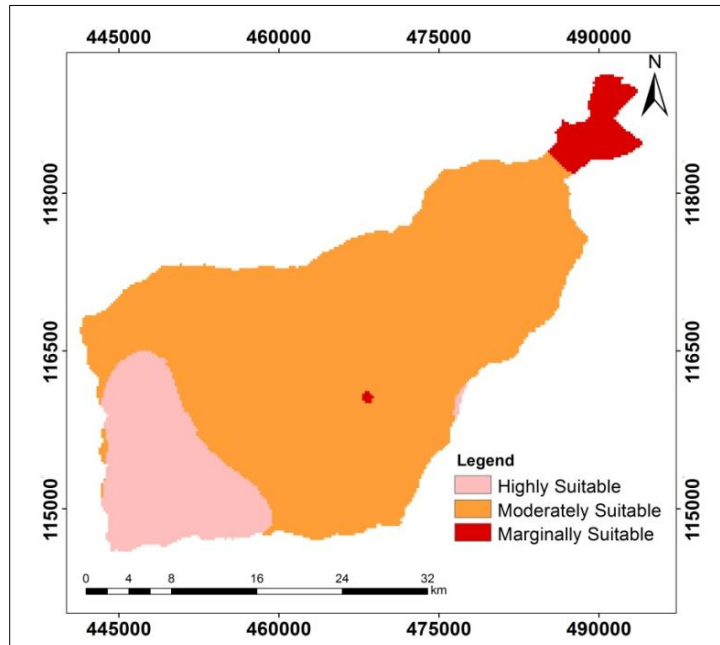


Fig.20. Rainfall suitability map of Sorghum crop.

From the reclassified suitability map of rainfall for sorghum crop the area has highly suitable, moderately suitable and marginally suitable classes and their area coverage was also shown in Table 20. Most part of the present study area was covered by moderately suitable rainfall variation and some are covered by highly suitable rainfall variation for sorghum crop.

Table 20. Rainfall suitability classes and area coverage for Sorghum crop.

Rainfall classes(mm)	Suitability classes	Area coverage(km ²)
868-942	Highly suitable	270
942-1197	Moderately suitable	759
1197-1310	Marginally suitable	72
Total		1101

The results showed that 270 km² (24.5%), 759 km² (68.9%) and 72 km² (6.6%) of the area coverage were highly suitable, moderately suitable and marginally suitable for sorghum crop production in the study area. Therefore, the rainfall of the area was good for wheat rather than sorghum crop. This result indicated as 75.5% of the study area was moderately and marginally suitable for sorghum crop and the result of this parameter

undermine the other parameter suitability classes for sorghum crop in to marginal and moderate classes while running the overall suitability classes for sorghum crop in the study area.

4.1.8. Temperature

Temperature is one of the most important climatic parameters, which determine crop production. The mean temperatures that were found in the study area was raised from a minimum of 16°C to a maximum of 24°C and shown in figure 21 below.

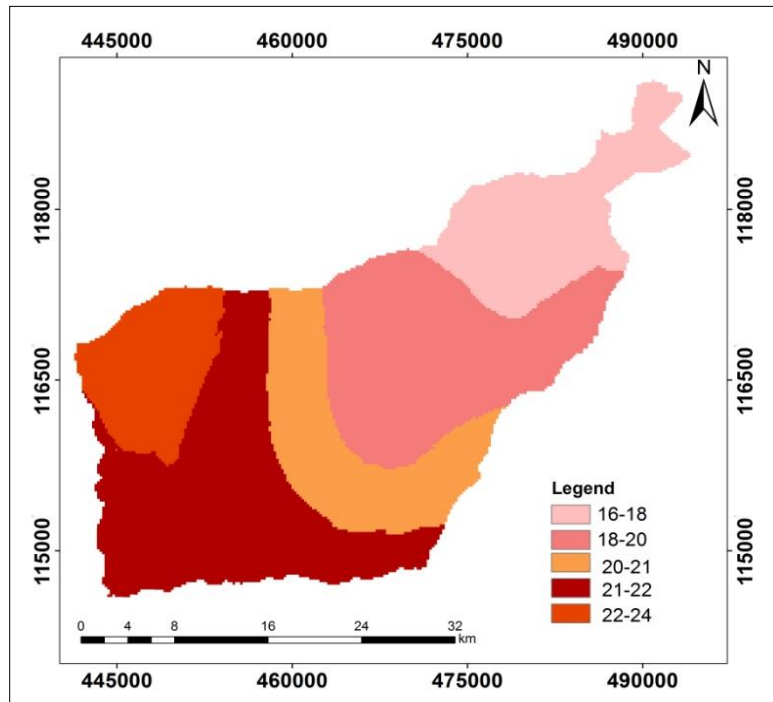


Fig. 21. Temperature map of the study area in (°C).

The temperature of the study area for wheat crop was from 16-20°C which is very highly suitable, 20-22°C highly suitable, 22-24°C moderately suitable for wheat crop. Similarly, for Sorghum crop the temperature from 21-24°C is highly suitable, 18-21°C moderately suitable, 16-18°C marginally suitable in the study area. From this, the temperature suitability for wheat and sorghum crop was produced below.

The temperature that was used as an input data has been reclassified for wheat crop based on wheat crop requirement standard to show only the temperature suitability classes for wheat crop and this is shown in figure 22 below.

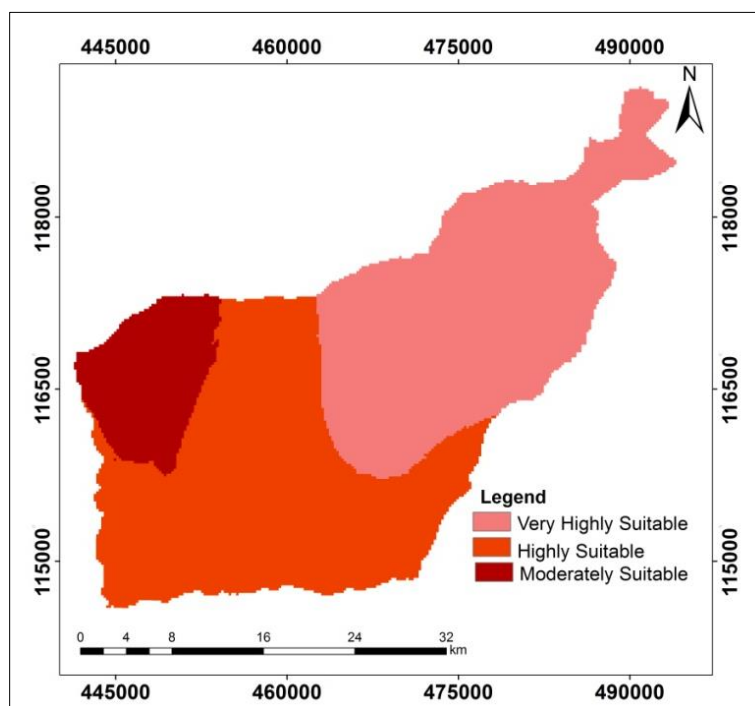


Fig. 22. Temperature suitability map for Wheat crop.

As this result indicated that temperature of the area for wheat crop has very highly suitable, highly suitable and moderately suitable classes. This temperature suitability classes for wheat crop and their area coverage was shown in Table 21.

Table 21. Temperature suitability classes and area coverage for Wheat crop.

Temperature class (°C)	Suitability class	Area (km ²)
16-20	Very highly suitable	526
20-22	Highly suitable	426
22-24	Moderately suitable	149
Total		1101

Based on Table 21 the area coverage of 526 km² (47.8%), 426 km² (38.7%) and 149 km² (13.5%) from the total area coverage were very highly suitable, highly suitable and moderately suitable for wheat crop in the area in terms of temperature. From this result, 52.2% of the study area was highly and moderately suitable for wheat crop in terms of temperature.

The suitability analysis of each crops were produced based on their requirement threshold. Therefore, the suitability analysis classes of temperature for sorghum crop was produced by reclassifying the temperature that was used as input data and illustrated in figure 23.

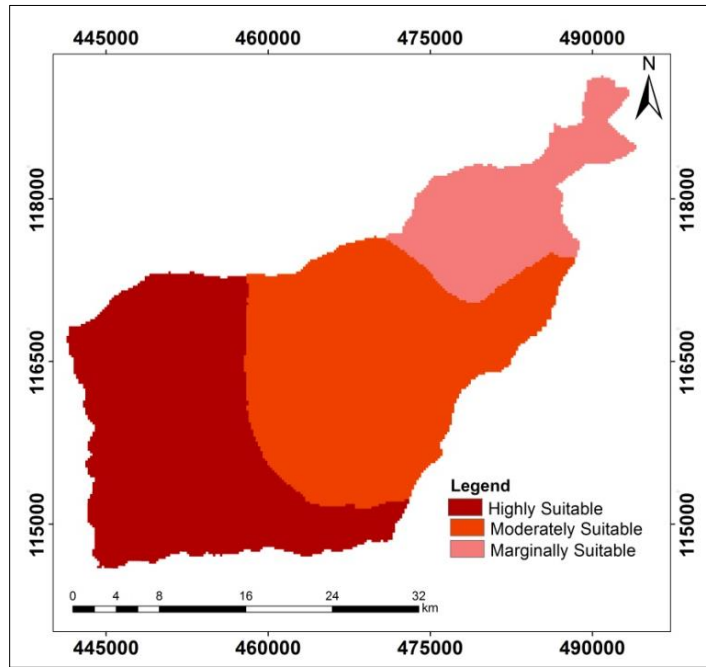


Fig. 23. Temperature suitability map of Sorghum crop.

According to the reclassification temperature result, the study area was classified in to three-suitability classes such as highly suitable, moderately suitable and marginally suitable and their area coverage is depicted in Table 22.

Table 22. Temperature suitability classes and area coverage for Sorghum crop.

Temperature (°C)	Suitability classes	Area coverage (km ²)
21-24	Highly suitable	403
18-21	Moderately suitable	532
16-18	Marginally suitable	166
Total		1101

From the sorghum suitability result in terms of temperature in the study area 403 km² (36.6%) area coverage was highly suitable, 532 km² (48.3%) area coverage was moderately suitable and 166 km² (15.1%) of an area coverage was marginally suitable for sorghum crop from the total study area. This result indicated that 63.4% of the area

from the total area coverage were marginally and moderately suitable for sorghum crop. Therefore, the overall suitability of sorghum crop was reduced in to marginally and moderately suitability classes since the result of the temperature suitability classes for sorghum crop undermines the suitability result of other parameters in to moderate and marginal suitability classes.

Therefore, the abovementioned parametric processes were the suitability result of each individual parameter for wheat and sorghum crop production. To produce the suitability classes of the study area for wheat and sorghum all those parameters, which were described above, should be considered together. These suitability classes of the area were produced based on FAO standards using all parameter by the help of parametric maximum square root test equation.

4.2. The Overall Suitability Result for Sorghum and Wheat Crops using Square Root Test Formula

In this study, choosing the overall suitability site for wheat and sorghum production implies assessing the suitability index of all the parameters like; soil organic carbon, soil texture, soil depth, soil type, soil drainage, slope, temperature and rainfall. Since the suitability index of the area is calculated from the reclassified data based on crop requirement standard by taking the average degree of limitation values and masking by each land unit. For the masked 33 land unit from the reclassified suitability classes based on sorghum and wheat crop requirement standard of the area, their suitability indices were calculated by square root test equation and the crops suitability were illustrated in figure 24 and 25 respectively. Based on the calculated suitability indices of each land unit, their suitability classes and area coverage were shown for wheat and sorghum crops.

The suitability analysis result of these wheat and sorghum crop in the study area, were computed by the mathematical formula in land province level of a land unit. These computed and produced suitability indices of each land unit are illustrated in Table 23.

Table 23. Wheat and Sorghum Land Suitability Indices Result of the Study Area.

Land unit name	Sorghum			Wheat			
	Suitability Indices	Suitability classes	Yield (Q/ha)	Suitability Indices	Suitability classes	Yield (Q/ha)	Area (km ²)
Werewayu	38	S3	7	38	S3	9.1	80
Gindo	38	S3	7.1	35	S3	9	62
Abahoch	38	S3	6.9	35	S3	8.8	87
Abeygorba	38	S3	6.9	38	S3	9	41
Tebela	51	S2	9.4	49	S3	10.8	9
Guba	48	S3	8.7	52	S2	11.3	12
Haleku	50	S2	9.2	52	S2	11.4	10
Golel	46	S3	8.2	49	S3	10.6	17
Lomiwha	36	S3	6.9	43	S3	10.4	38
Sekashibera	42	S3	7.5	50	S2	11	62
Abey	41	S3	7.4	48	S3	10.6	44
Wereabu	42	S3	7.5	39	S3	9.2	47
Menedega	46	S3	7.9	52	S2	11.5	22
Awayu	50	S2	9.3	52	S2	11.2	17
Kereaba	37	S3	6.9	38	S3	9.1	46
Adisamba	35	S3	6.8	38	S3	9.2	35
Tglfera	40	S3	7.2	40	S3	9.4	48
Makefta	41	S3	7.3	47	S3	10.5	18
Haway	41	S3	7.2	48	S3	10.7	24
Sertomasaya	34	S3	6.6	42	S3	10.4	12
Abado	34	S3	6.7	40	S3	9.3	12
Taye	46	S3	7.8	50	S2	11.2	39
Abote	29	S3	6.3	47	S3	10.6	31
Yeshum	24	N1	5.8	39	S3	9.2	17
Demasiko	25	S3	6.2	41	S3	10	22
Dibibiso	25	S3	6.1	39	S3	9.3	28
Lencho	22	N1	5	34	S3	8.9	24
Tunne	32	S3	6.4	41	S3	9.8	21
Tungi	33	S3	6.4	41	S3	9.7	34
Kabiwebo	34	S3	6.5	41	S3	9.9	21
Gelebe	39	S3	7.1	50	S2	11.2	31
Zemode	43	S3	7.6	50	S2	11.3	32
Lemlemambi	33	S3	6.3	40	S3	9.5	55

In square root test computation, even if different land units are found in the same suitability class, they have different degree of suitability. As the result for wheat crop in Table 23 showed, Haway and Lencho land province were found in one suitability class, which is marginally suitable, but Haway has a suitability index value of 48 and Lencho has 34 suitability index values. This indicated that the land units, which were found in the same suitability class, has different level of suitability for the selected crop. Similarly, in

sorghum suitability classes, Guba land unit having 48 suitability index values and Demasiko land unit having 25 suitability index values were found in the same suitability class, but this did not mean they have the same suitability level for sorghum crop. Guba land unit was more suitable than Demasiko land unit for sorghum crop production. In this result the land units, which have different suitability classes did not mean that the land unit found in the upper suitability class is more suitable than the land unit found in the preceding class. For instance, in wheat suitability result, the land unit Tebela has suitability index value of 49, which is found in marginally suitable class, and land unit Zemede has 50 suitability index values, which is found in moderately suitable class. Therefore, this did not mean that Tebela is more suitable than Zemede for wheat crop production rather they have nearly similar in level of suitability for the selected crop. The same is true for sorghum crop in other land units. This makes the methods and the results of the present study accurate and reliable.

In this study, urban area was assigned as a restricted value, which means that the corresponding area cannot be used for these crop productions. Therefore, urban area was restricted from the suitability analysis results of the present study.

The suitability model result of the wheat crop in (Fig. 24) has showed two suitability classes. These are, S2, which indicated that areas with moderately suitable land for wheat production and S3, which indicated that locations with marginally suitable class for wheat crop production in the area. Further, in the result there is a restriction area, which is an urban area that is not used for crop production.

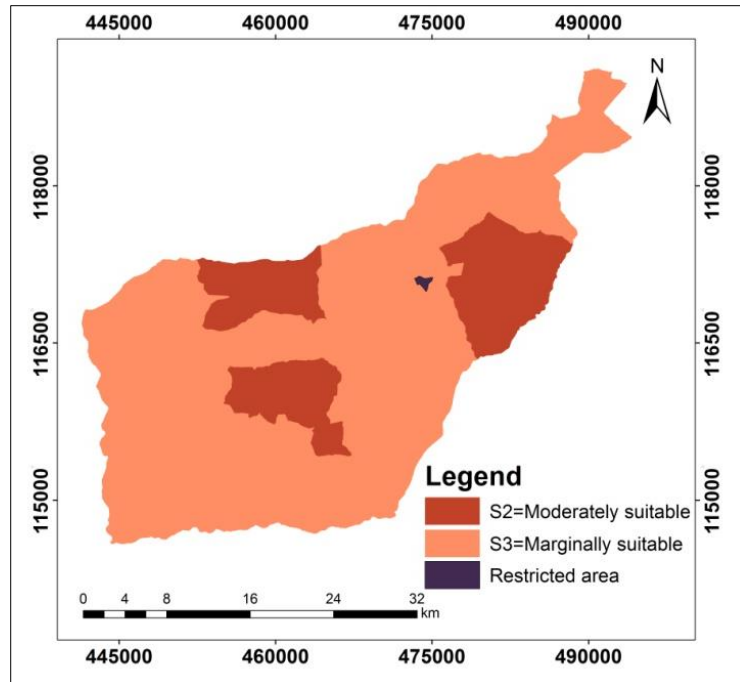


Fig. 24. Wheat suitability map.

Similarly, the mathematical suitability model outcome of sorghum suitability in (Fig. 25) has resulted with three suitability classes. These are S2, which indicated the areas with moderately suitable land for sorghum production, S3, which indicated the areas with marginally suitable class for sorghum crop production and N1, which indicated the area with currently not suitable for sorghum production. Further, in this result there is a restriction area, which is an urban area that is not used for crop production.

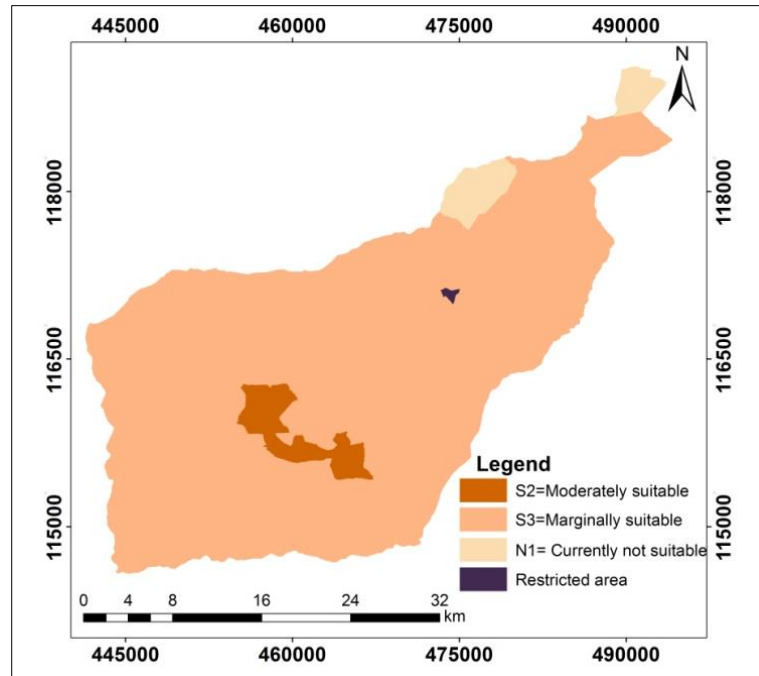


Fig. 25. Sorghum suitability map.

The suitability classes of the study area and their area coverage for wheat and sorghum crops were shown in Table 24 below.

Table 24. The overall land suitability classes and area coverage for the crops.

Crops	Suitability class	Area (km ²)
Wheat	Moderately suitable	225
	Marginally suitable	873
Sorghum	Moderately suitable	36
	Marginally suitable	1021
	Currently not suitable	41

Table 24 demonstrated that 36 km² (3.3%), 1021 km² (93%) and 41 km² (3.7%) of the study area are classified as moderately suitable, marginally suitable and currently not suitable respectively for sorghum crop production in the study area. Similarly, the table also demonstrated that 225 km² (20.5%) and 873 km² (79.5%) of the study area are moderately suitable and marginally suitable respectively for wheat crop production. The result also indicated that there is no land that is classified as highly suitable, currently and permanently not suitable for wheat crop and there is no land, which is highly suitable and

permanently not suitable for sorghum crop in the study area. There is also an urban area, which is a restricted area with an area coverage of 3 km² in the study.

4.3. Suitability Result Validation

The suitability classification results of these wheat and sorghum crops are validated through correlating the observed yield with the suitability index value of each land unit.

The table that showed the correlation between observed yield and suitability index value of each land units for wheat crop result was illustrated in Table 25 below and the rest Table found in appendix 2.

Table 25. Regression statistics for Wheat crop results.

SUMMARYOUTPUT	
Regression statistics	
Multiple R	0.956856791
R Square	0.915574918
Adjusted R Square	0.90713241
Standard Error	0.257218045
P-value	0.0044
Observations	13

The validated suitability results of wheat crop correlation in the area were shown in figure 26 below. The correlation coefficient of the suitability indices of each land unit for wheat crop with the observed yield gives 95.7% that is strongly positive and highly accepted correlation. The suitability index value of the area expressed the observed yield of its land unit at a regression value of 92.4%. The yield and suitability indices value were correlated at standard error of 0.26 quintal per hectare with P-value of 0.0044. Therefore, the suitability results of wheat crop in the area are accepted.

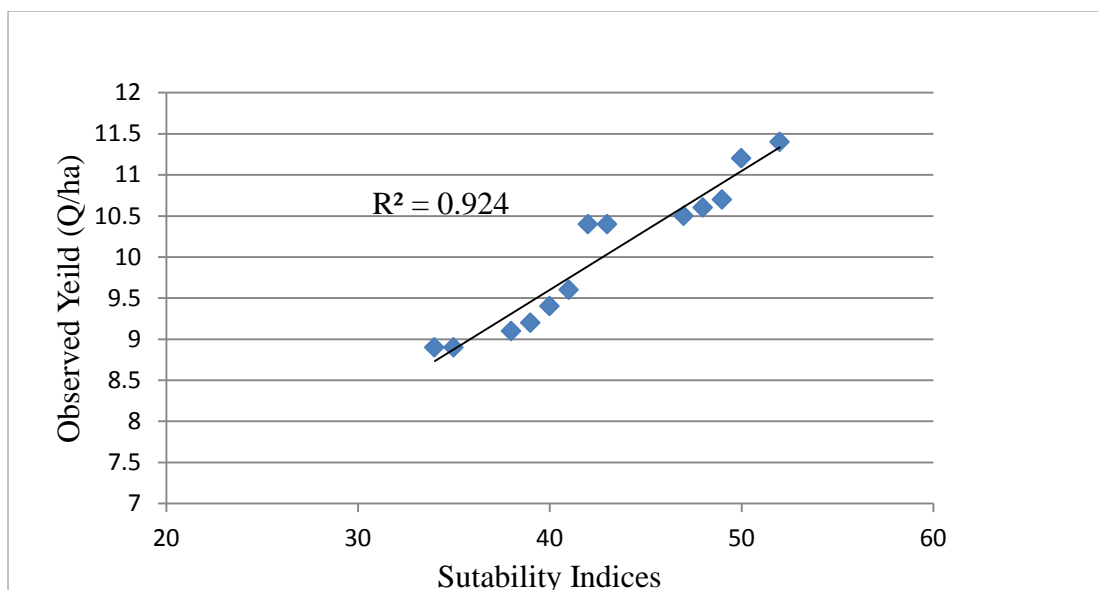


Fig. 26. Correlation between Yield and Suitability Indices for Wheat.

The suitability index value was highly fitted with the observed yield relatively in the moderately suitable classes than at marginally suitable classes for wheat crop.

Similarly, the table that showed the correlation between observed yield and suitability index value for sorghum crop was illustrated in Table 26 below and the left Table found in appendix 1.

Table 26. Regression Statistics for Sorghum Crop Results.

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.972930126
R Square	0.946593031
Adjusted R Square	0.943625977
Standard Error	0.236869137
P-value	0.0042
Observations	20

The overall suitability results of sorghum crop were validated by correlating the observed sorghum yield with the suitability index value of each land units. The correlation between yield and suitability index value of sorghum crop was shown in figure 27 below.

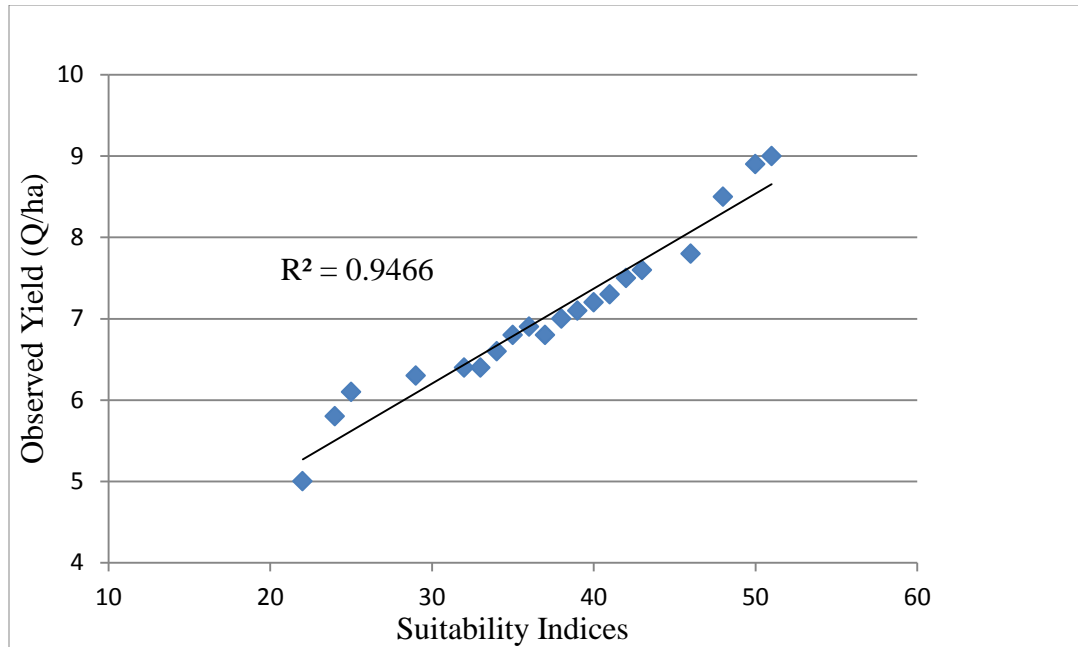


Fig. 27. Correlation between yield and suitability index for Sorghum crop.

The correlation coefficient of observed yields of sorghum crop with their suitability index value of each land unit is 97.3% that is strongly positive correlation and highly accepted. The suitability indices of the land unit were expressed the yield at 94.4% of regression value and correlated at a standard error of 0.24 quintal per hectare with P-value of 0.0042. The correlation result between suitability indices value and observed yield are highly fitted relatively at marginally suitable classes than moderately suitable classes. Therefore, the overall suitability results of sorghum crop in the area are accepted.

CHAPTER FIVE

5. DISCUSSION

The structure of the physical land suitability evaluation in the FOA framework and the data adapted from FAO, by different scholars makes the assessment result rigorous. In the nature of suitability analysis, only one parameter having low suitability class in the land use was enough to reduce the overall suitability classes from high to moderately suitable or not suitable, even if the relevance of this parameter was lower as compared with the other parameters. The selection of land characteristics and their limits are sensitive issues when performing the evaluation (Tobert et al. 2008 and Keshavarzi et al. 2010 as cited in Chandio et al., 2011). The former mentioned researcher also used 7 and 8 parametric characteristics which is similar with the work of Vanrast et al. (1996) and Sanchez et al. (2007). Therefore, the result and scientific explanation of the present study was in agreement with the abovementioned researcher result and scientific explanation.

The present study suitability class result of each parameter (soil depth, soil texture, soil drainage, soil type, soil organic carbon, slope, temperature and rainfall) were produced for the specified crop types after matching the crops with crop requirement standards. The suitability classes of each criterion for both crop is from very highly suitable to permanently not suitable. The process and results of each criteria suitability classes were supported and in agreement with the findings reported earlier by Mahabadi et al. (2012), Joshua et al. (2013) and Murage et al. (2013).

Murage et al. (2013) have done a similar study on the land suitability analysis for rice growing sites using GIS and multi criteria evaluation in Mwea Region, Kenya. The methodology and result of suitability analysis done for rice growing have similarity with the present study. The suitability analysis parameters implemented in their study were slope, humidity, temperature, soil pH, soil texture and soil drainage. For each parameter, crop requirement standards were used to reclassify and showed the suitability of each parameter for rice crop. The suitability levels of each factor was ranked as very highly suitable, highly suitable, moderately suitable, marginally suitable, currently not suitable and permanently not suitable for rice cultivation. Therefore, the way Murage et al. (2013)

gave the suitability reclassification of each criterion for the selected crop type and the present studies are comparable.

Mahabadi et al. (2012) conducted similar study on land suitability evaluation for Alfalfa and Barely on FAO and Fuzzy Multi Criteria Approaches in Iranian Arid region. The suitability analysis was done by comparison of AHP, fuzzy AHP, maximum limitation method and parametric square root test methods. As the results of the analysis showed parametric square root method result is the best confirmation method with the observed yield as compared with other methods. However, the parametric square root test method revealed nearly similar result confirmation with AHP fuzzy method even if the AHP fuzzy is not free from personal judgment. The methodology of parametric square root test method used was the same with the present study. In their parametric square root test method the criteria used are grouped in to different suitability classes based on comparison of crops with their requirement standard such as very highly suitable (1-0.95), highly suitable (0.95-0.85), moderately suitable (0.85-0.6), marginally suitable (0.6-0.4), currently not suitable (0.4-0.25) and permanently not suitable (0.25-0). Thus, the procedure followed and the result of the suitability classes of each parameter for the identified crop types were similar with the procedure followed and the result produced in the present study.

Joshua et al. (2013) have studied land suitability analysis for agricultural planning using GIS and multi criteria decision analysis in greater Karu Urban Area, Nasarawa, Nigeria. Even though, the suitability analysis was for urban agricultural planning, the methodology used in reclassification of each parameters using FAO standard was similar and agreed with the present study. In the aforementioned study, the suitability analysis parameters implemented were slope, soil type, geology and soil drainage. For each parameter, they have used agricultural requirement standards to the suitability classes of each criteria by assigning the subclasses of those criteria from 1 (not permanently suitable) up to 6 (very highly suitable) number, based on their suitability for urban agriculture. The result of the suitability classes of each factor was ranked as very highly suitable, marginally suitable and permanently not suitable for urban agriculture, which was parallel with the present study.

All published researches agreed on one parameter in suitability analysis having low suitability class for the land use is enough to reduce the other suitability classes from one to other lower level. In the present study the overall suitability classes of sorghum and wheat crops were affected by soil depth class in which 166 km² (15.1%) of an area has low soil depth which is permanently not suitable and 420 km² (38.1%) of an area has medium soil depth which is moderately suitable. The other factor, which affects the suitability class of the study area, was slope. In the study area 420 km² (38.1%) of the area is moderately suitable and 524 km² (47.6%) of an area is marginally suitable in terms of slope criteria. This factor has the capacity to restrict the overall suitability classes of the crops in to moderately and marginally suitable classes. The soil type of lithic leptosols covers an area of 166 km² (15.1%), which is currently not suitable for wheat and sorghum crop, and it reduce the index value of the area that it covers for those crops. Therefore, the soil depth, slope and soil type criteria of an area reduce the results of the wheat and sorghum suitability classes in the study area. In addition to this, the rainfall of the Woreda, which covers an area of 759 km² (68.9%), and the temperature amount of the Woreda, which covers an area of 532 km² (48.3%) are moderately suitable for sorghum crop and 166 km² (15.1%) of an area was covered by marginally suitable temperature for sorghum crop. Therefore, this result also plays its contribution for the reduction of the sorghum suitability classes in the area and even controls the result to be moderately suitable, marginally suitable and currently not suitable classes. The overall wheat and sorghum suitability results of the present study area were comparable with the finding report of Mahabadi et al. (2012), Kassa Teka and Mulu Haftu (2012) and Yitbarek et al. (2013).

The results of the present study is in agreement with the study carried out by Mahabadi et al. (2012) in land suitability evaluation for Alfalfa and Barely crop in the Iranian arid region. They were applied the four suitability analysis methods and conclude that the parametric square root test method is more accurate than other methods. The result of this research for the crops by square root test method was moderately suitable, marginally suitable and currently no suitable. Since the result of these crops suitability classes in their area were limited by soil texture, soil pH and soil organic carbon factors.

This result was achieved after the land units of the study area were determined and their land indices were calculated by the mathematical formula as revealed by Mahabadi et al. (2012). Therefore, this was equivalent with the way of limiting the results of the present study.

The overall suitability analysis result of the present study also agreed with the study of Kassa Tekla and Mulu Haftu (2012) for crop and fruit production in the midlands of Tigray, Ethiopia. The overall result of their research were based on parametric method, which showed the suitability classes for the crops and fruits were highly suitable, moderately suitable, marginally suitable and permanently not suitable. Particularly the suitability classes of sorghum crop in the area were marginally suitable and very small area was highly suitable. These suitability results of crops and fruits were reduced by soil organic carbon, soil depth, soil pH and soil texture limiting factors. Therefore, it was parallel with the way of limiting the results of the present study.

Yitbarek et al. (2013) have studied the physical land suitability evaluation for cotton, maize, rice and sorghum in Abobo area, western Ethiopia by using parametric method. Similarly, in the aforementioned research, the study area was classified in to different land units based on terrain features of the area and comparison of crops with their requirement was done to calculate suitability index of each land unit by using parametric formula. Therefore, as the overall suitability result of this research showed the sorghum crop suitability classes were moderately suitable and marginally suitable. These suitability classes were limited by soil depth and soil fertility factors. Thus, their results (S2, S3 and N1) were agreed with the result of sorghum suitability in the present study.

The result of the present study was contradicted with the result report of Elaalem (2012) on land suitability evaluation for sorghum crop in Jeffara plain region, Libya. Their suitability results for sorghum crop were S1, S2, S3 and N1. Since the aforementioned research was used soil pH, soil erosion, soil salinity and stoniness factors in addition to the factors used by the present study and applied weighted overlay that was affected by subjectivity and inconsistent judgment.

Mustafa et al. (2011) have studied on land suitability analysis for different crops in Uttar Pradesh, India. The suitability results of wheat and sorghum crops were S1, S2, S3 and N1. These results were contradicted with the result of the present study since in the aforementioned studies only the chemical and physical properties of soil were used as a factor and applied AHP method that deals with the inconsistent judgment.

The results of the present study were agreed with the finding results of physical land suitability evaluation for specific cereal crops using GIS by Bagherzadeh and Daneshvar (2011) at Mashad plain, Iran. The standard methods applied in both researches were similar. In their studies, the results of wheat (S2 and S3) were limited by soil physical properties and soil fertility whereas the results of sorghum crop (S2, S3 and N1) were limited by climatic factors like rainfall and temperature. Therefore, these results were agreed and similar with the results of the present study.

The suitability analysis result of the present study was contradicted with the finding results of Albaji et al. (2009) on qualitative evaluation of land suitability for principal crops in the west Shoush plain, Southwest Iran. This is because of the difference in factor classes that was found in aforementioned and present study area. For instance, the slope factor classes that found in the present study area were not very highly and highly suitable whereas very highly suitable and highly suitable classes in the abovementioned studies. Due to this the results of aforementioned study was contradicted with the results of the present study.

Keshavarzi et al. (2011) studied spatially based model of land suitability analysis for wheat crop in Ziaran, Iran. In the aforementioned research result validation the correlation coefficient between land index and observed yield reported as $r=0.77$ in wheat crop for AHP method. Whereas in the result validation of the present study the correlation coefficient between land index and observed yield is $r=0.95$ in wheat and $r=0.97$ in sorghum crop for parametric method. Therefore, the parametric method is superior than AHP method and the present study result validation is more accepted than the aforementioned research results.

CHAPTER SIX

6. CONCLUSION AND RECOMMENDATION

6.1. Conclusion

In this study the physical land suitability analysis were evaluated for specific land utilization types. The factors considered in the suitability analysis result were soil depth, soil texture, soil type, soil drainage, soil organic carbon, slope, rainfall and temperature. In this study, the suitability level of each factors were evaluated and the result expressed in qualitative and quantitative terms. As the land suitability evaluation results of each factors showed that 15.1% of the study area was currently and permanently not suitable in terms of soil type and slope respectively and 85.7% of the area was moderately and marginally suitable in terms of slope, in which those are the maximum limiting factors for wheat and sorghum crops. 68.9% of the area in the study was moderately suitable in terms of rainfall and 63.4% of the area was moderately and marginally suitable for sorghum crop in terms of temperature. As the results of the study showed, the area that is currently not suitable in terms of soil type is permanently not suitable and marginally suitable in terms of soil depth and slope respectively. Similarly, the area that is marginally suitable in terms of soil type is moderately suitable in terms of soil depth and moderately and marginally suitable in terms of slope. As the overall suitability result of wheat and sorghum crops for each land units showed that the study area were classified in to moderately and marginally suitable for wheat crop and moderately suitable, marginally suitable and currently not suitable for sorghum crop production.

6.2. Recommendation

- ❖ The parameters used for land suitability analysis in this study were entirely biophysical whereas further studies can be made by including socioeconomic variables, soil pH, length of growing period and WRSI factors to improve the suitability results.
- ❖ The land utilization types considered in this study were limited in to two selected crops such as sorghum and wheat whereas further studies can be made to increase the choice and identify the best alternative use of a land for different land utilization types by considering pulses, oilseeds, teff and maize.

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Appendices

1. Summary output of sorghum

<i>Regression Statistics</i>	
Multiple R	0.972930126
R Square	0.946593031
Adjusted R Square	0.943625977
Standard Error	0.236869137
Observations	20

<i>ANOVA</i>					
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	1	17.90007	17.90007	319.0347	0.0042
Residual	18	1.009926	0.056107		
Total	19	18.91			

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>
Intercept	2.701921979	0.249128	10.84552	0.53	2.178523789	3.22532
Class	0.116726927	0.006535	17.86154	0.0042	0.102997195	0.130457

RESIDUAL OUTPUT

<i>Observation</i>	<i>Predicted Yield</i>	<i>Residuals</i>	<i>Standard Residuals</i>
1	5.269914367	-0.26991	-1.17073
2	5.503368221	0.296632	1.286618
3	5.620095147	0.479905	2.081552
4	6.087002854	0.212997	0.923859
5	6.437183635	-0.03718	-0.16128
6	6.553910561	-0.15391	-0.66758
7	6.670637488	-0.07064	-0.30638
8	6.787364415	0.012636	0.054806
9	6.904091342	-0.00409	-0.01775
10	7.020818268	-0.22082	-0.95778
11	7.137545195	-0.13755	-0.59659
12	7.254272122	-0.15427	-0.66914

PROBABILITY OUTPUT

<i>Percentile</i>	<i>Yield</i>
2.5	5
7.5	5.8
12.5	6.1
17.5	6.3
22.5	6.4
27.5	6.4
32.5	6.6
37.5	6.8
42.5	6.8
47.5	6.9
52.5	7
57.5	7.1

13	7.370999049	-0.171	-0.7417	62.5	7.2
14	7.487725975	-0.18773	-0.81425	67.5	7.3
15	7.604452902	-0.10445	-0.45306	72.5	7.5
16	7.721179829	-0.12118	-0.52561	77.5	7.6
17	8.071360609	-0.27136	-1.17701	82.5	7.8
18	8.304814462	0.195186	0.846603	87.5	8.5
19	8.538268316	0.361732	1.568984	92.5	8.9
20	8.654995243	0.345005	1.496433	97.5	9

2.Summary output of wheat

<i>Regression Statistics</i>	
Multiple R	0.961225
R Square	0.923953
Adjusted R Square	0.91704
Standard Error	0.252238
Observations	13

ANOVA					
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	1	8.503214919	8.503215	133.6483	0.0044
Residual	11	0.699862004	0.063624		
Total	12	9.203076923			

	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>
Intercept	3.818299	0.541256148	7.054513	0.42	2.627001928	5.009595
class	0.144556	0.012504136	11.56064	0.0044	0.117034347	0.172077

Residual output

<i>Observation</i>	<i>Predicted yield</i>	<i>Residuals</i>
1	8.733195	0.166805293
2	8.87775	0.022249527
3	9.311418	-0.211417769
4	9.455974	-0.255973535
5	9.600529	-0.200529301
6	9.745085	-0.145085066

PROBABILITY OUTPUT

<i>Percentile</i>	<i>yield</i>
3.846154	8.9
11.53846	8.9
19.23077	9.1
26.92308	9.2
34.61538	9.4
42.30769	9.6

7	9.889641	0.510359168	50	10.4
8	10.0342	0.365803403	57.69231	10.4
9	10.61242	-0.11241966	65.38462	10.5
10	10.75698	-0.156975425	73.07692	10.6
11	10.90153	-0.201531191	80.76923	10.7
12	11.04609	0.153913043	88.46154	11.2
13	11.3352	0.064801512	96.15385	11.4

3. Meteorologically calibrated satellite data

Point	Latitude (Y)	Longitude (X)	Mean Temperature	Mean rainfall
1	104811	382333	17	1300
2	104821	383016	22	1250
3	104826	383610	21	1310
4	104821	384215	16	1260
5	104826	384814	16	1245
6	104831	385410	19	1200
7	104835	390013	18	1146
8	104210	382343	22	1116
9	104203	383011	21	1172
10	104208	383611	19	1152
11	104211	384208	17	1092
12	104212	384814	19	972
13	104203	385409	17	983
14	103558	382343	21	1101
15	103603	382359	21	975
16	103553	383017	23	1019
17	103558	383616	20	905
18	103555	384210	19	945
19	103558	384810	16	922
20	103554	385414	18	951
21	103604	390817	16	889
22	102959	382338	17	866
23	103004	383016	21	877
24	102959	383011	20	901
25	102954	384215	16	876
26	102949	384814	21	882
27	103008	385405	18	870
28	103005	390427	19	950
29	102359	382338	18	958
30	102350	383611	24	918
31	102405	384211	23	869
32	102359	384809	24	866
33	102352	385414	24	868
34	102411	390213	24	871