

Land Suitability Evaluation for Sorghum and Barley Crops in South Wollo Zone of Ethiopia

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Abstract
This study was conducted to assess the physical land suitability of South Wollo Zone for sorghum and barley crops; and to produce land suitability maps for each crop. The study focuses on such an issue because land suitability analysis is a prerequisite to achieve optimum utilization of the available land resources. Lack of knowledge on best combination of factors that suit production of different agricultural crops has contributed to the low production. All criteria maps have been reclassified into five classes (S1, S2, S3, N1 and N2) values ranging from 1 to 5, where 1 represents S1 and 5 represents N2. Each of the criteria was separately reclassified and analyzed for their suitability for supporting barley and sorghum crops based on the FAO crop requirements specified for them. The land evaluation assessments of this study were conducted based on the methodology outlined in the FAO Guideline for Land Evaluation for Rain Fed Agriculture. The major data sources were climatic data, topographic data and length of growing period as well as crop requirements which have been considered to undertake suitability assessments of the study area. Moreover, both published and unpublished materials were used. The climatic data, topographic data and length of growing period were extracted from Ethio-GIS-2007 with the help of Arc Map 10 version. After clipping map of the study area with the help of the input data (mean annual rainfall, mean annual temperature, slope, elevation and length of growing period), it was reclassified and finally weighted overlayed with the Arc Map GIS software. This was done for sorghum and barley crops separately. Results of the study revealed that most of the lands in the study area are suitable for the cultivation of the two crops. Consequently, land suitability maps for both sorghum and barley crops were extracted using weighted overlay techniques. The suitability map of sorghum crop shows that 237.58 km^2 of the investigated area are highly suitable (S1), 14,492.57 km^2moderately suitable (S2) and 2,208.87 km^2 marginally suitable (S3). On the other hand, the suitability map of barley crop shows that 649 km^2 of the investigated area are highly suitable (S1), 7,169 km^2 moderately suitable (S2), 9,171 km^2 marginally suitable (S3) and 122 km^2unsuitable for economic reasons (N1). The total resulting areas for both crops reveal the importance of agriculture in the study area, and the suitability of the terrain.
Keywords: Land evaluation; Land suitability; Ethiopia.

INTRODUCTION

Land evaluation, as defined by Van Diepen *et al*. (1991) and Rossiter (1996), is the process of making predictions of land performance over time based on specific types of uses. These predictions are, then, used as a guide in the strategic land use decision making. Therefore, the primarily traditional bases of land evaluation are soil resource inventories, commonly known as soil surveys. These have been conducted for more than a hundred year period in Russia, the USA and Hungary and for a period of, at least, fifty years in most of the other parts of the World (Bouma *et al*. 1999, Yaalon and Berkowicz, 1997, Zinck, 1995). Soils are affected by landforms, and through their developmental accessions and features, they in turn influence geomorphic evolution (Schaetzl and Anderson, 2005). In addition, according to Bibby *et al*. (1991) and Klingebiel (1991), they were initially used mainly to support rural land use decision making, in particular decisions regarding the matching of production systems (crops, varieties, rotations, fertilization and other land practices, conservation measures) to soil types. This support became a system in the land capability approach where soil types were grouped into general classes of land use based on their ability of sustainability. The degree of suitability for a land use, regardless of the economic conditions, is indicated by a physical suitability evaluation (Rossiter and Van Wambeke, 1997). Thus, the process of land suitability classification is the assessment and categorization of specific areas of land in terms of their suitability for defined uses (FAO, 1976). Overall, land evaluation, as defined by Beek (1978), is a process of matching a series of selected land qualities and comparing them with land use requirements. The ever increasing demands for increasing food grain production could be met through systematic survey of the soils, evaluating their potentials for wide range of land use options and formulating land use plans which were economically viable, socially acceptable and environmentally sound (Sathish and Niranjana, 2010). The evaluation of the suitability of a territory to a given crop is a complex multidisciplinary procedure. Many of suitability evaluation procedures in use are adaptations to the local conditions of the Framework for Land Evaluation (FAO, 1976), and focus on the severity of land limitations related to crops and land use. The distinction between the classes is based on the rise of the costs for the reduction or elimination of these limitations (Madrau *et al*., 2009). Thus, generated data is integrated in GIS to obtain different thematic information for using in land evaluation techniques.

Agriculture is one of the World's most important activities supporting human life. On a global scale, agriculture has the proven potential to increase food supplies faster than the growth of the population, a pattern to be expected in the foreseeable future (Davidson, 1992). According to a United Nations report (2013), the current World population of 7.2 billion is projected to increase by 1 billion over the next 12 years and reach 9.6 billion by 2050, which points out that growth will be mainly in developing countries, with more than half in Africa. Thus, there is growing concern about food security in Africa and especially in Sub - Saharan Africa. While the aggregate global food supply/demand picture is relatively good, there will be a worsening in food security in Sub - Saharan Africa (FAO, 1993). Therefore, evaluation of land suitability which has great physical and chemical land qualities is very needed to contribute to the World's food production in general and the country, Ethiopia, in particular to improve food security. Land suitability is the fitness of a given type of land for a defined use. The process of land suitability classification is the appraisal and grouping of specific areas of land in terms of their suitability for defined uses (FAO, 1976). Agricultural productivity in Ethiopia has not kept pace with population increase, and the region is now in a worse position nutritionally than it was 30 years ago: Food production has achieved a growth of about 2.5% per year, while population has risen at a rate of over 3% per year (Hailu, 2008). With the increase in population, as well as human activities, pressure on land has been intensified. In Rain Fed agriculture production systems, natural resources need to be used in such a manner that the productivity potential of the farm land is optimized. The sustained land use planning, therefore, involves the decision of land use so that available resources are put into use according to the assessed potentiality.

In Ethiopia, agricultural land suitability analysis is very important since agriculture accounts on average for about 46.3% of Gross Domestic Product, 83.9% of exports and 80% of the labor force (MoFED, 2009). The same source indicated that Ethiopia has great agricultural potential because of its vast areas of fertile land, diverse climate, generally adequate rainfall, and large labor pool. Despite this potential, however, Ethiopian agriculture has remained underdeveloped because of drought, a poor economic base, and low level of technologies on agricultural application. GIS, geo - spatial mapping ,and remote sensing technologies are central to achieving a successful transition from traditional environmental and resource management practices to sustainable development because of their integrative quality (linking social, economic and environmental data) and their place - based quality (addressing relationships among places at local, national, regional and global levels) (World Bank, 2006). For instance, there is a growing recognition by decision makers that problems at the intersection of agriculture and environmental management, climate change, and land vegetative cover change, with their attendant social and economic consequences, will be at the forefront in the new century. Technological advances in GIS fostering the integration of satellite imagery with other data (such as socioeconomic or health data) are opening new ways to synthesis complex and diverse geographic data sets, creating new opportunities for collaboration among natural and social scientists and decision makers at all levels (World Bank, 2006).

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

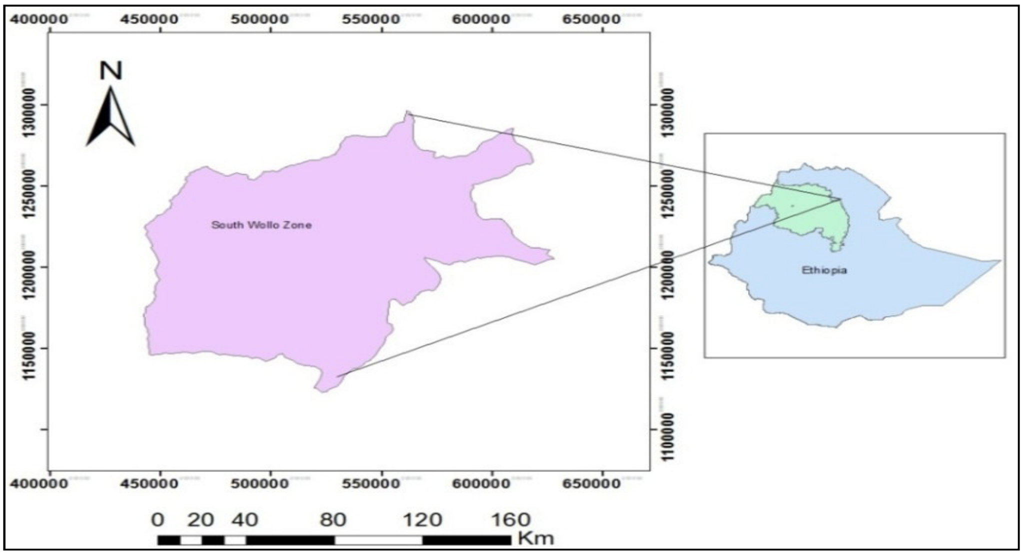

Figure 1. Location Map of the Study Area. Source: Derived from Ethio-GIS-2007.

With advances in information and communication technology, computer based decision support models have been developed towards land evaluation (De la Rosa et al., 1992; Shim et al., 2002; cited in Bandyopadhyay et al., 2009). Land evaluation through map analysis techniques has been accomplished using a Geographical Information System (Malczewski, 2003).In many countries the pressure on land is ever increasing which leads to a decrease in the area of agricultural land. Many developing countries, especially in Africa, need to increase their agricultural production in order to feed a growing urban and rural population and to produce raw materials for local industry and export in sufficient quantities to sustain a healthy economy (World Bank, 2006).

In Ethiopia, as in many developing countries, current land use practices are not based on suitability analysis; therefore, there is an urgent need to use land in the most rational and possible way. One of the most important and urgent problems in Ethiopia is to improve agricultural land management and cropping patterns to increase the agricultural production with efficient use of land resources (Hailu, 2008). In this sense, the combined use of GIS and Remote Sensing technology offers a dynamic tool for multidimensional process of land use. This study used GIS to delineate the suitable areas for agricultural crops (barley and sorghum) using the relevant variables of soil, climate, land use/land cover and topographic factors within a GIS context to improve crop productivity and allocate the land of the study area to the most suitable use type.

MATERIALS AND METHODS

Description of the Study Area

Socio-Economic Characteristics

This study was carried out in South Wollo Zone. It is located in the North Eastern highlands of Ethiopia. It is one of the eleven administrative zones of the Amhara National Regional State. It is situated between the Eastern highland plateaus of the region and the North Eastern highland plateaus of Ethiopia. It is divided into 21 administrative districts (*weredas*) and has two major towns (Dessie and Kombolcha) and 19 rural districts. South Wollo Zone is located between latitudes $10^0$10'N and $11^0$41'N and longitudes $38^0$28'E and $40^0$5'E. Based on the 2007 Census conducted by the Central Statistical Agency of Ethiopia (CSA), this Zone has a total population of 2,519,450, an increase of 18.60%, of whom 1,248,698 are men and 1,270,164 women; with an area of 17,067.45 square kilometers. Of these cultivated lands account 35.3%.

South Wollo Zone is bordered on the south by North Shewa and the Oromia Region, on the west by West Gojjam, on the North-west by South Gondar, on the North by North Wollo, on the North-east by Afar Region, and on the East by the Oromia Zone and Argoba special *wereda* (Figure 1). Its highest point is Mount Amba Ferit (4,247 meters). In the Zone food security is precarious because of high population and small per capita landholding which also lead into continuous cultivation and hence erosion resulting into poor soil fertility. All these features lead to low productivity in the Zone. This low productivity is further aggravated because nearly all of the farmers are reliant on the unreliable and at times erratic rainfall. In addition, the undulating and devoid of vegetation mountains also enhance runoff resulting into land degradation and hence low productivity. This therefore makes South Wollo a drought stricken zone and food deficit. Hence, food aid is a major source of livelihood for most of the population. Therefore, many farmers supplement subsistence agriculture with income from seasonal labor, sale of firewood or charcoal and other sources.

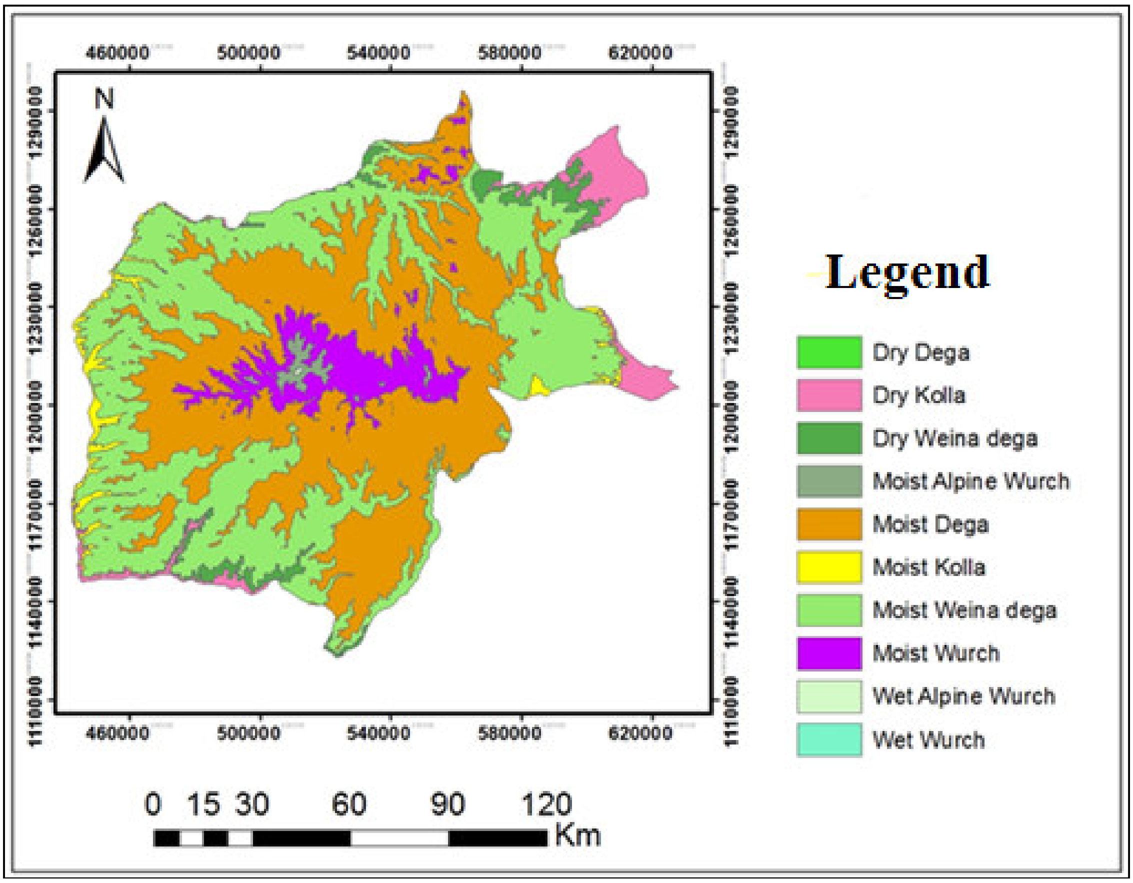

Figure 2. Agro-ecological Map of the Study Area.Source: Derived from Ethio-GIS-2007.

Bio-Physical Characteristics

Climate, Topography, Geology and Soils

According to the local system, Ethiopia is classified into 5 agro-ecological zones: *Wurch, Dega*, *Weyna-Dega*, *Kolla* and *Berha* (NMSA, 1996; Hurni, 1998). Dry-*Dega*, Dry-*Kola*, Dry-*Weina Dega*, Moist Alpine W*urch*, Moist-*Dega*, Moist *Kola*, Moist *Weina Dega*, Moist *Wurch*, Wet Alpine *Wurch* and Wet-*Wurch* agro-climatic zones are found in the study area (Figure 2). Based on Koppen´s Classification, the Wollo area is classified in three climatic regions: cool highland climate, tropical climate with dry summer, and tropical climate with distinct dry winter. South Wollo Zone also has three distinct seasons namely *Bega, Belg* and *Kiremt*. *Bega* is a dry season from October to January (NMSA 1996). *Belg* is the small rainy season that occurs between mid-February and mid-May, while *Kiremt* is the main rainy season that extends from mid-June to mid-September (NMSA, 1996). The mean annual temperature and mean annual rainfall ranges from 14°c to 20°c and from 680 mm to 1200 mm, respectively (Gonfa, 1996). Based on the moisture index, the climate of South Wollo Zone is also classified as dry with arid to dry sub-humid conditions.

The Digital Elevation Model (DEM) reveals that larger parts of South Wollo are characterized by rugged topography that consist very high mountains, deeply incised canyons and gorges, valleys and plateaus. The rugged topographic condition of the area was also reported in other studies (e.g. FAO, 1984; Tefera *et al.*, 1996; Coltorti *et al.*, 2007). Due to the strong relief differences, anthropogenic activities have led to extensive degradation. South Wollo Zone is covered by Cenozoic volcanic rocks with some sedimentary rocks. The Cenozoic volcanic rocks have developed from tertiary flood basalt sequences with intercalation of felsic lava and pyroclastic rocks up to 3 km thick. The Cenozoic volcanic rocks and the associated sedimentary rocks are further subdivided in various formations (Tefera *et al.*, 1996).

Wollo areas have various soil types, the major soils being Leptosols, Cambisols, Vertisols, Andosols and Luvisols (FAO, 1984). Leptosols are the dominant soil types, which cover over 35% of the study area and followed by Cambisols, Vertisols, Andosols and Luvisols (FAO, 1984). Leptosols are shallow, mostly brown or yellowish brown and clay to clay loam. Leptosols are characterized by common to abundant surface stoniness, few to common rock outcropping and many coarse fragments throughout the profiles. At the second level, the Leptosols are further classified into Eutric, Dystric and Lithic. Cambisols are further classified as Vertic and Dystric. Cambisols have wide physical, chemical and morphological characteristics and are shallow to moderately deep. Vertisols in the study area are moderately deep to very deep on flat to almost flat lands. They are characterized by dark to dark gray color, clayey texture, poor drainage and workability, and develop wide and deep cracks upon drying and swell upon wetting. The Vertisols of Wollo are further classified into Euthric and Calcic (Figure 3). Luvisols occur in cooler areas in very small parts and on gently sloping lands. They are well drained, brownish in color, clayey textured, have high CEC (>24 cmol/kg clay) and higher base saturation, mostly >50%. Andosols cover small parts of the study area in the Rift Valley and the escarpments towards the valley.

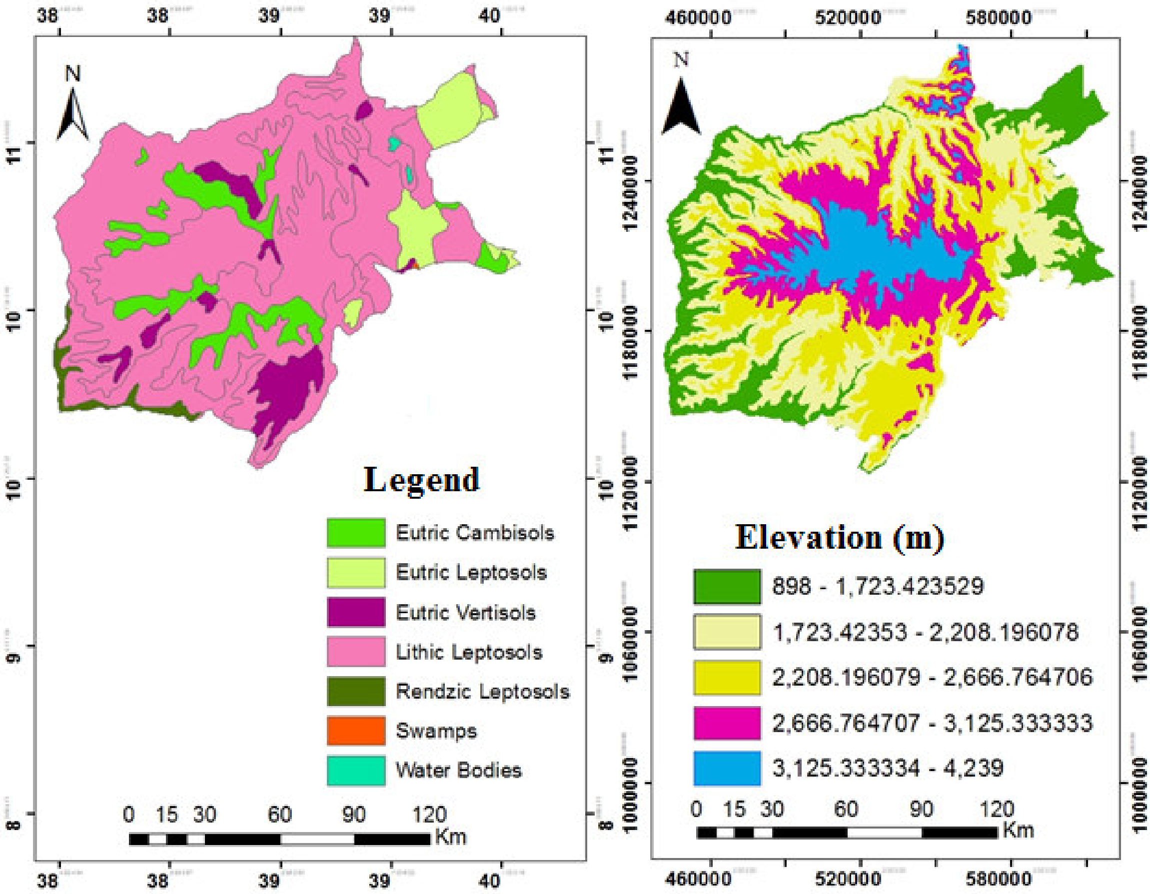

Figure 3. Soil Map (Left) and Elevation Map (Right) of the Study Area.
Source: Derived from Ethio-GIS-2007.

Agriculture and Farming System

The main livelihood base and economy of the Ethiopians is agriculture. Like other parts of the Ethiopian highlands, the major farming system of Wollo is mixed cereal-livestock (Haileslassie *et al*., 2005). The farming system is diversified and determined by agro-ecology. Cereals are the dominant crop accounting for over 73%, followed by pulses (24%) and the remaining 3% is oilseed (ANRS-BFED, 2008). Among the cereal crops tef(*Eragrostis tef*), sorghum, wheat (*Triticum vulgare*) and barley (*Hordeum vulgare*) are dominant, accounting for 25%, 18%, 16% and 11% of the total, respectively (ANRS-BFED, 2008). Horse bean, lentil, chickpea and field bean are the major legume crops accounting for 16% of the total crop production (ANRS-BFED, 2008). Farmers rotate cereals with legumes to maintain soil fertility and crop yield. Like in other parts of the country, the farming system and farm implements are traditional and inherited from indigenous knowledge (Ehret, 1979). The traditional tillage implement known as *Maresha* is an ox-drawn plough, which has been used for more than two thousand years (Ehret, 1979; McCann, 1995). Traditional re-tillage practices, known as *Shilshalo*, are usually performed about six weeks after maize and sorghum sowing. *Shilshalo* has various purposes such as harrowing, which improves soil air, water and nutrient circulation, root development, and uproots and kills weed and optimizes plant density. The traditional up and down cultivation across the slope of the land practiced for centuries has led to severe soil erosion and land degradation. Weeding and harvesting is manual.

The components of the mixed cereal-livestock farming system support each other (Haileslassie *et al*., 2005). Ehret (1979) reported that domestication of grasses was accompanied or even preceded by small ruminants (sheep and goat) husbandry, which indicate long standing history of the two sectors in Ethiopia.

Livestock husbandry supports crop production mainly through providing traction power, while crop residue is used as a major livestock feed. Consequently, farmers keep wide variety and high livestock population. The livestock include cattle, small ruminants, equines, poultry and bees (ANRS-BFED, 2008). Small ruminants and cattle are the dominant animals accounting for 40% and 32% of the total population, respectively. (Figure 4).

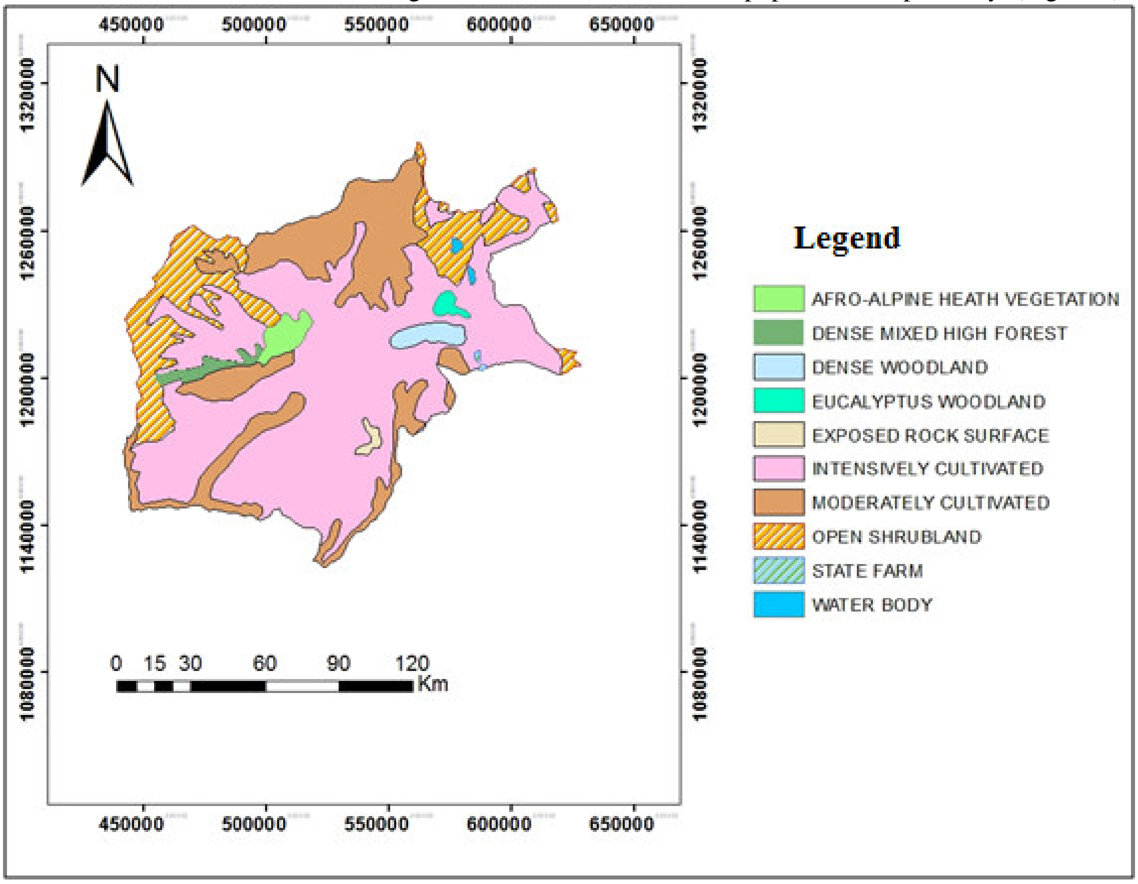

Figure 4. Land Use/Land Cover Map of the Study Area. Source: Derived from Ethio-GIS-2007.

Methods

Data Sources

The land evaluation assessments of this study were conducted based on the methodology outlined in the FAO Guideline for Land Evaluation for Rain Fed Agriculture. The major data sources were climatic data, topographic data and length of growing period as well as crop requirements which have been considered to undertake suitability assessments of the study area. Moreover, both published and unpublished materials were used. The climatic data, topographic data and length of growing period were extracted from Ethio-GIS-2007 with the help of Arc Map 10 version. After clipping map of the study area with the help of the input data (mean annual rainfall, mean annual temperature, slope, elevation and length of growing periods), it was reclassified and finally weighted overlayed with the Arc Map GIS software. This was done for sorghum and barley crops separately. The following table indicates the soft-wares and materials used for this study.

Table 1. Materials Used in the Study.

S.N	Type	Description	Source
1	Maps	Digital soil Map	FAO
		Zone shape files	CSA
		Agro-ecological Map	MOA
2	Soft-wares	Arc Map 10	
		SRTM_30 (DEM)	
3	Climatic data	Temperature, rainfall and LGP	MOA
4	Topographic data	Slope and elevation	

(Table 1) Collecting high quality Geographic data for GIS input marks a critical stage. Data collection is one of the most time - consuming and expensive, yet important for GIS - base studies. GIS can contain a wide variety of geographic data types originating from many diverse sources. To achieve the objectives of the study, both primary and secondary raster and vector data were used. The methodology that was used to evaluate land suitability for different Land Utilization Types (LUTs) was based on FAO guidelines (FAO, 1976). This guideline is standard and is accepted by many researchers. It has procedures to evaluate the suitability of the land for intended land use.

Climatic data like mean annual temperature and rainfall were obtained from Ministry of Agriculture (MOA). Furthermore, slope and elevation of the land are essential for land suitability analysis. Hence, they were derived from Digital Elevation Model (DEM), which was extracted from 30 meters solution Shuttle Radar Topographic Mission (SRTM) data of NASA satellite. Weighted Overlay Analysis (WOA) in a GIS environment was used to map the land suitability for each LUTs after weights are calculated in Analytical Hierarchy Process (AHP).

Selection of Crop Types

The selection of LUTs was based on data availability on the crop environmental requirement, crops adaptability to climatic factors like temperature and rainfall, and length of growing period of the study area. Hence, barley and sorghum crops are considered for this study.

Selection of Evaluation Criteria

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

Identification of criteria is a technical activity, which is based on theory, empirical research or common sense. Evaluation criteria, objectives and attributes, should be identified with respect to the problem situation. A set of criteria selected should adequately represent the decision making environment and must contribute towards the final goal. Criteria identification can be done using the participatory approach by a group of experts from various disciplines. FAO (1976) has given a framework for land suitability analysis for crops in terms of suitability classes from highly suitable to not suitable based on the crop specific soil, climate and topographic data. Hence, climate factors (temperature and rainfall), topographic factors (slope and elevation), and length of growing period of each crop are considered as evaluation criteria to address the suitability of the land for sorghum and barley agricultural crops in the study area.

Land Suitability Analysis

Factors of Suitability for Agricultural Crops

The slope map generated for the evaluation study has an immense influence on work efficiency, erosion control practices and crop adaptability. Rainfall being the only source of water for Rain Fed Agriculture, its distribution and dependability plays a significant role in optimizing crop production.

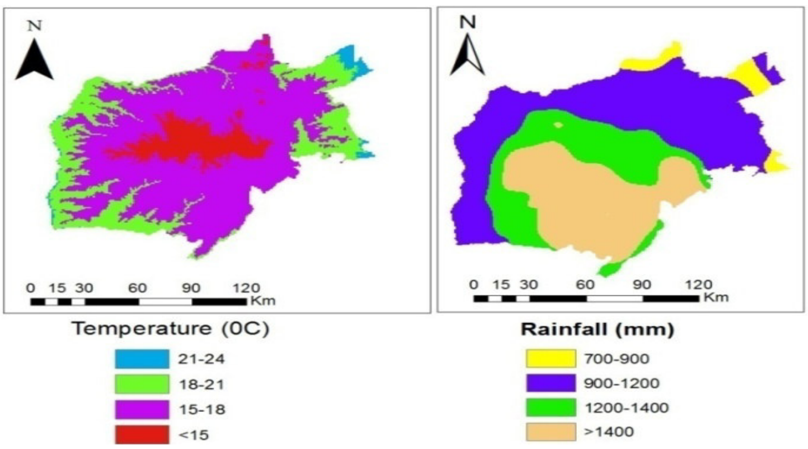

Figure 5.Temperature (Left) and Rainfall (Right) Suitability Maps for Sorghum Crop.

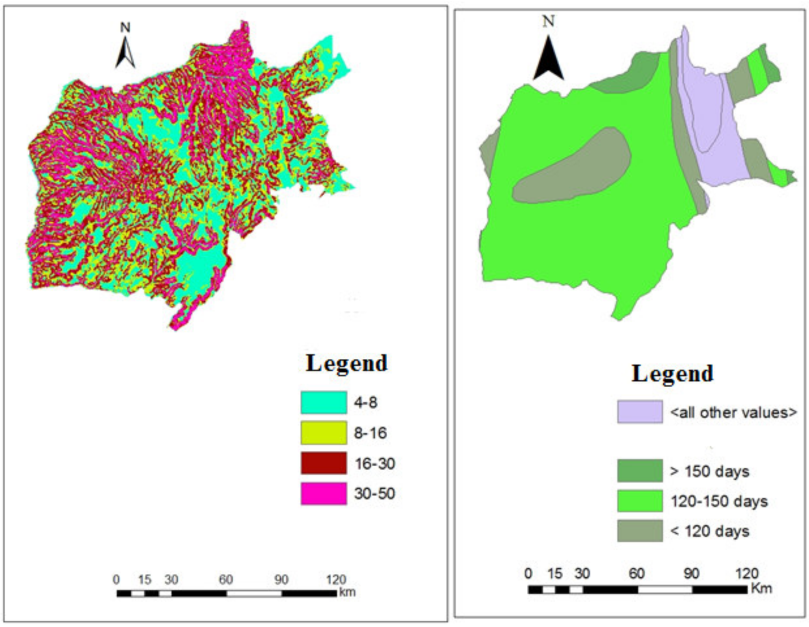

Figure 6. Slope (Left) and Length of Growing Period (Right) Suitability Map for Sorghum Crop.

Criteria Standardization

All criteria maps have been reclassified into five classes (S1, S2, S3, N1 and N2) values ranging from 1 to 5, where 1 represents S1 and 5 represents N2. Figure 5 and 6 below show the standardized criteria maps for sorghum crop suitability. Each of the criteria is separately reclassified and analyzed for their suitability for

Table 2. Land and Climatic Characteristics and Rating Scales for Sorghum and Barley Crops.

Land and Climatic Characteri	Diagnostic Factor	Unit	Class, degree of limitation and rating scale	
			Barley	Sorghum
Slope		%	4-8 = S1 8-16=S2 16-24=S3 24-30=N1 >30=N2	4-8 = S1 8-16= S2 16-30= S3 30-50= N1 >50= N2
Temperature	Mean annual temperature	^{0}C	12-18 = S1 18-24=S2 24-28=S3 >28=N2	21-24 = S1 18-21= S2 15-18= S3 <15= N2
Rain fall	Mean annual rainfall	mm	900-1100= S1 1100-1300=S2 1300-1500=S3 >1500=N2	700-900= S1 900-1200= S2 1200-1400= S3 >1400= N2
Length of growing period		Day	120-180 days=S1 90-120 days=S2 <90 days=N1	>150 days= S1 120-150 days= S2 <120 days= N1
Elevation	Above mean sea level	M	2000-3000= S1 3000-3300= S2 3300-3800= S3 <1500=N1 >3800=N2	1500-2200= S1 2200-2400= S2 1000-1200= S3 <1000=N1 >2400= N2

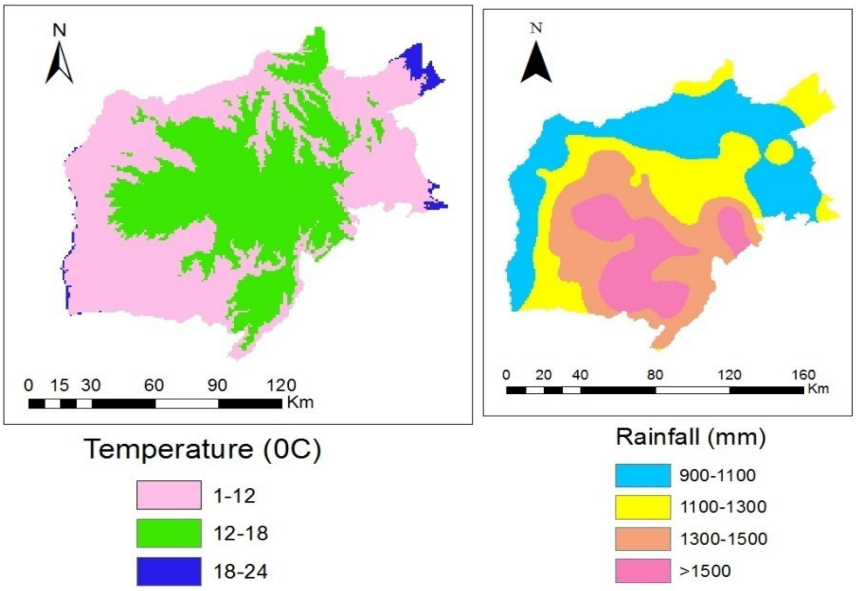

Figure 7. Temperature (Left) and Rainfall (Right) Suitability Maps for Barley Crop.

supporting barley and sorghum crops based on the FAO crop requirements specified for them (Table 2). Since each criterion has been reclassified and analyzed separately for the two crops, the following Figure 7 and 8 also show the standardized criteria maps for barley crop.

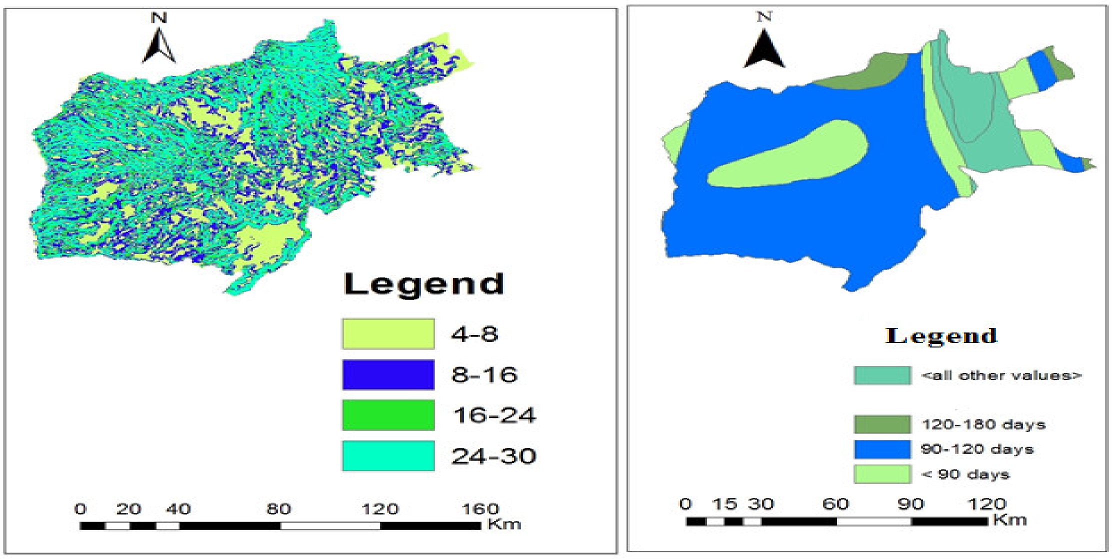

Figure 8. Slope (Left) and Length of Growing Period (Right) Suitability Maps for Barley Crop.

RESULTS AND DISCUSSIONS

This study was conducted to assess the physical land suitability of South Wollo Zone for sorghum and barley crops; and to produce land suitability maps for each crop. The study focuses on such an issue because land suitability analysis is a prerequisite to achieve optimum utilization of the available land resources. Biophysical variables like climate, topography, and crops length of growing period were considered for suitability analysis. All data were stored in Arc Map 10 environment and the factor maps were generated. The current land cover map of the area was developed from a land cover map of Ethiopia. Crop suitability analysis involves major decisions at various levels. It is an integral part to build up an efficient crop production system. Land evaluation as a significant element towards analyzing crop suitability has great physical and chemical land qualities. Hence, it is needed to contribute to the World's food production to improve food security. In order to determine an optimum land use type for an area, a systematic integration of data from various sources like soil science to meteorology is important. However, every criterion will contribute towards the suitability at variable degrees. The relative degree of contribution of various criteria can be addressed well when they are grouped into various categories and organized at various hierarchies. Relative importance of these parameters can be well evaluated to determine the suitability of lands for crops.

In this study, a GIS method was undertaken to study the suitability of barley and sorghum crops. Most of the lands in the study area are suitable for the cultivation of the two crops as shown by the findings (Figure 9). Consequently, land suitability maps for both sorghum and barley crops were extracted using weighted overlay techniques. The suitability maps resulting from the spatial overlay of factors in the study area are shown in Figure 9 below. The suitability map of sorghum crop shows that 237.58 km^2 of the investigated area are highly suitable (S1), 14,492.57 km^{2}moderately suitable (S2) and 2,208.87 km^2 marginally suitable (S3). On the other hand, the suitability map of barley crop shows that 649 km^2 of the investigated area are highly suitable (S1), 7,169 km^2 moderately suitable (S2), 9,171 km^2 marginally suitable (S3) and 122 km^{2}unsuitable for economic reasons (N1). The total resulting areas for both crops reveal the importance of agriculture in the study area, and the suitability of the terrain.

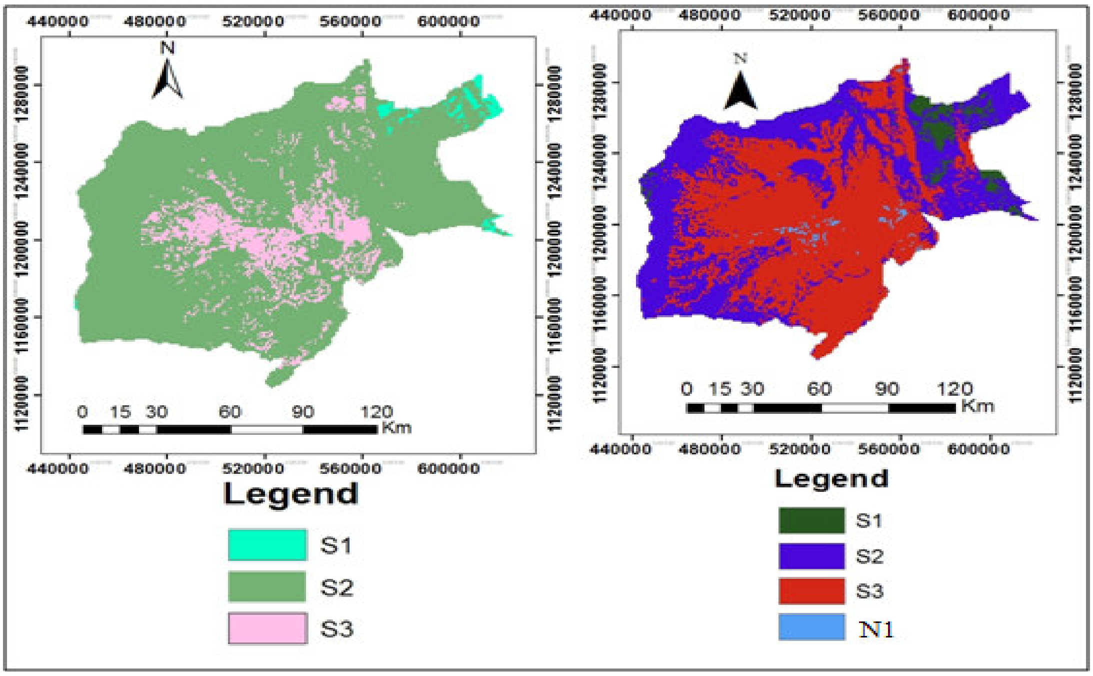

Figure 9. Land Suitability Maps for Sorghum (Right) and Barley (Left) Crops in the Study Area.

The findings of this study may give clue to ensure that the adopted methodology can be further generalized and applied to the other natural resources of the particular area or any other area of interest. In this study, limited numbers of factors pertaining to the requirements of barley and sorghum crops have been considered due to limitation of data availability. Keeping in mind the future developments, this method can be further enriched by incorporating other soil data, socio-economic and environmental variables to obtain the optimum results. Although the technique has only been applied for barley and sorghum crops, it has the potential to be applicable for a multitude of crops.

CONCLUSION

Based on the findings of this study, 237.58 km^2, 14,492.57 km^2 and 2,208.87 km^2 of the study area are highly suitable (S1), moderately suitable (S2) and marginally suitable (S3) for sorghum crop production, respectively. On the other hand, the suitability map of barley crop shows that 649 km^2 of the investigated area are highly suitable (S1), 7,169 km^2 moderately suitable (S2), 9,171 km^2 marginally suitable (S3) and 122 km^2 unsuitable for economic reasons (N1). It was also found that land suitability analysis for agricultural crops using a GIS environment is a strong tool towards measuring and valuation of the long-term impacts of land suitability analysis on land productivity. However, the parameters used for land suitability analysis in this study were entirely physical; much improvement can be made if some socio-economic variables were considered. In addition, the land utilization types (LUTs) considered in this study were limited to two selected crops, whereas further studies can be made so as to increase the choice and identify the best alternative use of a specific landscape parcel for different LUTs by considering pulses, oilseeds, cash crops , and livestock management.

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