A GIS based land suitability assessment for agricultural planning in Kilte Awulaelo district, Ethiopia

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ABSTRACT

Land Suitability refers to the ability of a portion of land to tolerate the production of crops in a sustainable way. Such kind of analysis allows identifying the main limiting factors for the agricultural production and enables decision makers to develop crop managements able to increase the land productivity. Objectives of this study were to develop a GIS based approach for land use suitability assessment which will assist land managers and land use planners to identify areas with physical constraints for a range of nominated land uses. Also to help identify the management requirements that will ensure that a particular land use can be sustained without causing significant on-site or off-site degradation to land quality. Georeferenced Soil survey data and field work observations have been integrated in a GIS based land use suitability assessment for agricultural planning in Kilte Awulaelo District, Ethiopia. A suitability map for each land use was developed to illustrate these suitability degrees and display the spatial representation of soils suitable for agriculture. Results showed that land units which have no limitations cover about 7% of the study area. Total area of land units that are suitable for rainfed, irrigated agriculture and open vegetation growth is around 67% of the study area. The study showed also that GIS based approach is a useful tool in land suitability assessment for agricultural planning.

Key words: Land Suitability; agriculture planning, Cereals, GIS; Remote sensing; Ethiopia.

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INTRODUCTION

The land capability evaluation characterizes and appraises land development units from general point of view without taking in consideration the kind of its use. There are defined classes ranging from I to VIII (Landon, 1991). This classification is useful as some soils can be suitable for specific crops and unsuitable for another’s; therefore precision of land utilization types is necessary. It cloud be expressed not only in terms of types of crops productions, but also how this specific crops are produced (Sys et al., 1991). According to (Sys et al., 1991) the land use types have to be defined considering production (crops or crops rotations) and the factors influencing management, for example the size of farm, capital available, labour, farm power and technical knowhow. Land Suitability refers to the ability of a portion of land to tolerate the production of crops in a sustainable way. Its evaluation provides information on the constraints and opportunities for the use of the land and therefore guides decisions on optimal utilizations of the resources, whose knowledge is an
essential prerequisite for land use planning and development. Moreover, such a kind of analysis allows identifying the main limiting factors for the agricultural production and enables decisions makers such as land users, land use planners, and agricultural support services to develop a crop management able to overcome such constraints, increasing the productivity.

Cereals are strains of grasses that are cultivated and harvested for their grains; more than any other type of crops constitute the worldwide base for human nutrition. In Ethiopia, cereals, among which teff, barley, maize, sorghum, oats, millet and wheat, make up 85% and 90% of the total production of field crops and account for over 90% of input consumption (CSA, 2000). However, low productivity remains the major constraint of cereals cultivation, where yields are less than 1 ton per ha (Pender and Gebremedhin, 2006). In addition, during the last years cereals prices continued to decrease throughout the country since September 2008, especially for maize and sorghum. Among the typical Ethiopian cereals, teff is the most important in terms of area and production in the country (two million hectares of land annually) (Harrison, 2007). The grain is ground into flour, fermented and made into enjera (sour dough type) flat bread. Teff is eaten or used as an ingredient of home-brewed alcoholic drinks. Teff is also grown for livestock forage. In Ethiopia teff straw from threshed grains are considered to be excellent forage, superior to straws from other cereal species.

Objectives of this study were to develop a GIS based approach for land use suitability assessment which will assist land managers and land use planners to identify areas with physical constraints for a range of nominated land uses. Also to help identify the management requirements that will ensure that a particular land use can be sustained without causing significant on-site or off-site degradation to land quality.

MATEIALS AND METHODS

Study Area Description:

The study area (Figure 1), Kilte Awulaelo District in Tigray, is located between 36 degrees and 40 degrees east longitude. Its north-south extent spans 12 and half degrees to 15 degrees north. Tigray is located at the northern limit of the central highlands of Ethiopia. The landform is complex composed of highlands (in the range of 2300:3200 meters above sea level, (masl), lowland plains (with an altitude range of <500:1500 masl), mountain peaks (as high as 3935 masl) and high to moderate relief hills (1600:2200 masl). Tigray has diversified agro-ecological zones and niches each with distinct soil, geology, vegetation cover and other natural resources. The climate is generally sub-tropical with an extended dry period of nine to ten months and a maximum effective rainy season of 50 to 60 days. The rainfall pattern is predominantly uni-modal (June to early September) (United Nations Office for the Coordination of Humanitarian Affairs).

Figure 1-The study area
Morphologically, Kilte Awulaelo District is partitioned into four main land systems. The northern part of the district comprises the Negash batholite, the Negash hilly relief on metavolcanics and glacial bedrock, the Negash folds. In the Negash batholite, the prevalent lithologies are grey granite, granodiorite and quartz diorite. Generally the shape of this land system is circular. With regard to the Negash hilly relief, glacial white quartz sandstones and metavolcanic green schist with marble and quartzite characterised the parent materials. The Negash folds resulting from the tectonic activities in the region are essentially comprised for the lithology of metasedimentary pebbly slate, grey-green slate, black limestone, and dolomite. The central and southern parts of Kilte Awulaelo District are the domain of Mekele plateau, which occupies two-thirds of the study area. Many of studies have been done on the Tigray region (Rabia, 2012a, b, c). Among these studies, Regosols, Leptosols, Arenosols, Vertisols, Luvisols, Phaeozems, Cambisols and Calcisols were found to be the dominant soil types in the study area (Descheemaeker et al. 2005, Gebremichael et al. 2005, Gebrehiwot et al. 2005, Mintesinot et al. 2004 and Nyssen et al. 2004)

**Land Suitability assessment methodology:**

The methodology used for evaluation of land suitability based on FAO, 1976 (Figure 2). It consists in matching land characteristics against crop requirements and assigning a suitability rate for each land characteristic. The FAO approach defines Land Suitability as aptitude of a given type of land to support a defined use. The basic idea underlying the proposed method of land suitability classification is that the land should be rated only on its value for a specific purpose.

![Figure 2: FAO, 1976 methodology for land suitability evaluation.](image)

According to the classification proposed by (FAO, 1976), five different classes, ranging from "Unsuitable" to "Highly suitable", whose codes are constituted by a capital letter (indicating the order) and a number (indicating the class), identify the land suitability for a certain purpose (Table 1).
SUITABILITY CLASS | Suitability index (SI) | DESCRIPTION
---|---|---
Class S1: Highly suitable | >40 | Land having no limitations for a given use, or limitations that do not reduce appreciably the productivity and benefits, with no need for a high level of input
Class S2: Moderately suitable | 30-40 | Land having minor limitations that could reduce productivity or benefits, additive inputs are required to reach the same yield as that of class S1
Class S3: Marginally suitable | 20-30 | Land having moderate limitations for a certain use, in which the amount of surplus input is only marginally justified
Class N1: Currently unsuitable | 10-20 | Land with severe limitations for the land use under consideration. Every sustainable use is precluded at the present time and the costs for correction are unacceptable with the existing condition. Only new technologies could improve land productivity
Class N2: Permanently unsuitable | <10 | Land use type under analysis is not acceptable at all for the land

Table 1. Suitability indices for the different suitability classes.

The land suitability evaluation for the majors cereals founded in the study area has been done in order to define the land fitness for specific land uses and cultivations, but also to estimate the possible increase of crops production after improving land management. Barley, teff, wheat, and maize are the cereals considered in the suitability appreciation. The crop requirements are compared with landform attributes: depth, slope, surface coarse fragments, drainage, and with soil parameters such as texture, \( \text{CaCO}_3 \), EC, ph. Climate is a common factor for the six cereals (Sys *at al.*, 1991). The parameter’s values calculated provide the different suitability classes for each crop in each Land Unit. Seven parameters and rates have been assigned to each factor affecting the suitability for each crop. Thus, a suitability index (\( Si \)) has been developed as shown in the equation below:

\[
Si = \frac{A \times B \times C \times D \times E \times F \times G}{100 \times 100 \times 100 \times 100 \times 100 \times 100}
\]

Where:
- \( Si \): Suitability index;
- A: rating of soil texture;
- B: rating of soil depth;
- C: rating of \( \text{CaCO}_3 \) status;
- D: salinity/alkalinity rating;
- E: drainage rating;
- F: slope rating;
- G: rating of surface stoniness

RESULTS AND DISCUSSION

The land suitability for agriculture ranges from high suitable to permanently unsuitable. In case of heterogeneous Land Units, mixed suitability classes have been
assigned. For example, the mixed class S3N1 goes from marginally suitable to permanently unsuitable and represents the minimum condition category for cereals cultivation. Results showed that land units which have no limitations cover about 7% of the study area. Total area of land units that are suitable for rainfed, irrigated agriculture and open vegetation growth is around 67% of the study area. The most representative classes for the four cereals evaluated are N1N2 (currently unsuitable to permanently unsuitable) and N2 (permanently unsuitable), which in percentage cover more than 55% of the study area. The high suitable area (S1) presents, within the crops, an average cover of 4% of the total area in ha, where the lowest value is related to barley (1.3% of S1) and the highest to maize (6.1% of S1). From a general analysis, it is possible to assume that chemical and physical soil parameters such as the high surface coarse fragment coverage percentage and the high CaCO$_3$ values are, in association with the topology, the major constraints factors for good land suitability. Most of the unsuitable areas match with moderate to steep slopes or scarpes, where the soil is shallow and the texture is not helpful for water infiltration. 4% of the study area is classified as NR (not relevant) because it’s including the urban, water body, military camp surfaces.

**Teff**

Out of the total surface of Kilte Awulaelo district, the 3.6% of the land is high suitable for teff (Figure 3-A). Endemic cereal of Ethiopia, teff is considered also one of the most important traditional food plants of highlands (Harrison, 2007). It’s a drought resistant cereal grain crop, with an annual growth habit. The unsuitable lands for this cereal, represented by the class N2, N1, N1N2, like exemplify in the chart below (Figure 4-A), reach together the 64%. For teff, the slopes and the drainage have the major impact on the suitability in addition to other limiting factors.

**Wheat**

Despite its diffuse cultivation in the world, wheat appears to be less suitable to be cultivated in the district (Figure 3-B). In fact the classes: N2, N1, and N1N2, reach a percentage of about 65% of the total cover (Gavian and Degefa, 1995). The class S1 is limited to the flat fluvial deposit of Genefel River, and corresponds to 3% of the study area (Figure 4-B). In the central part of the district it’s possible to appreciate an area with marginally and high suitability (S3/S1), that has a relation with the type of soils, Vertisols and Calcisols, on colluvial deposits. Looking at the limiting factors it’s evident that the surface coarse fragments percentage is the most frequent constraint, but also the topography and the low values of organic carbon play an important role.

Figure 3: Land suitability map for A-Teff and B- Wheat

Figure 4: Land suitability classes percentages for A- Maize and B- Barley.
Maize
Maize suitability is distributed in different categories, S1 has for maize the highest value (6%) in distribution among the others cereals (Figure 5-A). This class has been found along the main fluvial and colluvial deposits (Seyoum et al, 1998). Also the moderately and marginally suitable classes characterize the lands in the central and northern part of the study area. The unsuitable lands, represented by the classes N1, N2, N1N2 are 70% of the Woreda (Figure 6-A). It’s interesting to notice that the Negash Synclirnirum shows almost uniform distribution of permanently unsuitable class N2 for the maize (but also for the other crops). This is in alternation with small longitudinal parts of class S1S2 in correspondence to the anticline gently sloping open depressions on colluvial deposits with irrigated annual crops on Cambisols. In the case of maize, like in other crops, the limiting factors are the combination of slope within the grades of escarps and moderate and steep, but also the combination of high percentage of coarse fragments and high levels of CaCO₃. The mixed category S1/N1, found in correspondence to the Land Unit 61. It is possible to infer that the secondary class comes from the good soil (Vertisols) in this part of the study area.

Barley
For barley the high suitability is 1.3% of the total land, and it is represented only in the south of the Woreda in the Land Unit 47 (Figure 5-B). This cereal has the highest percentage of unsuitable land compared to other crops (Lakew et al, 1997). In fact the N1, N2,N1N2 classes display the 80.5% of the cover (Figure 6-B). Even if ph, slopes and in some parts the depth, influence negatively the growth of the crop, the most important limiting factor is the high concentration of CaCO₃ in the soil.
Figure 5: Land suitability map for A- Maize and B- Barley.

Figure 6: Land suitability classes percentages for A- Maize and B- Barley.
CONCLUSION
Land suitability for agriculture is a very important piece of information for agriculture development and future planning. Based on that, a land suitability assessment for agriculture purpose has been conducted in order to help decision makers and agriculture development planners. The results showed variety in land suitability for different crops in the study area. Although, we can say in general that only 7% of the study area showed no limitations for agricultural crops while sum of 67% of the study area was suitable for rainfed, irrigated agriculture and open vegetation growth. Both the classes N1N2 (currently unsuitable to permanently unsuitable) and N2 (permanently unsuitable) were the most representative classes for the four cereals evaluated are, which in percentage cover more than 55% of the study area. Generally speaking, the main restricting factors for good land suitability in the study area were topology, high CaCO₃ and surface coarse fragment coverage percentage. Where, for teff cultivation, topology and draining were the limiting factors and for wheat were surface coarse fragments percentage; topography and low organic carbon were the limiting factors. Maize and Barley shared the negative impact of high CaCO₃ concentrations in the soil on land suitability. Barley growth was negatively influenced also by high pH, topography and in some parts the soil depth. GIS based approach cannot be overlooked in this study as a useful tool in land suitability assessment for agricultural planning.

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