GIS-based Agricultural Land Suitability for Target Crops

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Research Report

Ethiopian Institute of Agricultural Research
GIS-based Agricultural Land Suitability for Target Crops

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Introduction

The use of land is not only determined by the user, but also the land capabilities. The land capability is governed by the different land attributes such as the types of soil, which is critical for productivity, topography, hydrology, temperature. These attributes limit the extents of land available for various purposes. To get the maximum benefit out of the land, proper use is inevitable (FAO, 1985). Proper use of land depends on the suitability or capability of land for specific purposes. Careful planning of the use of land resources is based on land evaluation, which is the process of assessing the suitability of land for alternative land uses (Fresco et al., 1994). Its purpose is to select and put into practice those land uses that will best meet the needs of the people while safeguarding resources for the future (FAO, 1993).

Agricultural cropland suitability analysis requires range of datasets to determine land quality based on land attributes. Geographic Information Systems (GIS) techniques have become very useful tools in this respect and it can offer various opportunities to increase production, and manage the land in their care more efficiently (Aspinall et al., 1995). The use of GIS to incorporate the different land attributes that differ spatially to identify the best suitable land use in general and for crop suitability classification in particular has been increasing over the past decades (FAO, 1997).

In order to consider sustainable agricultural land use in Ethiopia, crop suitability analyses that incorporate the different land characteristics is very essential. With this, a GIS based suitability map of the whole country for each target crops were developed.

The crops considered in this study are those targeted by the Ethiopian Institute Agricultural Research (EIAR) for developing technologies through need-based research. These crops are finger millet, barely (malting and food), tef, maize (highland, lowland), chickpea, lentil, wheat (bread, durum), soya bean, groundnut, sesame, and chickpea. Most of these crops are the major staple food for many millions of people throughout the country and provide a valued source of income through local and international trade.
Materials and Methods

Study Sites

The study is conducted for the whole country, Ethiopia. Ethiopia occupies the interior of the Eastern Horn of Africa stretching between 3° N and 15° N latitude and 33° E and 48° E longitude, with a total area of 1.13 million km² (EMA 1988). At present, the country has a population of more than 79 million. The average population density in the country is about 34 persons/km², and ranges between eight and 95 persons/km² (EMA 1988). It is a country with great geographic diversity with its topographic features ranging from the highest peak at Ras Dashen (4,550 m above sea level) down to the Afar Depression (110 m below sea level).

The climatic condition of the country varies with the topography, and can be categorized as dry, tropical and temperate rainy climate types, with three sub-divisions each, making a total of nine principal climate types. Temperature varies from as high as 47 °C in the Afar Depression to as low as 10° C in the highlands. The southwestern parts of the country are the wettest, receiving the heaviest rainfall, i.e. mean annual rainfall (MAR) of about 1500 mm (-2800 mm) and with only two to four dry months per year. MAR decreases gradually towards the northeastern and eastern parts of the country. In the central and north-central parts, MAR is about 1100 mm, with some pockets receiving more than 2000 mm (Anonymous, 1988). The flora of Ethiopia is also diverse with about 7000 species of higher plants and about 12% endemic elements. Similarly, the country has about 240 mammal species and 845 bird species, of which 22 mammals and 24 birds are endemic to the country. It has the largest livestock populations in Africa.

Datasets

Different datasets to select land use requirements (LURs) were used to this agricultural land suitability analysis. Criteria were used to select LURs like availability of data with which to evaluate the corresponding land quality (LQ). In this study, 6 datasets were used for the analysis. They are temperature, Length of Growing Period (LGP), Soils, slope, land cover or forest boundary, and administrative boundary.
**Temperature**
The mean temperature was used for this analysis. The mean temperature during the growing period is described in terms of Thermal zone, which are mainly based on a correlation between altitude and temperature.

**Length of Growing period**
LGP generally refers to the cumulative time in normal year when moisture conditions are adequate for plant growth. FAO define LGP as the number of days per year that sufficient water is available in the soil profile to support plant growth. Here, LGP is based on the number of days with a mean daily temperature above 5°C and with available water (from precipitation or stored soil moisture) in excess of half the potential evapotranspiration. LGP captures multiple factors (rainfall, potential evapotranspiration, and soil moisture storing properties) that together define the most important dimension of agricultural potential. Thus, a longer LGP generally indicates higher agricultural potential. LGP classes were used in this analysis even if the existing LGP generated for the country shows a broad class ranges.

**Slope**
Slope is a measure of terrain steepness that is, the degree to which land is not horizontal. Slope affects the agricultural suitability of different areas: steep slopes are more difficult to cultivate and more likely to lose soil and nutrients through erosion. Slope is measured as percentage rise. A slope of zero indicates flat ground, while a slope of 100 percent is equivalent to 45-degree angle. With this, slope angle in percent were used for the analysis.

**Soil**
Together with climate and terrain, soil conditions determine what agricultural production possibilities exist in a given biophysical perspective. Soil types of the existing digital data with 1:1,000,000 scales were used as a criterion for generating soil suitability for the target crop.

**Administrative boundary data**
This data set is used to set the boundary so that to map crop suitability regional or zonal base.
Other data sets
These data set includes; protection areas (forest priority area, national parks); and water bodies (lakes). These data sets were used to filter out those areas from analysis.

Data sources
Effort was made to collect all available information that serve the above-mentioned objectives from different governmental offices and based on reliability of data time of production and further possibility of updating / modifying only selected few were found worth of consideration.

The environmental requirements of the target crops was taken from the findings of Land Use Planning and Regulatory Department (LUP&RD) as set by Food and Agriculture Organization of the United Nations (FAO) whilst the land characteristics of the country is derived from the digital output of Ethiopian development research Institute (EDRI).

Materials used
Digital images of: Soil, temperature and precipitation covering the whole country and a hard copy that depict the crop environmental requirement were used to conduct the study. The tools used were computer with high processing speed. GIS software; ArcGIS, and ArcView were used for the analysis and mapping.
Methodology

Data Preparation

After all the necessary data collected, the data were prepared for the analyses. This includes checking the datum/projection, the file type; and even converting some data to the format to be used before it is subjected for analysis.

Analysis of Area Suitability

The spatial data are analyzed to generate suitability for crop planting for the whole country. The suitability is divided into two levels: highly suitable area and moderately suitable to marginally suitable area. Crop Suitability is generated first by extracting suitability of each environmental requirement for each target crop. Then, all the environmental requirements for each target crops are analyzed to generate suitable agricultural cropland. The simplified overall procedure is illustrated in Figure 1. The steps are including:

- Analyze soil series of an area and soil type suitability for each crop was generated;
- Slope suitability is generated for each target crop;
- Analyze the temperature suitability of the area for each crop;
- Analyze Length of growing period (LGP) for each crop. The levels of LGP suitability are determined based on different requirements of each crop.
- Analyze to refine the present land use, example national parks, protected areas and lakes filtered out to improve the level of suitability for agricultural crop production; and
- The suitability information’s of each factor necessary for crop planting are then analyzed by overlaying technique to generate crop suitability class of each.
Figure 1. Simplified methodology flow chart
Results and Discussion

Land Suitability may be defined as the fitness of a given type of land for a specified kind of land use (FAO, 1985). Based on the suitability analysis, suitable areas for the production of each target crops were determined. The suitability analyses were based on soil type, slope, temperature, and length of growing period (LGP). Suitability class categories were considered as highly suitable to medium to marginally suitable. This will enable to rapid identification of locations of each target crops for national planning. The results of this land suitability analysis for each crop are shown in figure 2-9 with suitability maps.

Tef

Tef is cultivated with quite wide range of crops in mixture. It is chief stable food of most Ethiopian population.

The highly suitable areas identified in Ethiopia include; the Becho plain (south-eastern west Shewa just to south west of Addis Ababa in the upper catchment area of Awash), Akaki-Debre Zeit a continuation to Becho plain, Selale west central Shewa, Upper Gibe Valley, Arsi highland to west of Chilalo plain, Agew Awi, south west of Alaba, south west of Amaro, around Bahir, Bale, Bench Maji, Borena, south west of Burji, Central Tigray, Dawro, south west of Derashe, Dire Dawa, east Gojam, east Hararge, east Shewa, east Tigray, east Wellega, Gamo Gofa, Gedeo, Godere, Guji, Gurage, Hadiya, Illubabor, Jijiga, Jimma, Kefta, south west of Konso, Liben, Metekel, North Shewa, some parts of North Wello, Oromiya, South Gonder, South Tigray, South Wello, south west of Shewa, Sheka, Shinile, Sidama, South Omo, south west of Tongo, west Gojam, west Hamer, West Hararge, west Tigray, west Wellega, Welaita, and west Shewa.

However, very extensive cover of the country which includes most of highlands and high to low plateaus are moderately to marginally suitable. These include; Afder, Bale, Borena, Degehabur, Dire Dawa, East Hararge, East Shewa, East Tigray, Guji, Korahe, South Tigray, Shinile, West Hararge, Warder, and Afar. The prepared tef suitability map is presented in Figure 2.
Wheat cultivation is known practice locally. It is produced over wide thermal ranges of highland Ethiopia. Bread wheat and durum wheat share similar environments.

North central west Shewa, Selale to north Mugger Valley, south slope of west Hararge plateau, upper Wabe catchment between Arsi and bale, west Shewa, Sheka, Shinile, south Omo, south west of Tongo, west Gojam, west Hararge, west Tigray, west Wellega, Welayita, west Shewa, Agew Awi, south west of Alaba, south west of Amaro, Bale, Bench Maji, Borena, south west of Burji, central Tigray, Dawro, south west of Derashe, Dire Dawa, east Gojam, east Hararge, east Shewa, east Shewa, west Wellega, Gamo Gofa, Gedeo, Godere, Guji, Gurage, Hadiya, Hadiya, Illubabor, Jijiga, Jimma, Kamashi, Keffa, Konso Liben, Metekel, North Gonder, North Shewa, North Wello, Oromiya, South Gonder, South Tigray, and South Wello are highly suitable.
Extensive highland and others areas of the country which include Shewa highland plateau, Wellega highland, Bale, central Tigray, East Hararge, east Tigray, Guji, Jimma, Mekelle, South Tigray, West Shewa, are moderately suitable. The prepared tef crop suitability map is presented in Figure 3.

![Ethiopia: Bread/Drum Wheat Suitability Map](image)

**Figure 3. Bread wheat/Durum wheat Suitability Map of Ethiopia**

**Malt Barley**

Food barely is usually used for traditional brewery. However, modern brewery requires malting barley and its production is being encouraged by the government demand for growing parallel with the rate brewery industrial growth.

Gedeo, Guji, Gurage, Hadiya, Jijiga, Mekelle, north Gonder, north Shewa, north Wello, south Gonder, south Tigray, south Wello, south Shewa, Shinile, Sidama, South Omo, west Gojam, west Hararge, west Tigray, Agew Awi, south western Amaro, Arsi, Bale, Borena, central...
Tigray, central Tigray, south western Derashe, Dire Dawa, east Gojam, east Hararge, east Shewa, east. Tigray, east Wellega, Gamo Gofa, Welaita, and west Shewa are highly suitable areas

On the other hand; east Wellega, Gurage, Jijiga, Kamashi, Liben, Metekel, north Gonder, north Shewa, north Wello, Oromiya, south Gonder, south Tigray, south Wello, south west Shewa, Shinile, Agew Awi, south west of Alaba, Arsi, Bale, Borena, centeral Tigray, Dire Dawa, east Gojam, east Hararge, east Shewa, west Gojam, west Hararge, west Tigray are moderately to marginally Suitable. The prepared Malting barley suitability map is presented in Figure 4.

**Figure 4. Malting barley suitability map of Ethiopia**

**Food Barely**

Food barely is one of the important traditional crops f highlands Ethiopia. It is produced in mix with other wide varieties of crops. Southwestern Arsi, East Shewa, East Wellega, Gamo Gofa, Gedeo, Guji, Gurage, Hadiya, Metekel, North Gonder, North Shewa, North Wello, South Gonder, South Tigray, Southwest Shewa, Silte, Shinile, Sidama, South
Omo, West Gojam, Awi, Amaro, Arsi, Bale, Borena, Southwest of Burji, Central Tigray, southwest of Derashe, Dire Dawa, East Gojam, East Hararge, West Hararge, west Tigray, Welaita, West, Shewa are highly suitable for food barely.

On the other hand; Arsi, Bench Maji, central Tigray, east Gojam, east Hararge, East Shewa, East Tigray, East Wellega, Gamo Gofa, Gedeo, Gurage, Hadiya, Jimma, Keffa, Mekelle, north Gonder, North Shewa, South Tigray, Southwest Shewa, Sheka, Sidama, West Gojam, West Shewa, Zone of Afar are moderately to marginally Suitable(Figure 5).

Figure 5. Food barely suitability map of Ethiopia

Highland Maize

Highland maize is some of the traditionally produced important crops in the country.

Jimma, Kamashi, Keffa, south west Konso, Liben, Metekel, north Gonder, north Shewa, north Wello, Oromiya, south Gonder, south
Tigray, south Wello, south west Shewa, Silte, Sheka, Shinile, Sidama, South Omo, Tongo southwest, West Gojam, West Hararge, West Tigray, west Wellega, Welaita, Afder, Agew Awi, southwest Hlaba Arsi, Asosa, Bahir Dar, Bale, Bench Maji, Borena, southwest Burji, central Tigray, Dawro, Derashe, Dire Dawa, East Gojam, East Hararge, East Shewa, East Wellega, Gamo Gofa, Gedeo, Godere, Gurage, Hadiya, Illubabor, Jijiga, West Shewa are highly suitable areas.

South Tigray, Southwest Shewa, Sheka, Shinile, Sidama, South Omo, West Gojam, West Hararge, west Tigray, Awi, southwest Amaro, Arsi, Bale, Bench Maji, Borena, southwest Burji, Dawro, Dire Dawa, East Gojam, East Hararge, East Shewa, Gamo Gofa, Gedeo, Guji, Gurage, Hadiya, Jijiga, Jimma, Keffa, southwest Konso, Metekel, North Gonder, North Shewa, North Wello, South Gonder, Welaita, West Shewa are moderately to marginally suitable (Figure 6).

Figure 6. Highland Maize suitability map of Ethiopia
Lowland maize

Suitable areas are North Gonder, North Shewa, North Wello, Oromiya, South Gonder, South Tigray, South Wello, Shinile, Sidama, South Omo, West Gojam, West Hararge, West Tigray, West Wellega, Awi, Arsi, Bahir Dar, Bale, southwest Basketo, Bench Maji, Borena, southwest Burji, central Tigray, southwest Derashe, East Gojam, East Hararge, East Shewa, East Wellega, Gamo Gofa, Hadiya, Harar/Hundene, Jijiga, Kamashi, Keffa, southwest Konso, Liben, Metekel, Welaita, West Shewa.

Dire Dawa, East Gojam, East Hararge, East Shewa, East Tigray East Wellega, Gamo Gofa, Godere, Guji, Gurage, Hadiya, Harar/Hundene, Illubabor, Jijiga, Jimma, Kamashi, Keffa, southwest Konso, Metekel, North Gonder, North Shewa, North Wello, South Gonder, South Tigray, South Wello, South west Shewa, Sidama, South Omo, Afder, Awi, Arsi, Asosa, Bale, Bench Maji, Borena, Borena, central Tigray, Dawro, Degehabur, southwest Derashe, southwest Tongo, West Gojam, West Hararge, west Tigray, West Wellega, Welaita, West Shewa, are moderately to marginally (Figure 7).

Figure 7. Lowland Maize suitability map of Ethiopia
Soybean

Soybean is a lowland pulse grown to supply baby food and oil industries. In comparison to other crops, areas suitable for this crop are limited.

Areas of Illubabor, Jijiga, Kamashi, Konso, Liben, Metekel, North Gonder, North Shewa, North Wello, Oromiya, South Gonder, South Tigray, South Wello, Shinile, Sidama, South Omo, West Gojam, Agew Awi, southwest Amaro, Arsi, Bale, Bench Maji, Borena, southwest Burji, central Tigray, Degehabur, East Gojam, East Hararge, East Shewa, East Wellega, Gamo Gofa, Gamo Gofa, Guji, Harar/Hundene West Hararge, west Tigray, West Wellega, Welaita are highly suitable areas.

Arsi, Asosa, Bale, Bench Maji, Borena, Dawro, east Gojam, east Hararge, east, Wellega, east Wellega, east Wellega, Gamo Gofa, Godere, Hadiya, Illubabor, Jimma, Jimma, Kamashi, Kamashi, south Konso, Metekel, North Gonder, Sidama, South Omo, West Gojam, west Tigray, West Wellega, Welaita, west Shewa are moderately to marginally suitable (Figure 8).

Figure 8. Soybean suitability map of Ethiopia
Groundnut and Sesame

Both groundnut and sesame are important lowland oil crops grown in hot dry areas of the country. Sesame is more widely produced as compared to groundnut. Groundnut and sesame share similar environments. Suitable areas are; Afder, Asosa, Bale, southwest of Basketo, Bench Maji, Borena, southwest Burji central Tigray, Derashe, East Shewa, Gamo Gofa, Keffa, south west Konso, Liben, Metekel, North Gonder, North Shewa, Shinile, South Omo, southwest Tongo, West Hararge, west Tigray, West Wellega, East Shewa, East Tigray, East Wellega, Gamo Gofa, Gedeo, Godere, Gurage, Hadiya, Harar/Hundene, Illubabor, Jijiga, Jimma, Keffa, south Konso, Liben, Metekel, North Gonder, North Shewa, Awi, southwest of Amaro, Arsi, Asosa, Bahir Dar, Bale, Bench Maji, Borena, central Tigray, Dawro, Degehabur, southwest Derashe, East Gojam, East Hararge, North Wello, Oromiya, South Gonder, South Tigray are moderately to marginally Suitable (Figure 9).

Figure 9. Groundnut/ Sesame suitability map of Ethiopia
Chickpea and Lentil

Kamashi, Keffà, southwest Konso, Liben, Metekel, North Gonder, North Shewa, North Wello, Oromiya, South Gonder, South Tigray, South Wello, Southwest Shewa, Sheka, Shinile, Sidama, southwest Tongo, West Hararge, west Tigray, West Wellega, Welaita, Agew Awi, south west Alaba, south west Amaro, Arsi, Asosa, Bahir Dar, Bale, Bench Maji, Borena, central Tigray, Dawro, southwest Derashe, Dire Dawa, East Gojam, East Hararge, East Shewa, East Wellega, Gamo Gofa, Gedeo, Godere, Guji, Gurage, Hadiya, Harar/Hundene, Illubabor, Jijiga, Jimma, and West Shewa are Highly Suitable Areas. South Tigray, West Shewa, and Zone two of Afar are moderately to marginally Suitable(Figure 10).

Figure 10. Chick pea/Lentil suitability map of Ethiopia
Finger Millet

North Shewa, North Wello, Oromiya, South Gonder, South Tigray, South Wello, Shinile, Sidama, West Gojam, West Hararge, west Tigray, West Wellega, Welaita, West Shewa are highly suitable areas,

Harar/Hundene, Jijiga, Jimma, Keffa, Konso Metekel, North Gonder, North Shewa, North Wello, Oromiya, South Gonder, Afder, Awi, Amaro Southwest, Arsi, Asosa, Bale, Bench Maji, Borena, central Tigray, Dire Dawa, East Gojam, East Hararge, East Shewa, East Wellega, Gamo Gofa, Gedeo, Guji, Gurage, Hadiya, South Tigray, Southwest Shewa, Shinile, Sidama, South Omo, West Gojam, West Hararge, west Tigray, West Wellega, Welaita, West Shewa are moderately to marginally suitable(Figure 11).

Figure 11. Finger Millet suitability map of Ethiopia
Potentials and Constraints

This study used available spatial information for the identification of suitable agricultural areas for each target crop in the whole country.

The results of crop suitability analysis have ample potentials, which can be used for broad-scale land use planning that can give a generalized view of the area most suited to the target crop, to have effective decision-making tool for selection of commodity production, to reduce production cost, to increase income, and to reduce market risk and to select areas for more detailed survey and evaluation. In addition, the consumer will obtain high quality of agricultural products as well as stability in price, quantity, and market release.

Despite the potentials, the present suitability analyses have constraints. The analyses were based on datasets having broad scale (1:2000000). Hence having rugged topography in Ethiopia, some areas that could be suitable to the target crops may be lumped together as non-suitable area and vice versa. Therefore, users of this output should take care of using planning. However, it can be used for general overview of the suitability pattern at national level planning.
Conclusions and Recommendations

Conclusions

Proper use of land depends on the suitability or capability of land for specific purposes. Geographic Information Systems (GIS) techniques have become very useful techniques in this respect and it can offer various opportunities to manage the land in their care more efficiently. In order to consider sustainable agricultural land use in Ethiopia, GIS based suitability map of the whole country for each target crops were developed and it is revealed that this GIS based approach is the best in identifying agricultural land to be considered for target crop production. Through the analysis, the suitable areas for each target crops were identified. The results can be used for broad scale land use planning, as a basis for assessing priorities and selecting areas for detailed survey and evaluation. Depending on the available additional spatial data, the accuracy and reliability of the result could be high.

Recommendations

This study underlines the fact that, GIS techniques can offer range of possibilities to assist role of the Ethiopian agricultural research and development fueling the Ethiopian economy in a sustainable way. The following crucial factors need serious attention.

- The basis for the present analysis was secondary datasets. This limited to the choice of parameters in terms of number as well as scale relevant to the target crop production. Therefore, it is recommended to use additional parameters whenever it is available in order to refine the present output.
- Since there was no national digital information regarding to diseases and pest of the country, it was not handled in this analysis. It is advisable to this aspect for the sustainable production of the targeted crop.
- Since this agricultural land suitability classification is only validated using expert knowledge, it should also be confirmed under field condition using data collection/ field observation.
- After the result is validated and by considering other additional datasets it is advisable to build biophysical and social spatial database that influence decision making processes in crop production.
References

EMA.
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