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GIS Based Land-Use Suitability Analysis for Selected Perennial Crops in Gumay Woreda of Jimma Zone, South West Ethiopia

Girma Alemu[1] and Kenate Worku[2]

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Abstract

This study was aimed at identifying the current physical land suitability for selected perennial crops in Gumay woreda of Jimma zone, Southwest Ethiopia. Relevant land quality (LQ) and land characteristics (LCs) data like climate, topography and soil has been utilized for land suitability analysis. Consequently, through the querying analysis, the suitability rating process was run for individual LCs and based on the maximum limitation method. The overall suitability was assigned for specific land mapping units with the integration of ArcGIS10.3. Accordingly, the results showed that out of the 40976ha, 23% of the land was highly suitable (S1); 21% moderately suitable (S2); 47% marginally suitable and only 9% of the land was not appropriate (N) for guava production. Similarly, 47% of the land was highly suitable, 27% moderately suitable, 6% marginally suitable and 20% was not appropriate for mango growing. On the other hand, only 1% of the area was highly suitable, 6% was marginally suitable and the remaining 93% of the land were not suitable for growing avocado. Overall, more of the twenty LMUs fall under highly, moderately and marginally suitable class for guava and mango production and the reverse is true for avocado; 93% was not suitable and based on the individual LCs, slope status (which is not assigned as S1) was found to be the most severe limiting factor. So, based on the analysis, guava and mango cultivation is better suited in the area whereas cultivation of avocado is not, because it needs more treatments.

Key words*: /Ethiopia/ GIS/Gumay/ Land-Use Suitability/Perennial Crops/*

[1] PhD candidate, lecturer at the Dep. of Geography and Environmental Studies, Jimma University, Ethiopia. Contact: e-mail: girmaalemu83@gmail.com
[2] PhD, assistant professor of Urban and Regional Geography at the Dep. of Geography and Environmental Studies, Jimma University, Ethiopia. Contact: e-mail: keneni2009@gmail.com

1. Introduction

1.1. Background

Land comprises the physical environment including climate, relief, soils, hydrology and vegetation, to the extent that these influence potential for land use. It includes the results of past and present human activity (FAO, 1976). So, Land needs careful and appropriate use that is vital to achieve optimum productivity and to ensure environmental sustainability for future generation. This requires an effective and operative management of land information on which such decisions should be based, because land is one of the non-renewable natural resource (Kalogirous, 2002).

Land evaluation is concerned with the assessment and valuation of land when used for specified purposes (Sys *et al*., 1991). It involves the execution and interpretation of basic surveys of data on climate, soils, vegetation and other aspects of land in terms of the requirements of alternative forms of land use. According to FAO (1976), land suitability is the fitness of a given type of land for a defined use. The land may be considered in its present condition or after improvements. The process of land suitability classification is the appraisal and grouping of specific areas of land in terms of their suitability for defined uses. So, suitability is a function of crop requirements and land characteristics and it is a measure of how well the qualities of land unit match the requirements of a particular form of land use. Suitability analysis can answer the question (what to grow where?). In order to define the suitability of an area for a specific practice, several criteria need to be evaluated (Belka, 2005).

Inappropriate land use leads to inefficient exploitation of natural resources, destruction of the land resource, poverty and other social problems. Society must ensure that land is not degraded and that it is used according to its capacity to satisfy human needs for present and future generations while also maintaining the earth's ecosystems. Part of the solution to the land-use problem is land evaluation in support of rational land-use planning and appropriate and sustainable use of natural and human resources (Rossiter, 1996). The evaluation process, therefore, provides information on the major constraints and opportunities for the use of land for particular use type which will guide decision makers on how resources are optimally utilized.

1.2. Statement of the Problem

The problem of selecting the correct land for cultivation of a certain agricultural product is a long standing and mainly empirical issue(Pirbalouti *et al.*, 2011). Although many reserchers and institutions have tried to provide a framework for optimal agricultural land use, it is sespected that much agricultural land used currentlly is below its opitimal capacity in defernet part of the world. The classification of land into different capability classes is useful in some soil, climate, topographic and other attributes of land that can be suitable for specific crops and unsuitable for others; therefore, precision of land utilization types is necessary.

Even though the issue of agricultural productivity and food security is widely studied in different part of the world, the impact of unwise use of land resource and absence of utilization of the land according to its potential suitability is still a serious problem particularly in developing countries. Study conducted in northern Ethiopia by Ahmed (2012) on land suitability assessment for agricultural planning demonstrated that land use suitability analysis using GIS tool allows identification of the main limiting factors for agricultural production. Ethiopia in general and southwestern Ethiopia in particular currently face various problems resulted from unwise use of land resource while the degree of the problem is not clearly identified. As a result, still there is lack of information on the status and classification of land use suitability in southwest Ethiopia particularly in the targeted area. Accordingly, this study was started to classify the land of Gumay district based on their suitability for maintainable use.

1.3. Objectives

The overall objective of this study was to evaluate and develop GIS based map for physical land-use suitability for selected perennial crops in Gumay Woreda of Jimma Zone, Southwestern Ethiopia using GIS techniques. More specifically, the study intended to achieve the following objectives:

1. To identify the types of perennial crops those are more suitable and productive in the study area.
2. To identify areas with physical constraints and the maximum limiting factors for fruit trees land use suitability in Gumay district.
3. To develop perennial crops land use suitability map and to recommend the possible management requirements for better land use suitability for the study area.

1.4. Significance of the Study

Ethiopia currently faces various problems resulted from unwise use of land resource even though the degree of the problem is not clearly identified. Therefore, evaluating land suitability for comparable crops in the study area is very important for selecting optimum land use types which will bring sustainable agricultural production. Moreover, it allows in identifying the main limiting factors for agricultural production and enables stakeholders such as land users, land use planners, and agriculturalists to develop crop management, to be able to overcome such constraints and to increase productivity. Concurrently, it ensures food security which is one of the national issues that still attracts researchers and police makers in the field of sustainable land use planning and ensures production that does not compromise the needs of the coming generation. In light of the situation and profile of the study area, very little was done on land-use suitability. Thus, this study could be used as a benchmark for further studies particularly for the targeted area. So, this study would have a notable piece of work which clearly depicts the prevailing situation.

2. Review of Related Literature

2.1. Concept and Definition of Land Use Suitability

Land suitability has been defined by different scholars and most of the definitions adhere to the definition given by FAO (1976): "the fitness of a given type of land for a specified kind of land use". According to Ritung *et al.* (2007), land suitability is the degree of appropriateness of the land for a certain use. It could be assessed for present condition (actual land suitability) or after improvement (potential land suitability). Land suitability has often been confused or even regarded as synonymous with land capability. However, land capability stands for a much broader use such as agriculture, grazing, or urban development (Verheye, 1992). Capability is viewed by some as the inherent capacity of land to perform at a given level for a general use, while suitability as a statement of the adaptability of a given area for a specific kind of land use.

In land use suitability analysis, the land may be considered in its present condition or after improvements. Land use suitability analysis is the process of determining the suitability of a given land area for a certain type of use and the level of suitability. An important part of this process is the determination of the criteria that affect the suitability of the land (Al-Shalabi *et al.,* 2006). The process of land suitability classification is the appraisal and grouping of specific areas of land in terms of their suitability for defined uses. Land use suitability is also confused with land evaluation which refers to the process of assessing the performance of land when used for a given purpose. Therefore, the concept of land suitability is different from the other two but there is a close interdependence among the three in assessing efficient way of utilization of land for sustainable development.

2.2. GIS and Land Use Suitability Analysis

Geographic Information Systems (GIS) is a powerful tool for collecting, storing, retrieving, transforming and displaying spatial data from the real world (Burrough, 1986). It is a useful technique to investigate multiple geospatial data with precision and higher flexibility in land suitability analysis (Mokarram & Aminzadeh, 2010). GIS have been used for the site-selection of areas such as service facilities, recreational activities, retail outlets, hazardous waste disposal sites and critical areas for specific resource management and control practices (Jankowski, 1995). GIS have been widely recognized as the most promising tool capable of providing reliable information for both planning and decision-making tasks (Michalak, 1993). Expert systems and GIS technologies are combined to help with an implementation of a land suitability evaluation model (Kalogirou, 2002). Suitability analysis in a GIS context is geographic and GIS-based analysis process is important to determine the appropriateness of a given area for a particular use.

Various studies witness that GIS-based land-use suitability analysis has been applied in a wide variety of situations including ecological approaches for defining land suitability/habitant for animal and plant species, suitability of land for agricultural activities (Cambell *et al*., 1992; Kalogirou, 2002), and many others. The basic premise of GIS suitability analysis is that each aspect of the landscape has distinctive characteristics that are to some degree either suitable or unsuitable for the activities being planned. Suitability is determined through systematic, multi-factor analysis of the different aspect of the terrain (Murphy, 2005).

2.3. Empirical Literature on Land Suitability Analysis

Land has been considered as an important natural resource that provides basis of life to both flora and fauna (Giriraj *et al*., 2008). Land suitability for agriculture is a very important piece of information for agricultural development and future planning. Land suitability analysis (LSA) is used to measure the degree of land usefulness for current and potential land use based on socio-economic and natural attributes (FAO, 1976; Hopkins, 1977; Malczewski, 2004). The capability of GIS and remote sensing in land use suitability analysis has been demonstrated in many parts of the world where various crops especially perennial crops like guava, olive and date palm in Egypt (Shalaby , Ouma & Tateishi, 2006); land suitability assessment using GIS in combination with other technologies for fruit trees in Thuy Bang community of Taiwan (Chuong, 2011). Land suitability evaluation for cash and perennial crops in East Amhara Region of Ethiopia (Gizachew, 2014), and a GIS based physical land suitability evaluation for crop production in Eastern Ethiopia (Rediet, Awdenegest and Quraishi, 2015).

3. Materials and Methods

3.1. Description of the Study Area

Location and Topography: Gumay woreda is located in Jimma zone of Oromia region, which is found in the southwestern part of Ethiopia, between $7^o 50'$ N-$8^o 5'$ N and $36^o 15'$ E-$36^o 40'$ E (Fig. 1). It covers an area of 40976 ha and is about 416 kms far from the national capital, Addis Ababa. Its average altitude approximately ranges between 1800-2000 meters above mean sea level. Gumay woreda is characterized by undulating topography with isolated mountains, hills, plateaus, and plains. The drainage pattern of the selected district is dendrite in nature with medium to high drainage density.

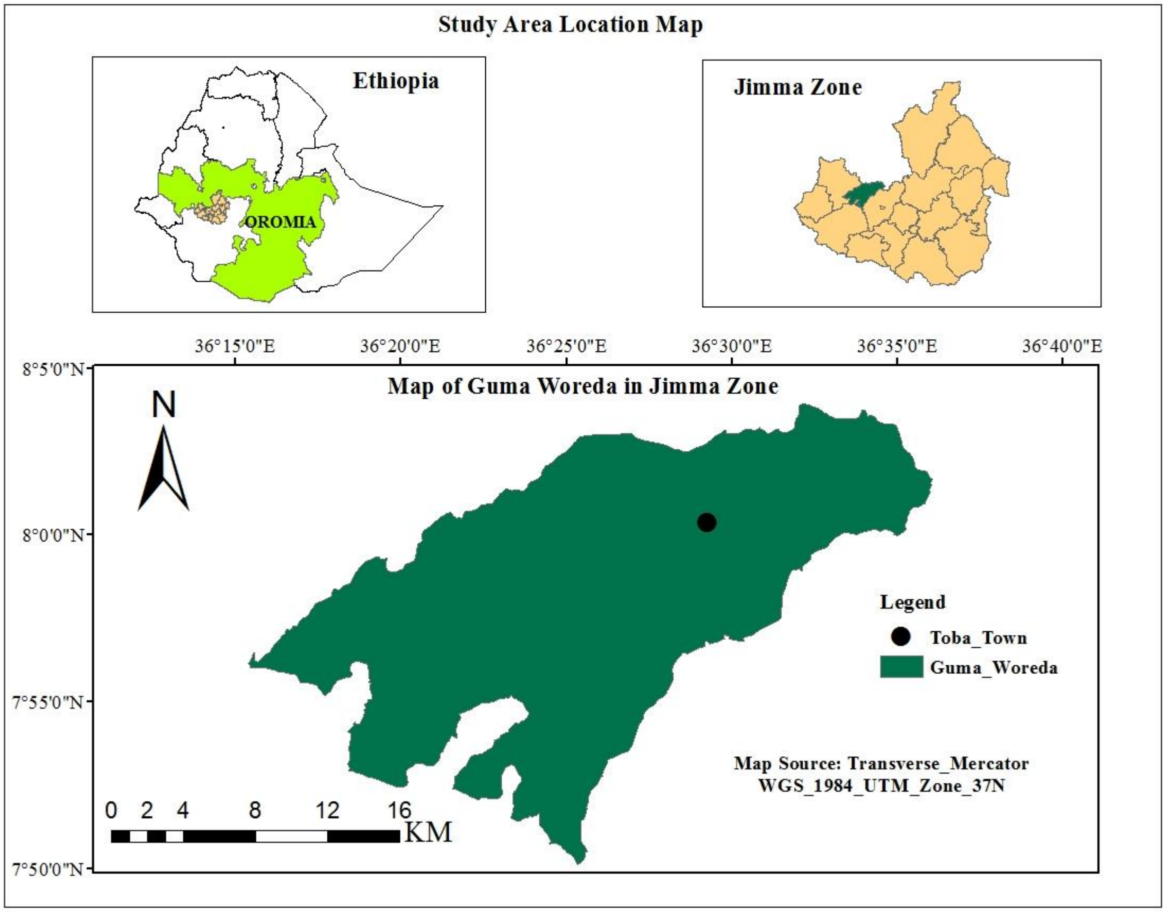

Fig1: Location map of study area

Climate and Vegetation: The climate of the study area is characterized by moderate climate condition; the mean annual temperature of Gumay woreda varies between 15^{o}c-22.5^{o}c (Fig. 2) and the rain fall varies between 1500-2000 mm (Fig. 2). In terms of vegetation, the study area is endowed with moist evergreen forest; which is characterized by tall emergent and medium- sized trees. (Central Agricultural Census Commission [CACC], 2003).

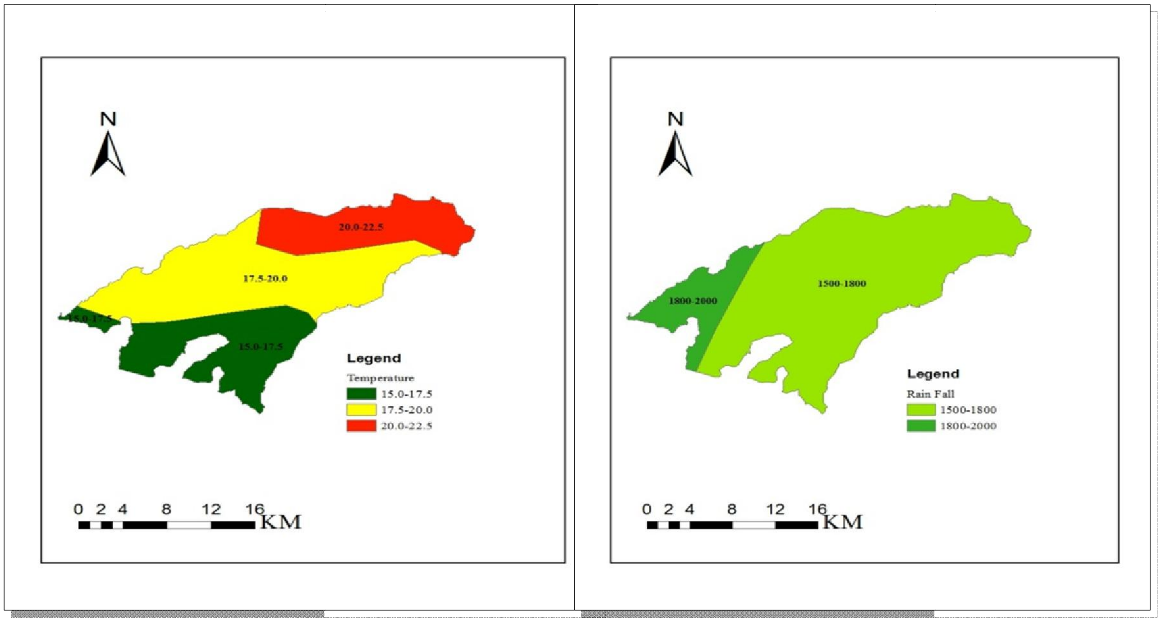

Fig 2: Temperature and rainfall distribution map

Soil: Soil types are associated with parent materials and are outcomes of the past geological phenomena. Cambisols, Nitososls, Lithosols, Acrisols, and Vertisols are the dominant soil types in the study area (Fig. 3).

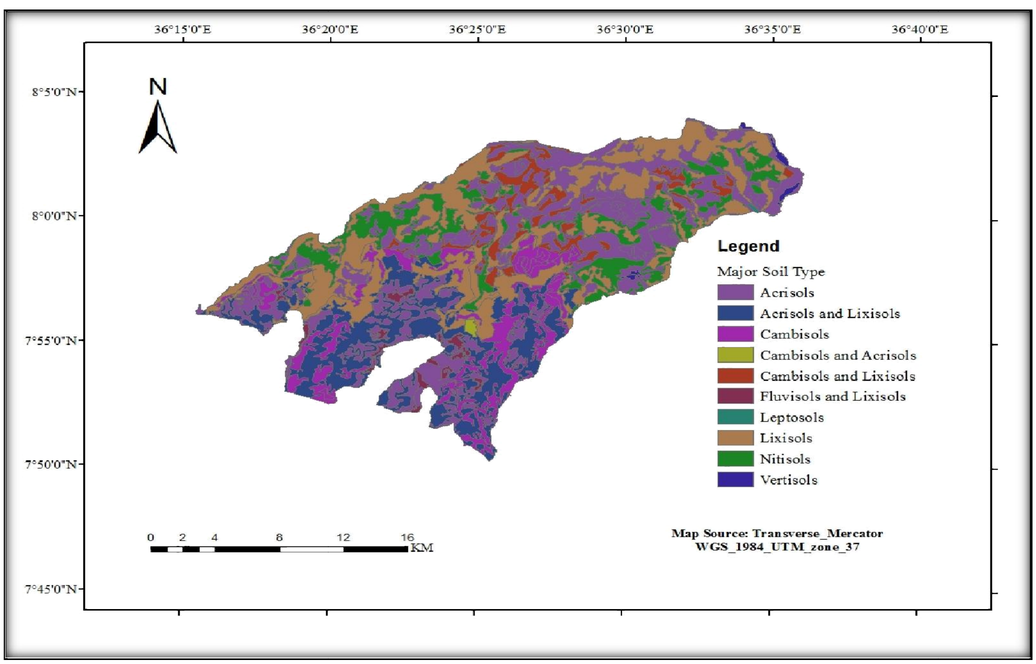

Fig 3: Soil map of the study area

Socio-economic characteristics: The dominant activity of the study area is agriculture. The farming system is one of the typical smallholders and subsistence rain fed-based agricultural activities. The smallholder farmers cultivate a varieties of crops (maize, and Sorghum), cash crops (coffee and Chat), fruits (banana, orange, mango, and guava), and vegetation. The area is well known by cash crop particularly coffee and its moist evergreen forest. In the area cattle, sheep, goat, poultry are the livestock types kept by the smallholder farmers. Crop production and livestock rearing are equally important activities in the study area (Central Agricultural Census Commission [CACC], 2003).

3.2. Data Sources and Type

The materials used to investigate land-use suitability analysis for selected perennial crops in study area were: ArcGIS10.3 Software, Aster DEM, Meteorological data, land use/ land cover, soil, climate and topographic data. The main sources of the data were both primary and secondary sources.

Accordingly, the primary data for this study was the SRTM (Shuttle Radar Topography Mission) DEM. DEM is a grid of cells in some coordinate system having land surface elevation as the value stored in each cell. DEMs are derived from elevation samples collected at varying spatial units or cell sizes. Thus, DEMs have varied spatial resolution based on their sampling levels. Simultaneously, different secondary source of data were employed to derive the required information for the study. These includes pertinent documents like available recorded documents, previous literatures, and review of relevant published and unpublished documents, journals, and reports which are written on the subject under investigation have been taken and included for the study.

3.3. Data Analysis

To analyze the data, the study has employed different methods and applications of ArcGIS10.3. The boundary was classified into relatively homogeneous units and land units, based on major soil types. The land unit map was used as a guide to collect other attributes (Land characteristics) of each mapping unit. The land evaluation was based on climate (Temperature & Rainfall), Topography (Slope), and soil conditions. The soil characteristics included drainage, soil texture, soil depth and Soil reaction (PH). So, based on all the available data and crop requirements, the index for each crop was calculated and analyzed.

a. Suitability weighting for each perennial crop

To have the same standard, all land characteristic values of each mapping unit were given a standard weight using the weighting. Then the suitability index was calculated for each land unit of each perennial crop using the formula shown below.

$$\mathrm{SI} = A * \frac{B}{100} * \frac{\mathrm{C}}{100} * \frac{\mathrm{D}}{100} * \frac{\mathrm{E}}{100}$$

Where A= Soil Texture rating,
B= Slope gradient rating
C= Soil Drainage rating
D= Soil depth rating
E= PH rating
SI=Suitability Index

Accordingly, based on the value of the suitability index, the suitability classes were generated for each land mapping unit of each perennial crop. The suitability map has been shown respectively for each fruit trees.

4. Results and Discussions

In land use suitability classification, soil depth/texture, slope and land use conditions were evaluated in remote sensing and GIS setting. All of the parameters which are used in the study have a great influence on the suitability of the land. Soil is the basic parameter in identifying the land use suitability since soil is the fundamental raw material for plant growth. Slope is also a basic element for analyzing and visualizing landform characteristics. Figure 8 depicts slope as a limiting factor for the growth of avocado in the district. Moreover, to classify land suitability for different types of perennial crops, the role of land use is undeniable. It is necessary to have information on existing land use since it is considered as an essential element for modeling and understanding the land or the environment as a system.

GIS is a powerful tool for collecting, storing, retrieving, transforming and displaying spatial data from the real world (Burrough, 1986). Shalaby *et al.* (2006) assure that the capability of GIS and remote sensing in land use suitability analysis has been demonstrated in many parts of the world where various crops especially perennial crops like guava, olive and date palm. Moreover, study conducted by Ahmed (2012) on land suitability assessment for agricultural planning demonstrated that land use suitability analysis using GIS tool allows identification of the main limiting factors for agricultural production. Similarly, this study also agreed that GIS provides great advantage to analyze multi-layer of data spatially and classify land based on its suitability.

4.1. Land Suitability Classes

Land Suitability is the degree of appropriateness of land for a certain use. Land suitability could be assessed for present condition (Actual Land Suitability) or after improvement (Potential Land Suitability). The land suitability classification, using the guidelines of FAO (1976), is divided in to Order, Class, Sub Class, and Unit. Class is the land suitability group within the Order level. Based on the level of detail of the data available, land suitability classification is divided into: Highly Suitable (S1), Moderately Suitable (S2), Marginally Suitable (S3) and Not Suitable (N). The Subclasses are a more detailed division of classes based on land quality and characteristics (soil properties and other natural conditions).

4.1.1. *Guava (Psidiumguijava)*

The land use suitability analysis result showed that out of the 40976 ha, 23% of the land was highly suitable (S1), 21% moderately suitable (S2), and 47 % marginally suitable. The remaining small area (9%) is having severe limitations that hinder the growing of guava. This indicates that the area has the potential for the production of guava with less improvement effort for the limitations. Topography and soil condition are the major limitations of this area and some of the soil conditions can be improved by specific management. Land use suitability map of guava is shown below.

Table 1: Land Suitability Class for Guava

Suitability classes	Area(ha)	Percentage
Highly suitable(S1)	9562	23
Moderately suitable(S2)	8542	21
Marginally suitable (S3)	19000	47
Currently not suitable(N1)	3155	8
Permanently not suitable(N2)	537	1
Total	**40796**	**100**

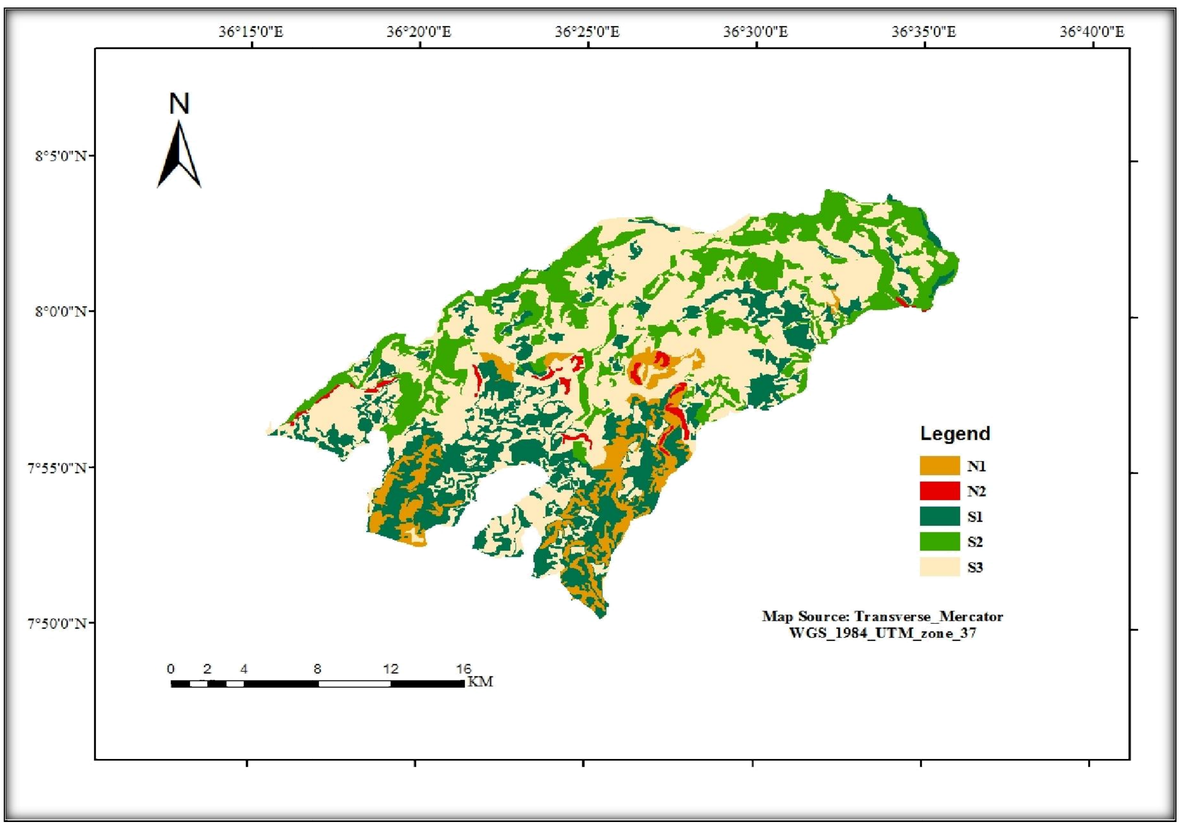

Fig4: Land suitability map of guava

4.1.2. Mango (Mangiferaindica)

Table 2: Land Suitability Class for Mango

Suitability classes	Area(ha)	Percentage
High suitable(S1)	19144	47
Moderately suitable(S2)	11158	27
Marginally suitable (S3)	2263	6
Currently not suitable(N1)	5087	12
Permanently not suitable(N2)	3144	8
Total	**40796**	**100**

As it is presented in Table 2, more than 80% of the land is suitable for the growing of mango; 47% of the land was highly suitable (S1), 27% moderately suitable (S2), and 6% marginally suitable (S3). The remaining 20 % of the area is not suitable for the growing of mango; out of which 12% is not currently suitable (N1) whereas the remaining 8% is not permanently suitable (N2). The major limitations for the growing of mango in the study area are topography and soil conditions.

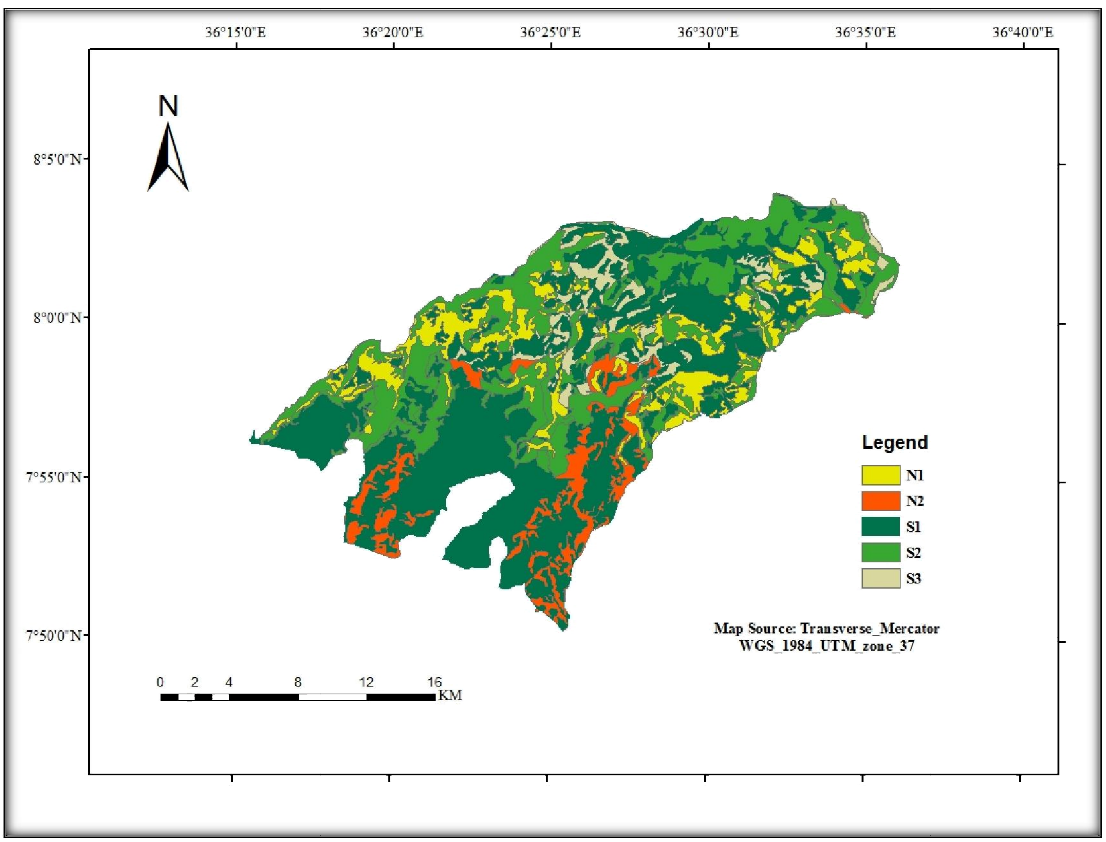

Fig 5: *Land suitability map of mango*

4.1.3. Avocado (Perseaamericana)

According to suitability analysis result shown in Table 3, more than 90% of the land area is not suitable for growing avocado and out of this 23% of the land is not currently suitable, but with great improvement effort it will be suitable. Only the remaining 7 % of the land is suitable for the growing of avocado. So investing more for growing of avocado in this area is not profitable and it needs more efforts. The major limitations for the growing of avocado in study area are topography and soil conditions.

Table 3: Land Suitability Class for Avocado

Suitability classes	Area(ha)	Percentage
High suitable(S1)	506	1
Moderately suitable(S2)	-	-
Marginally suitable (S3)	2393	6
Currently not suitable(N1)	11125	27
Permanently not suitable(N2)	26772	66
Total	**40796**	**100**

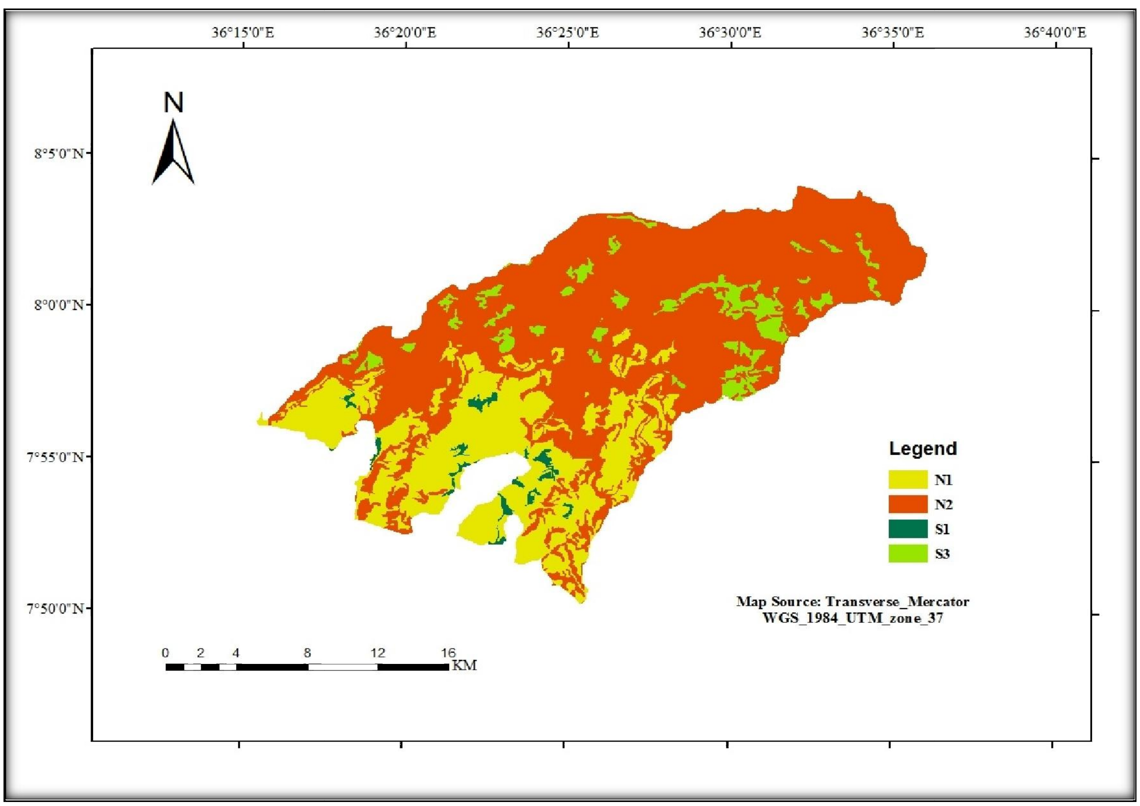

Fig 6: Land suitability map of avocado

4.2. Land Suitability Sub-classes

Land use-suitability sub-classes and limiting factors of each mapping unit have been identified by following the same procedure as that of suitability class. This was done to find out areas that need more management practice and to identify the limiting factors that hinder the productivity of the land. Accordingly, the suitability sub class and limiting factors have been identified and mapped (Fig. 7 and Fig. 8). So, it was found that topography and soil conditions are the major limitations; particularly topography is the dominant one which needs more capital and effort to improve and to be more productive in the area.

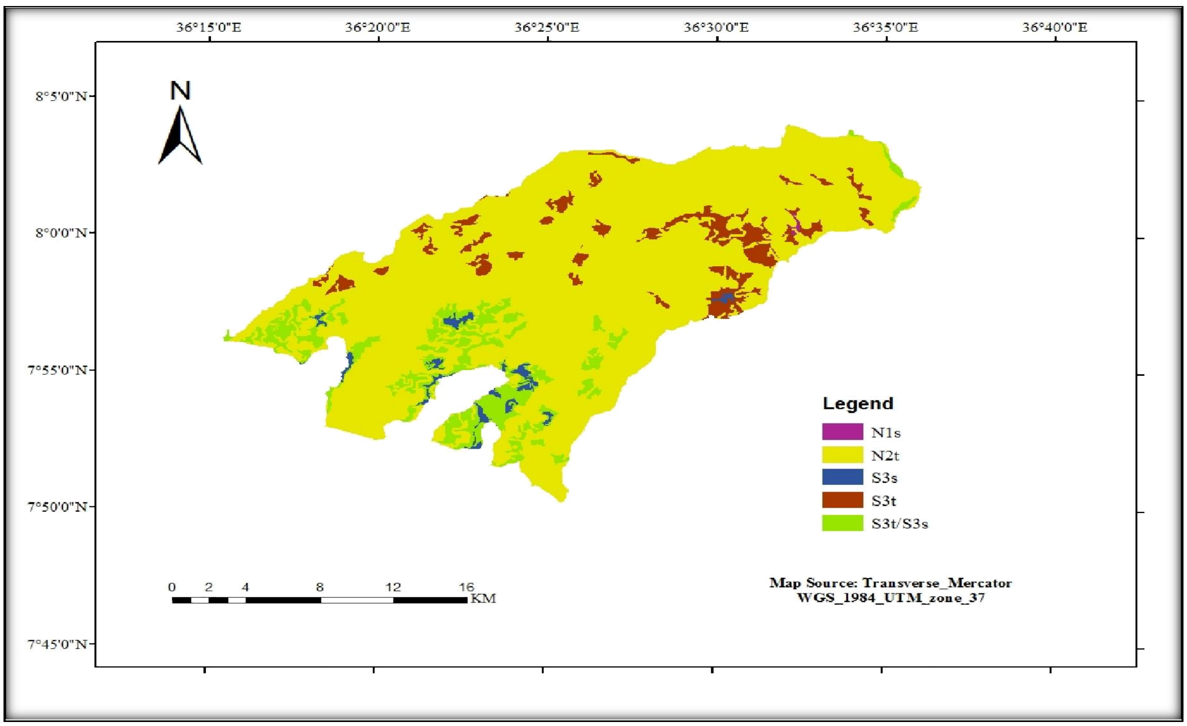

Fig 7: Land suitability sub class map of guava

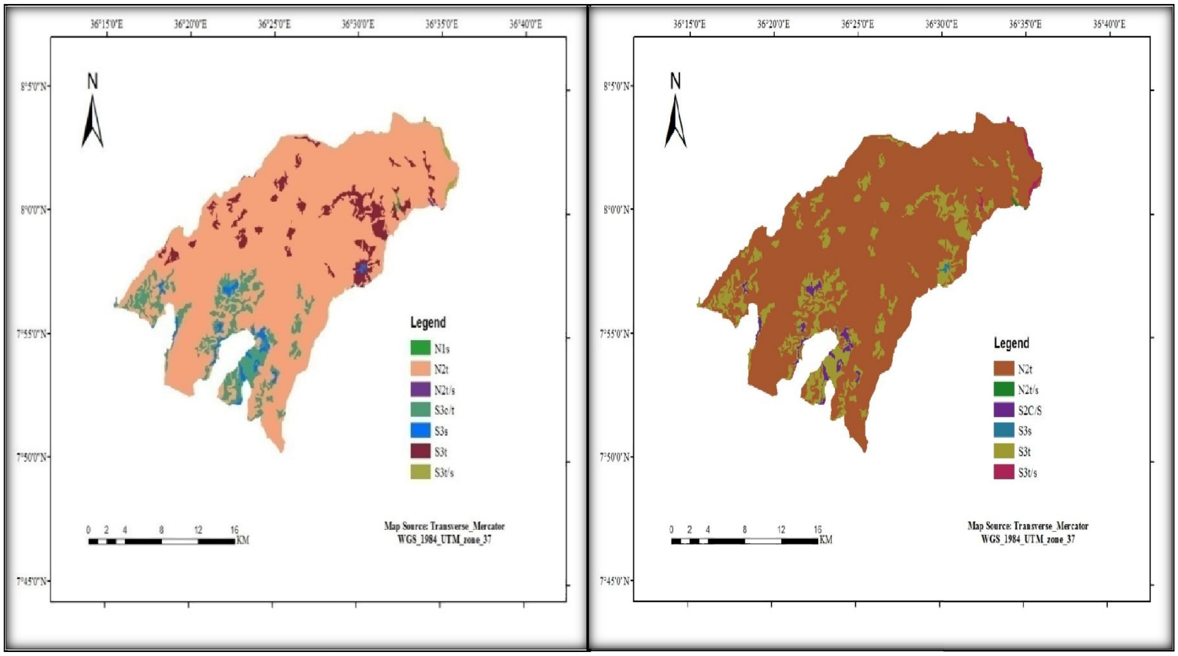

Fig 8: *Land suitability sub class map for mango and avocado*

5. Conclusion and Recommendations

5.1 Conclusion

The study demonstrates that the application of GIS and remote sensing has been regarded as highly effective method to provide the required information and analyze multi-layer of data spatially for land suitability assessment of selected perennial crops. Remote sensing can provide valuable information for land suitability assessment especially in arid areas in the absence of detailed soil maps. Similarly the application of GIS has been used to produce continuous soil properties maps which are relevant to land suitability for different crops. These maps have been then used to produce continuous land suitability maps.

The proposed methodology uses soil information and land cover information in a GIS environment to facilitate the exploration of different data coverage and to present the result spatially. The produced land suitability maps account of the spatial variability of the suitability for different crops. The output shows that the suitability of the study area for selected perennial crops like guava, mango and avocado cultivation ranges from highly suitable to unsuitable.

The main limitation was found to be due to topography and soil. More than 80% of the land area is suitable for the growing of guava and mango whereas the reverse is true for avocado; more than 90 % of the land is not suitable for the production of avocado. From the potential suitability maps that have been produced, it is clear that the suitability and productivity of the soil will be improved if soil reclamation is carried out particularly for guava and mango in the study area.

5.2 Recommendations

GIS and Remote sensing application not only minimizes the factors introduced in to the analysis but also provides data processing procedure steps and reliable outcome through clear cut steps of operation which could be updated. So, for further suitability studies it is advisable to adopt and employ this method.

Furthermore, for detail suitability studies, selection of additional factors likes soil, climate, irrigation facilities, and market infrastructure and socio-economic should be proposed.

Even though, the district is more suitable for production of mango and guava, it needs some treatments in line with the limitations. So farmers and the concerned stakeholders should give a great attention to make the area more productive and profitable by treating the identified limitations.

The result of the study has to be conveyed to local farmers and the concerned bodies to make them understand about capacity and limitation in range of suitability of their farm holding. Accordingly, they are advised to make use of research results to cultivate crops according to its suitability.

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