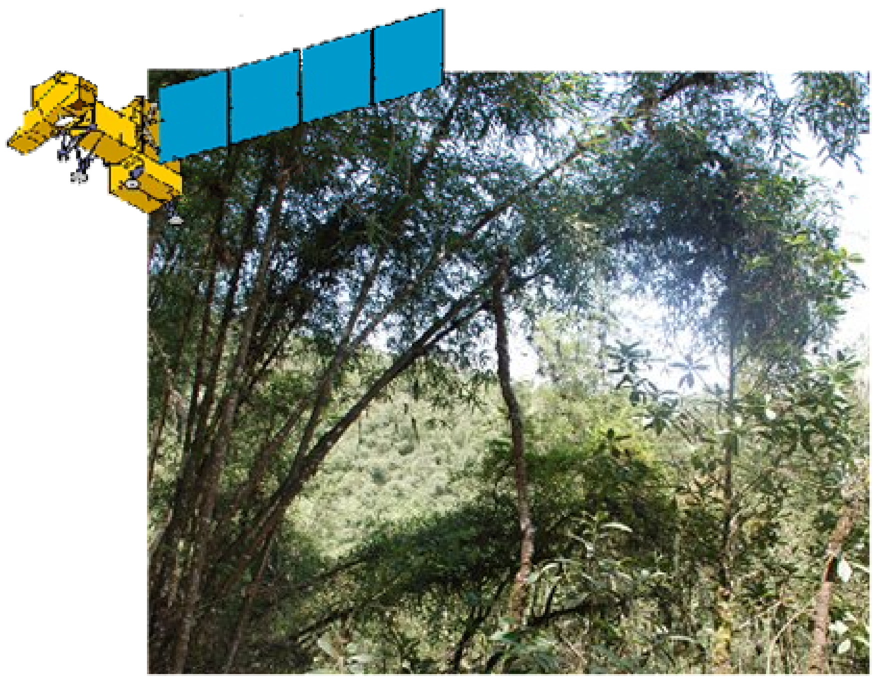
Addis Ababa University
School of Graduate Studies, Faculty of Science

COMPARISON ON THE PERFORMANCE OF SELECTED IMAGE CLASSIFICATION TECHNIQUES ON MEDIUM RESOLUTION DATA TOWARDS HIGHLAND BAMBOO RESOURCE MAPPING

A Thesis Submitted to
The School of Graduate Studies of Addis Ababa University
In Partial Fulfillment of the Requirements for the
Degree of Master of Science in
Remote Sensing and Geographical Information Systems



By

Tezera Chernet

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Acronyms and abbreviations used

AAU: Addis Ababa University
BESMP: Bale Eco-region Sustainable Management Programme
BMNP: Bale Mountains National Park
CSA: Central Statistics Agency
CSUMPP: Conservation and Sustainable Use of Medicinal Plants Project
DEM: Digital Elevation Model
EIAR: Ethiopian Institute of Agricultural Research
EFAP: Ethiopian Forestry Action Programme
EMA: Ethiopian Mapping Agency
ENVI: Environment for Visualizing Images
EOS: Earth Observing System
ERTS: Earth Resource Technology Satellite
ETM+: Enhanced Thematic Mapper plus
FaWCDA: Forestry and Wildlife Conservation and Development Authority
GCP: Ground Control Point
GIS: Geographical Information System
GPS: Global Positioning System
HRG: High Resolution Geometric
INBAR: International Network for Bamboo and Rattan
IR: Infrared
ISODATA: Interactive Self Organizing Data Analysis
LUPRD: Land-use Planning and Regulatory Department
m.a.s.l: Meters above sea level
MoA: Ministry of Agriculture
MoNRDEP: Ministry of Natural Resource Development and Environmental Protection
MSS: Multi-Spectral Scanner
NDVI: Normalized Difference Vegetation Index
NFPA: National Forest Priority Area
NH: National Herbarium
NIR: Near Infrared

NMSA:	National Meteorological Service Agency
NRS:	National Regional State
PCA:	Principal Component Analysis
RBV:	Return Beam Vidicons
ROI:	Region of Interest
SFCDD:	Soil and Forest Conservation and Development Department
SPOT :	Système Pour L'Observation de la Terre
SWIR:	Short-Wavelength Infrared
TIR:	Thermal Infrared
TM:	Thematic Mapper
UNDP:	United Nations Development Program
USGS:	United States Geological Survey
UTM:	Universal Transverse Mercator
WBISPP:	Woody Biomass Inventory and Strategic Planning Project
WCMC:	Word Conservation Monitoring Centre
WGS:	World Geodetic System

Abstract

This study was conducted with the objective of comparing the performance of different image classification techniques in discriminating *Yushania alpina* K. Shmann Lin. (highland bamboo) from other land cover classes, with the use of medium resolution images in three Woredas of the Bale highland. A subset of four Landsat 7 ETM+ images acquired on the 28th of November and 5th of February 2000, (path 167 / rows 55-56 and path 168 / rows 55-56), covering the study area were used for the classification. The image processing software employed was ENVI 4.3. After performing the necessary pre-classification processes, Decision Tree and Maximum Likelihood classification techniques were applied on the images and the results thereof were examined using confusion matrix. Landsat 7 ETM+ image derived data sets such as tasseled cap and as well the spectral values of the different bands of the images were used as the decision rules in the Decision Tree Classifier. Analysis of the accuracy assessment had revealed that it had an overall accuracy of 66.79% and a Kappa statistic of agreement of about 0.56. The technique also showed user's accuracy of 23.05% for bamboo class. The other classification technique evaluated was maximum likelihood, for which region of interest, based on the field data was delineated as a training guide in the classification process. The Maximum likelihood classification showed an overall accuracy of 87.75% and a Kappa value of about 0.84. User's accuracy for bamboo forest by this technique was 40.56%.

The potential highland bamboo growing areas of Ethiopia was mapped in order to provide an indication of the suitable areas for the growth and future expansion of Y. alpine, to guide the establishment of observation plots from which detailed ecological requirements of the species can further be investigated and to direct future mapping of the resource. The existing temperature, rainfall and altitudinal information were used to identify the location of these areas and it covered an estimated 7,632,788ha representing about 6.74% of the total country. Classification results showed that the existing Highland bamboo land units found in the study area cover a total of 63,407.32ha. The dominant corresponding soil types of these areas are Orthic Luvisols, Chromic Luvisols and with not less correlation with Eutric Cambisols, Eutric Fluvisols and Eutric Nitosols.

Keywords: *Yushania alpina*, Landsat 7 ETM+, remote sensing, Bale highland, bamboo

1. INTRODUCTION

1.1 Background

There are about 1200 bamboo species in the world (Bystriakova *et al.,* 2004), and of these, *Yushania alpina* K. Shmann Lin. or highland bamboo and *Oxytenanthera abyssinica* (A. Richard) Munro or lowland bamboo, are native to Ethiopia (Ensermu Kelbessa et al., 2000). Different studies (Kassahun Embaye, 2003; LUSO, 1997) show that the natural bamboo forest of Ethiopia is believed to cover as much as 1 million ha of the total land area, which is one of the highest in Africa. These resources are located in the south, south west and central part of the country where annual rainfall is over 600 mm and the rainy season exceeding 3 months (Kassahun Embaye, 2003).

Currently, on account of its ease of workability (Wolde-Michael Kelecha, 1980) bamboo is locally utilized for different purposes, such as house hold utilities, weaving and construction (Bystriakova, *et al.,* 2004; Kassa Oyicha, 1997; Arsema Andargatchew, 2008) and the limited harvest by the local people has no significant impact on the available stock. Increment, however, as Kassahun Embaye (2003) noted, is counterbalanced by death of the species due to age, disease and insect attack.

Ethiopia recognizes the economic potential of bamboo resources in contributing to the alleviation of poverty and rural development (Boa, 2006). In line with this, regional governments are calling for investments on bamboo based industry developments. Efforts are also being made, where the resources are available, to enhance the economic benefits of the rural people by adding values to the culms. Furthermore, the country's existing 2.7 percent closed natural forest is dwindling with an estimated annual loss of 150,000 to 200,000 ha and is particularly severe due to disruption in the supply of alternative fuels (EFAP, 1994). As it has been done in some countries, it will be a matter of time to use bamboo, which has a fast growth and versatile use, as a potential means of substituting timber to alleviate the pressure on the meager resource.

Within this context, it is clear that all these positive undertakings will make a huge demand on the bamboo resource. There is, thus, a need to monitor the resource by projecting demand and identification of future development pressure points and areas and to implement effective plans (Anderson *et al*., 1976) toward sustainable management.

The challenges

As Anderson *et al.* (1976) noted, there is no one ideal classification of land-use and land cover, and it is unlikely that one could ever be developed. There are different perspectives in the classification process, and the process itself tends to be subjective, even when an objective numerical approach is used. There is, in fact, no logical reason to expect that one detailed inventory should be adequate for more than a short time, as land-use and land cover patterns change in keeping with demands for natural resources. In this regard, commendable efforts had been exerted in the past towards mapping parts of the bamboo resource of Ethiopia. However, there were, as commonly shared and acknowledged, one or all of the followings limitations:

1. scarcity of adequate (large scale) mapping materials,
2. difficulty of interpreting the available materials as it lacks timeliness and
3. time constraint in their activity.

Advances in Remote Sensing technology and classification techniques

Traditional methods such as field surveys, literature reviews, map interpretation and collateral and ancillary data analysis are not effective to acquire vegetation covers because they are time consuming, date lagged and often too expensive (Xie *et al.,* 2008). Alternatively, remote sensing is an attractive source of thematic maps such as those depicting land cover as it provides a map-like representation of the Earth's surface that is spatially continuous and highly consistent, as well as available at a range of spatial and temporal scales (Foody, 2002).

With advancement in remote sensing technology and classification techniques, opportunities are also brought about allowing the retrieval of maximum information with increased efficiency. Therefore, not only to overcome the limitations mentioned above, but also for the proper understanding and monitoring of the resource toward sustainable utilization, the use of data collected by remote sensing technique becomes appropriate and necessary.

Rationale

- There exist variations between previous study results and updating of available data was not done (sub-title 2.1.2 and Annex 1-5).
- The available information is collected by using traditional methods and not by modern tools and techniques.
- In spite of the growing huge demand for bamboo resource, no supporting timely and accurate spatial information are available.
- The shelter which bamboo previously derive due to the physiographic disposition and remoteness of their location is now threatened by constructed road networks, heavy population pressure and the expansion of agricultural land and a host of other associated factors.
- Therefore, it would be critical and imperative to provide timely and accurate spatial information on the distribution and extent of the bamboo resource in order to support policy makers, researchers, and the general public as to make informed decisions and develop strategies that ensure the continuity of the resource-base both in terms of environmental factors and economic return.

1.2 Objectives

General objective:

To compare selected image classification techniques performance on medium resolution data and determine the best approach for mapping the highland bamboo resource of Ethiopia.

Specific objectives:

- To determine the appropriate classification method on a medium resolution image to map highland bamboo resource by comparing Maximum Likelihood classification performance with that of Decision Tree classification performance.
- To determine potential Y. alpina growing areas of Ethiopia
- To generate information on the geographic extent and distribution of bamboo trees in the study areas.

1.3 Approach

In order to achieve the stated objectives, the Bale highland was selected to conduct the study as it allowed capturing of the native species of highland bamboo in Ethiopia along with the opportunities for applying the techniques to other parts of the country. Moreover, the occurrence of diverse vegetation types permitted a better understanding of sources of confusion in the mapping of bamboo forest. The added advantage was also the presence of a previously conducted secondary data that enabled comparison with the present classification.

The choice of medium resolution image type is opted, based on the adoption by an interested group to map the extent and distribution of the existing bamboo resources for the whole of Ethiopia at low cost. Furthermore, dictated with availability of substantially cloud free images, since in Bale Mountains few are the days within a given year to capture cloudless images, and as well ease of image acquisition the Landsat data was selected from the images at hand.

1.4 Structure of the thesis

This thesis has four major parts. The first part presents the background of the study and its general and specific objectives. Part two is devoted to literature review in which the studied species, vegetation mapping and satellite images classification techniques are dealt upon in detail. Part three describes the study area, methodology, the data set and data analysis and materials used.

Part four deals with the results of the research and gives the classification findings and the accuracy assessment results. This part also covers discussion of the data and comparison of current results with previous works done on the same area. Finally, the conclusions derived from outputs of this research are discussed in part five.

2. LITERATURE REVIEW

2.1 Bamboo resources

2.1.1 The species

Taxonomy and distribution

Bamboo belongs to the family Poaceae (Gramineae), subfamily Bambuseae (Ohrnberger, 1999). There are about 75 genera and 1,250 species of bamboos growing in different parts of the world (Sattar, 1995; Bystriakova *et al.,* 2004). Of these, two native species, *Yushania alpina* K. Shmann Lin. previously known as *Arundinaria alpina*, and *Oxytenanthera abyssinica* (A. Richard) Munro occur in Ethiopia. The monopodial bamboo is found in the highlands of Ethiopia and grows in altitudes ranging from 2200 to 3500 m.a.s.l.. The highland bamboo is commonly known as Goia in geez, Anqay in Tigrinya, Chirata in Kefinya, Lemmanna in Oromiffa, Meka or Qerkeha in Amharic, and mountain bamboo in English (Phillips, 1995).

Growth habit

Bamboos are tall arborescent grasses whose variants can reach a height of more than 30 m and a diameter of 30 cm (Mauria and Arora, 1988). Kassahun Embaye (2003) noted the maximum size measured in the indigenous bamboo forests of Ethiopia as 23m and 20cm in height and diameter respectively and described the average stocking of highland bamboo forest as 6000 culms ha^{-1}.

According to Kassahun Embaye (2003), the aerial part of a bamboo plant contains the main stem called culm, branches and leaves while the underground part constitutes the rhizome and root system. The culm is the most versatile in use and is economically valuable part of the plant. The culm of the highland bamboo is hollow, while that of the lowland bamboo is solid at maturity. Highland bamboo is a single-stemmed evergreen species. New bamboo shoots grow during rainy season from rhizome buds that attain full height and diameter in about 3 months in a fully developed rhizome-root system in 3 to 7 years after seeding or establishment by seed. They mature and become strong and ready for utilization after 2 to 3 years. Most bamboo plants flower only once in their lifetime and die. In the lowland bamboo forest of Pawe, SW Ethiopia, the whole forest flowered and died in 1998. New seedling emerge in large quantity in the subsequent year. Such an event had also been recorded by Arsema Andargatchew (2008) in Shedem area (NE part of the study area), some 50 years back.

Uses of Bamboo

The main use of bamboo is for building houses, furniture, farm implements and other articles. Bamboo shoot is considered as healthy food. In recent years, the use of bamboo culm as the raw material for the manufacture of pulp and plywood has rapidly increased. Bamboo's role in stabilizing river and water reservoir embankments, and in protecting water sources have also been widely recognized. Many species of bamboos are beautiful in appearance, and this has come to be appreciated by gardeners, interior designers and landscape artists who use it as an ornamental plant (Wenyan and Naixun, 1995).

In Ethiopia, bamboo plays a very important role socially, economically and ecologically in areas where it occurs naturally and where it is planted. It is used for construction of houses, fences, rafts, vessels for carrying and storing water, water pipes, splits for baskets, beehives, hats, mats, furniture, poles, masts, sporting goods, needles, nails, handles, gutter, floats, walking-sticks, flutes, household utensils and agricultural tools. It is also used as fuel and medical plant. In certain localities it is also used for nutrition. In addition to this, young leaves and new sprouts of bamboo are usually browsed by domestic and wild animals as fodder (Ensermu Kelbessa *et al*., 2000; Kassa Oyicha, 1997).

Kassa Oyicha (1997) also noted that the workability, ease of handling, availability, ease of transportation, durability and strength of bamboo are the driving factors that render them preferable than other materials.

2.1.2 Review of the existing bamboo resource base

Different authors and organizations had made an attempt to estimate the extent and distribution of the bamboo resources of the country (Table 1). The earliest documented works of bamboo resource distribution and mapping dates back to the late 1940's, and include Logan's in 1946, Pichi-Sermolli's in 1957 and Von Breitenbach's in 1961.

Logan (1946) had described the tropical montane bamboo forest in his paper on the forest of central and southern Ethiopia. Pichi-Sermolli (1957) in his “Una carte Geo-botancia dell Africa Orientale” (Annex 1) had also made a general account of the vegetation of Eritrea, Ethiopia and Somalia. Breitenbach (1961) had made a generalized vegetation map of Ethiopia and identified 24 major vegetation types including *O. abyssinica* (Annex 2).

Table 1: Summary of estimated national Bamboo coverage

Source	Area coverage (in ha.)		
	Highland bamboo	Lowland bamboo	Data sources
Pichi-Sermolli (1957)	N/A	N/A	N/A
Von Breitenbach (1961)	N/A	N/A	N/A
Chaffey (1979)	109,700	113,400	Aerial photos and Landsat MSS
LUPRD (1980)	--	561,252	N/A
Wolde-Michael Kelecha (1980)	117,000	1,000,000	Secondary sources and field note
SFCDD (1990)	--	450,000	N/A
LUSO (1997)	129,626	700,000-850,000	topographic maps
WBISPP (2004)	31,003	494,564	Landsat TM

Chaffey conducted a reconnaissance inventory of the south western part of Ethiopia, in geographical ranges of 5^{o}20’ to 9^{o}15’ N latitude and 34^{o}15’ to 40^{o}25’ E longitude. He made interpretation of aerial photographs of the 1960’s and 1970’s to locate forests, woodlands and thickets, including highland bamboo (Annex 3) and estimated their size to be about 109,700 ha. Furthermore, he also mapped the location of the main blocks of lowland bamboo at a scale of 1:500,000, through interpretation of satellite imagery. His results showed that the lowland bamboo had an estimated area coverage of 113,400 hectares.

Wolde Michael Kelecha (1980) had indicated the existence of about 2,000 ha highland bamboo forest in Shewa (Jibat), 10,000ha in Sidamo, 100,000 ha in Illu-ababora and 5,000 ha in Kefa (Sentame) regions. Moreover, he also mentioned the existence of other scattered bamboo resources in Welega, Arsi (Chilalo/Munessa), and the Bale mountains.

In 1980, Land-use Planning and Regulatory Department (LUPRD) had produced the land cover map of Ethiopia at a scale of 1:1,000,000. Contrary to the preceding studies, LUPRD had estimated the area of lowland bamboo as 561,252 ha. Another study made in 1990 by Soil and Forest Conservation and Development Department) had also estimated the area coverage of lowland bamboo to be about 450,000 ha (SFCDD, 1990).

LUSO (1997), by combining available information from the works of Chaffey and Ethiopian Mapping Agency (EMA), had estimated the total area of highland bamboo to be about 129,626 ha and that of lowland bamboo in between 700,000 and 850,000 ha (Annex 4).

A study made by the Woody Biomass Inventory and Strategic Planning Project (WBISPP) in 2004 estimated the highland bamboo area cover about 31,003 ha. The project had also mapped 494,564 hectares of lowland bamboo that occur in Beneshangul-Gumuz National Regional State and other small patches mixed in with woodland as occurring in Amhara, Oromiya and Tigray National Regional States (Annex 5).

2.2 Application of remote sensing in land cover classification

Thematic mapping, such as those depicting land cover from remotely sensed data is typically based on either visual or computer-aided image classification (Foody, 2002). The process of extracting vegetation information by interpreting satellite images make use of the interpretation elements such as the image colour, texture, tone, pattern and association information. The diverse methods of doing this can be broadly grouped either as supervised or as unsupervised depending on whether or not true ground data are put into as reference. As objects, including vegetation, have their unique spectral features (reflectance or emission regions), they can be identified from remote sensing imagery according to their unique spectral characteristics. A good case in vegetation mapping by using remote sensing technology is the spectral radiances in the red and near-infrared regions (low reflectance in visible regions of the solar optical spectrum as well as high reflectance in infrared spectrums), in addition to others (Xie, *et al.*, 2008).

Improvements in spectral, spatial and temporal resolutions, the growth in number of new sensors launched and as well the increase in archived data will further make the use of a remotely sensed data the most necessary source of information for vegetation classification and land cover mapping.

2.3 Satellite imagery and classification techniques

2.3.1 Satellite imagery

A remote sensing sensor is a key device that captures data about an object or scene remotely and is thus an important source of land cover and land use information over large range of temporal and spatial scales (Baker, *et al.*, 2007; Melesse and Jordan, 2002). Of the first and most robust global monitoring system to acquire moderate resolution data (Lillesand and Kiefer, 2000), the Landsat series and a derived data set, tasseled cap are discussed here.

Landsat system

Landsat's more than a quarter century mission of observations on the Planet Earth from space had produced a virtual revolution in Earth Science Research, revealing the importance of remotely sensed images for monitoring the patterns and processes that define the Earth's land areas (Goward, *et al*. 2000). The first Landsat satellite was designed in the 1960s and launched in 1972. From the first launch to 1983, early Landsat vehicles (Landsat 1, 2 and 3) carried two sensor system; RBV and MSS. RBV had a high geometric accuracy but lower spectral and radiometric detail. In contrast, MSS had finer spectral detail but less positional accuracy. The second generation Landsat vehicles (Landsat 4 and 5), carried the MSS, as well as the TM, a more sophisticated imaging sensors. ETM was carried aboard Landsat 6, but failed at launch in 1993 (Campbell, 1996).

Landsat 7 satellite, with its ETM+ instrument payload was launched in April, 1999. The ETM+ ground sampling distance is 30m for the reflective bands and 60m for the thermal infrared band. The eighth band of the ETM+ instrument, called the panchromatic sharpening band (Table 2), is sensitive to reflected light energy across a broad range of wavelengths that includes blue, green, red and near infrared and has a 15 meter ground sampling distance (Campbell, 1996; Goward, *et al*. 2000).

Table 2: ETM + Spectral bands width

Bands	Band Width (µm)
1	0.45 - 0.52
2	0.53 - 0.61
3	0.63 - 0.69
4	0.78 - 0.90
5	1.55 - 1.75
6	10.4 - 12.5
7	2.09 - 2.35
8	0.52 - 0.90

(Source: Goward *et al.,* 2000)

Anderson *et al.* (1976) had proposed that, of the land-use and land cover categories, Level I land-use information can efficiently and economically be gathered over large areas by a Landsat type satellite. The authors had also described that the information derived from the same can be displayed at a wide variety of scales ranging from a standard topographic map of 1:24,000 scale or even larger, to the much smaller scale of the orbital imagery such as 1:1,000,000. Similarly, several Level II categories (and, in some instances, Level III categories) have been interpreted from Landsat data. By using ancillary data, in addition to spectral responses, however, it might be possible to achieve either greater classification detail or greater classification accuracy for a given combination of spectral and spatial resolutions (Lawrence and Wright, 2001).

Tasseled cap transformation

Tasseled cap transformations optimize data for vegetation studies. It rotates Landsat spectral data onto brightness, greenness and wetness axes that correspond to the physical characteristics of vegetation (Parmenter *et al*. 2003; Baker *et al*., 2007). Brightness, a weighted sum of all six bands (exception is thermal) is a measure of overall reflectance (e.g. differentiating light from dark soils). Greenness is a contrast between near-infrared and visible reflectance, and is thus a measure of the presence and density of green vegetation. Wetness is a contrast between shortwave-infrared (SWIR) and visible/ near-infrared (VNIR) reflectance, providing a measure of soil moisture content, vegetation density, and other scene class characteristics (Crist *et al.,* 1986) and have been widely used for land cover analysis (Parmenter *et al.* 2003).

2.3.2 Classification techniques

Thematic mapping via an image classification is one of the most commonly undertaken analyses of remotely sensed data (Foody, 2006). General steps involved in vegetation mapping include image preprocessing, that deals with all preparatory steps necessary to improve the quality of original images and image classification in which each pixel of the scene is assigned to one of the vegetation groups defined in a vegetation classification system (Xie *et al.,* 2008). The classification may be one that seeks to group together cases by their relative spectral similarity (unsupervised) or that aims to allocate cases on the basis of their similarity to a set of predefined classes that have been characterized spectrally (supervised). In each situation, the resulting classified image may be treated as a thematic map depicting the land cover of the region (Foody, 2002).

In supervised techniques, the user will provide the system with some information regarding either the land cover of the image or the spectral signature of different land covers. The system will then apply the known spectral information to the rest of the images and determine a class for some or all pixels. Unsupervised techniques, on the other hand, do not require a priori knowledge of the area. Instead, the system analyzes the spectra of every pixel and groups them into clusters. These clusters serve as classes and the user is left to determine what land cover classes correspond to each cluster.

Of the various image classification techniques that exist, hereunder, maximum likelihood and decision tree, which were selected for performance comparison, and unsupervised, conducted as an input to direct the field data collection was discussed.

A. Unsupervised classification

Isodata unsupervised classification calculates class means evenly distributed in the data space then iteratively clusters the remaining pixels using minimum distance techniques. Each iteration recalculates means and reclassifies pixels with respect to the new means. Iterative class splitting, merging, and deleting is done based on input threshold parameters (ENVI, 2005).

All pixels are classified to the nearest class unless a standard deviation or distance threshold is specified, in which case some pixels may be unclassified if they do not meet the selected criteria. This process continues until the number of pixels in each class changes by less than the selected pixel change threshold or the maximum number of iterations is reached (ENVI, 2005).

B. Ground data acquisition

Küchler and Zonneveld (1988) had explained that the data on the physiognomy and structure of vegetation, floristic compostition and its characteristics, and information on environmental features are important to consistently and accurately describe the extent and distribution of vegetation types.

C. Maximum likelihood classification

The maximum likelihood classification is the most common supervised classification method used with remote sensing image data (Deren *et al*., 2000). Maximum likelihood classification assumes that the statistics for each class in each band are normally distributed and calculates the probability that a given pixel belongs to a specific class. Unless a probability threshold is selected, all pixels are classified. Each pixel is assigned to the class that has the highest probability (that is, the maximum likelihood). If the highest probability is smaller than a threshold specified, the pixel remains unclassified (ENVI, 2005).

D. Decision tree classification

Decision trees have become increasingly important for land cover mapping due to their conceptual simplicity, ease of implementation and computational efficiency (Lawrence and Wright 2001; Pal and Mather, 2003; Lowry, 2005; Mannel *et al.*, 2002; Huggins, 2006). The basic idea involved in any multistage approach is to break up a complex decision into a union of several simpler decisions, hoping the final solution obtained in this way would resemble the intended desired solution.

A decision tree is constructed by recursively partitioning a data set into purer, more homogenous subsets on the basis of a set of tests applied to one or more attribute values at each branch or node in the tree (Pal, 2008). Thus, it is made up of a series of binary decisions that are used to determine the correct category for each pixel. The decisions can be based on any available characteristic of the dataset. Examples can be an elevation image and two different multi-spectral images collected at different times, and any of those images that can contribute to decisions within the same tree. No single decision in the tree performs the complete segmentation of the image into classes. Instead, each decision splits the data into one of two possible classes or groups of classes (Mannel *et al.*, 2002; ENVI, 2005). Further more, individual splits in a decision tree may also be checked for physical justification (Hochart *et al.,* 2004).

As Hochart *et al.* (2004) noted when vegetation types cannot be distinguished clearly from the information available in raw TM bands for a variety of reasons, ranging from complex topography to small-scale mosaics of adjacent vegetation types within a limited geographic area, techniques can be employed to address this natural complexity. For example, as vegetation is known to have a low reflectance in Landsat band 3 (0.63-0.69 nm) and a high reflectance in Landsat band 4 (0.76-0.90 nm) vegetation indices can be designed to isolate this spectral feature and distinguish the amount of vegetation in an area. When applying a decision tree to a new scene, it has often been found that only minor adjustments are needed to apply it in different paces, or the same place under different conditions. However, when scenes are used from different seasons, significant adjustments are required in the classification.

E. Accuracy assessment: theoretical background

Accuracy assessment has become an increasingly important component of any map generated from remotely sensed data (Plourde and Congalton, 2003). The accuracy of a classification is a key factor in determining an image classification fitness for purpose and is the main criterion used in evaluating a thematic map. The comparison of an accuracy statement is also the basis of evaluation of different classifiers (Foody, 2006).

The confusion matrix, by resampling classified imagery against reference data, provides the basis for both describe classification accuracy and to characterize errors (some discrepancy between the situation depicted on the thematic map and reality), which may help refine the classification or estimates derived from it (Foody, 2002). The statistical outputs of the error matrices are further elaborated hereunder.

Overall accuracy

The diagonal elements of the matrix show class coincidence or agreement between the reference and the classified data; and indicate correct mapped samples. The off-diagonal fields in the matrix indicate where errors of omission and errors of commission have occurred. The overall accuracy is derived by adding the main diagonal elements (total number of correctly classified field) of the error matrix and dividing it by the total number of samples in the entire matrix.

Producer's accuracy (Errors of omission/exclusion)

For a cover type, producer's accuracy is the number of units on the ground that are correctly depicted on the map and is of interest to producers of spatial data (USGS, 2008; Reiners and Driese, 2000). In the contingency table, producer's accuracy is the number of correctly classified units of a particular cover type divided by the total number of reference units of that type. Errors of omission (or errors of exclusion) are the occurrence of cover types on the ground that are omitted from the map (incorrectly excluded from a particular class). In the contingency table, omission errors are calculated by dividing the number of misclassified (off-diagonal) units of a particular cover type by the total number of units of that type in the reference data (represented by the column). Omission errors and producer's accuracy sum to 100% (Reiners and Driese, 2000).

User's Accuracy (Errors of commission)

User's accuracy is important from the users perspective, as it forms a guide to the agreement of a mapped unit actually corresponding to the same type on the ground (Campbell, 1996). This is calculated by dividing the number of correctly classified units for a given type by the total number of classified units for that type.

Commission errors occur when a type on the ground is assigned the wrong type on the map. The erroneous type on the map is committed; it is mapped where it should not be found. Errors of commission are the number of misclassified units of a particular type from the map (off-diagonal), divided by the total number of units (row total) that were classified as belonging to that type (Reiners and Driese, 2000).

Kappa Index

Kappa analysis, which assumes a multinomial distribution, generates a Khat statistic that measures the difference between actual and chance (or random) agreement between the map and reference data (Plourde and Congalton, 2003). The Kappa coefficient of agreement for a thematic map is based on the comparison of the predicted and actual class labels for each case in the testing set acquired for the assessment of map accuracy (Foody, 2006). A Khat statistics can also be used to test for significant differences between two error matrices (Plourde and Congalton, 2003).

3. METHODOLOGY

3.1 Description of the study area

3.1.1 Geographical setting

The study area, Bale highland, is located 600 km away from the capital city, Addis Ababa, in the South eastern part of Ethiopia, and encompass Goba, Nensebo and Harena Buluk Woredas (~ district), of the Oromia National Regional State. It lies between 6^o 13' to 7^{o}00' North and 39^{o}00' to 40^{o}15' East (Figure 1). The total land area is 526,704 ha.

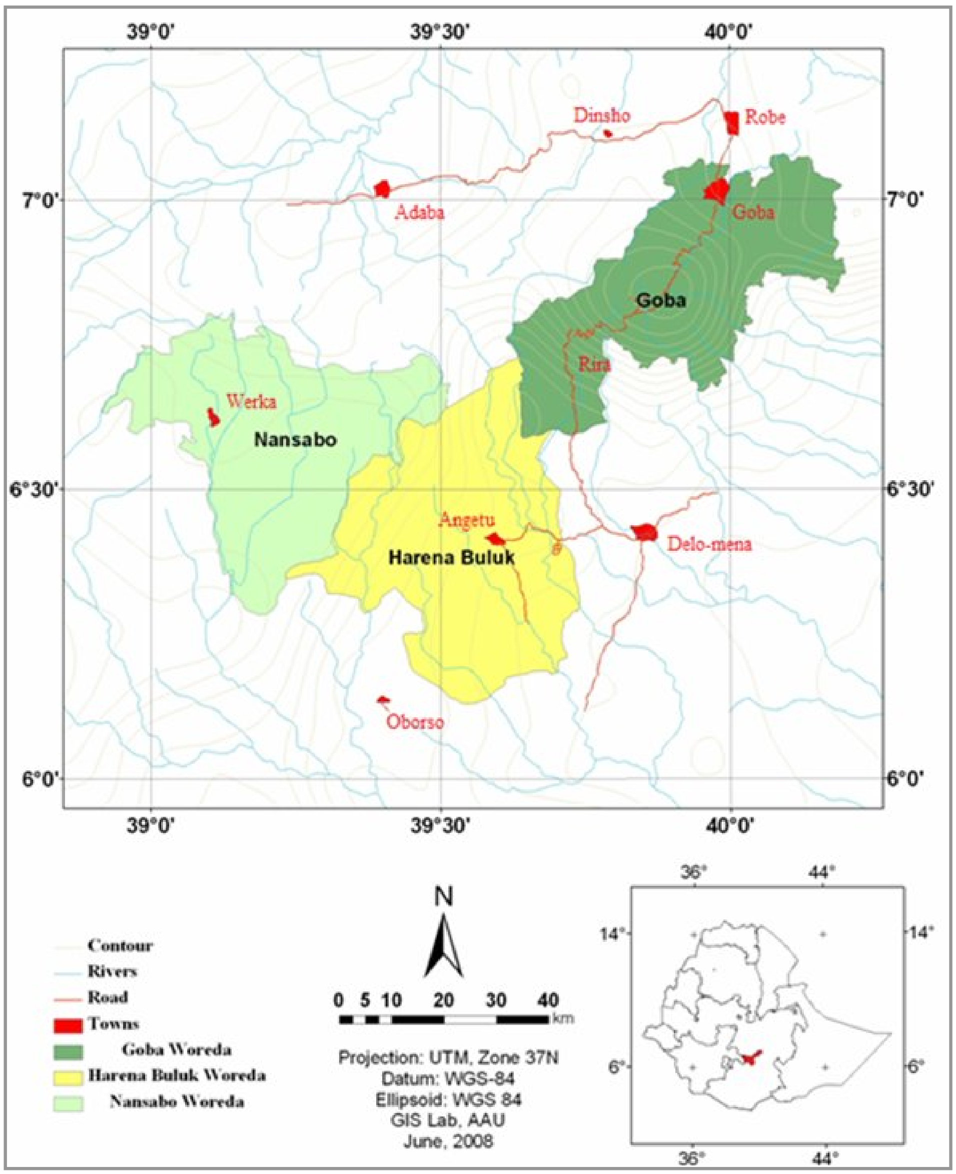

Figure 1. Location map of the study area

3.1.2 Topography

The study area lies within the Bale Mountains, which largely consist of a central plateau varying in elevation from 1000 to 4377 m.a.s.l. (Figure 2). The areas to the northeast include the Sanetti plateau (>4000 m.a.s.l.) that decline sharply to an elevation of about 2400 m.a.s.l. towards both the far north and southwest of the study area. The central part is characterized by variable topographic terrain as compared to the southeastern and north western parts, which are relatively uniform.

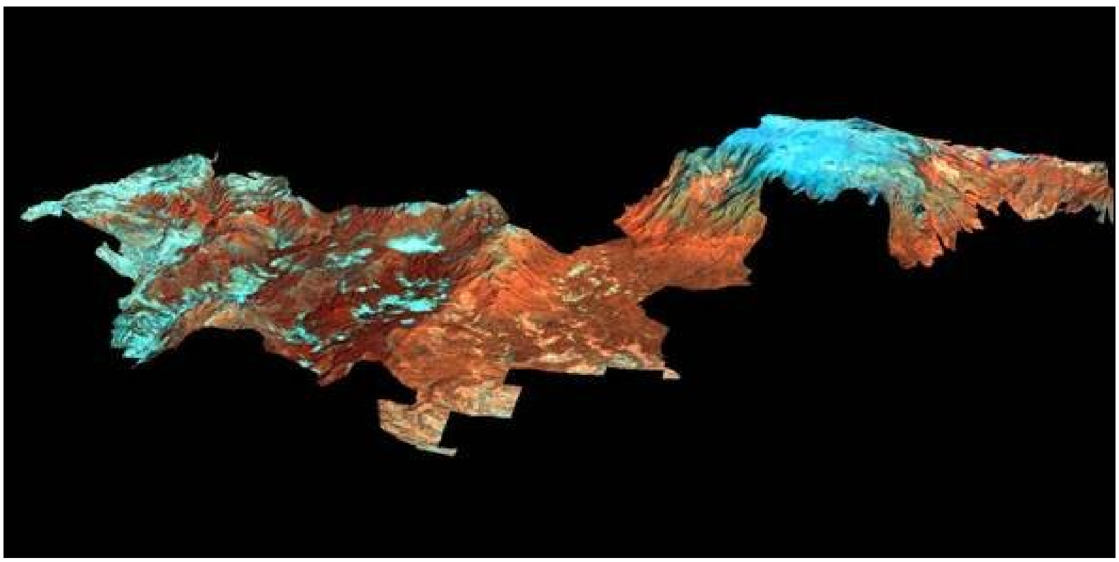

Figure 2: Three - D perspective view of the study area

The lowest area is found in the south eastern part of the study area and the highest at Mount Tulu-dimtu. There are four peaks above 4000 meters high in the area (Figure 3).

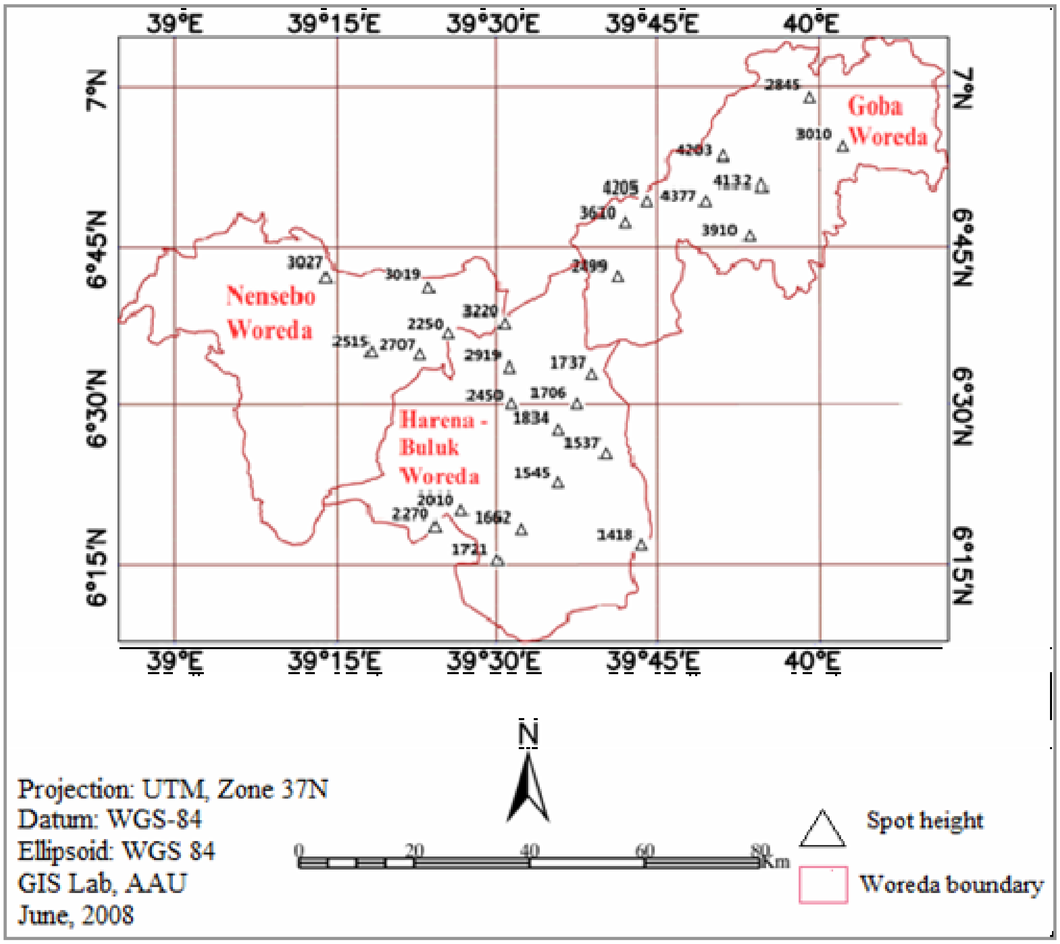

Figure 3: Location of selected peak points

3.1.3 Geology and soils

The study area consists of tertiary (Oligocene) lavas, which covered the Mesozoic marine sediments by underlying the Precambrian rocks after Eocene uplifting of the Ethiopian highlands. It is also described that in the Plio-Pleistocene rifting phase, the Arsi-Bale massif was separated from the northwest Ethiopian mountains by the rift valley system, which also isolated the southwest Arabian part of land mass (Miehe and Miehe, 1994)

The predominant soil types of the study area (Figrure 4) are Eutric Nitosols (35.83%) Eutric Fluvisols (18.28%), Leptosols (14.01%) and Eutric Cambisols (12.86%). The Northern area is dominantly characterized by Eutric Cambisols with inclusions of Eutric Fluvisols. The latter also dominates Sanetti plateau. The foot-slopes down to Harena is essentially Leptosols and further south Eutric Nitosols. The central part of the study area are characterized by Vertic Luvisols (4.76%) and Orthic luvisols (5.3%). Whilst western part of the study area is dominantly characterized by Eutric Fluvisols, Leptosols, Chromic Luvisols (6.96%) and Orthic luvisols. Other occasionally occurring soils are Chromic Cambisols (0.33%), Dystric Histosols (0.22%), Pellic Vertisols (0.35%), Chromic Vertisols (0.29%), and Orthic solonchaks (0.08%).

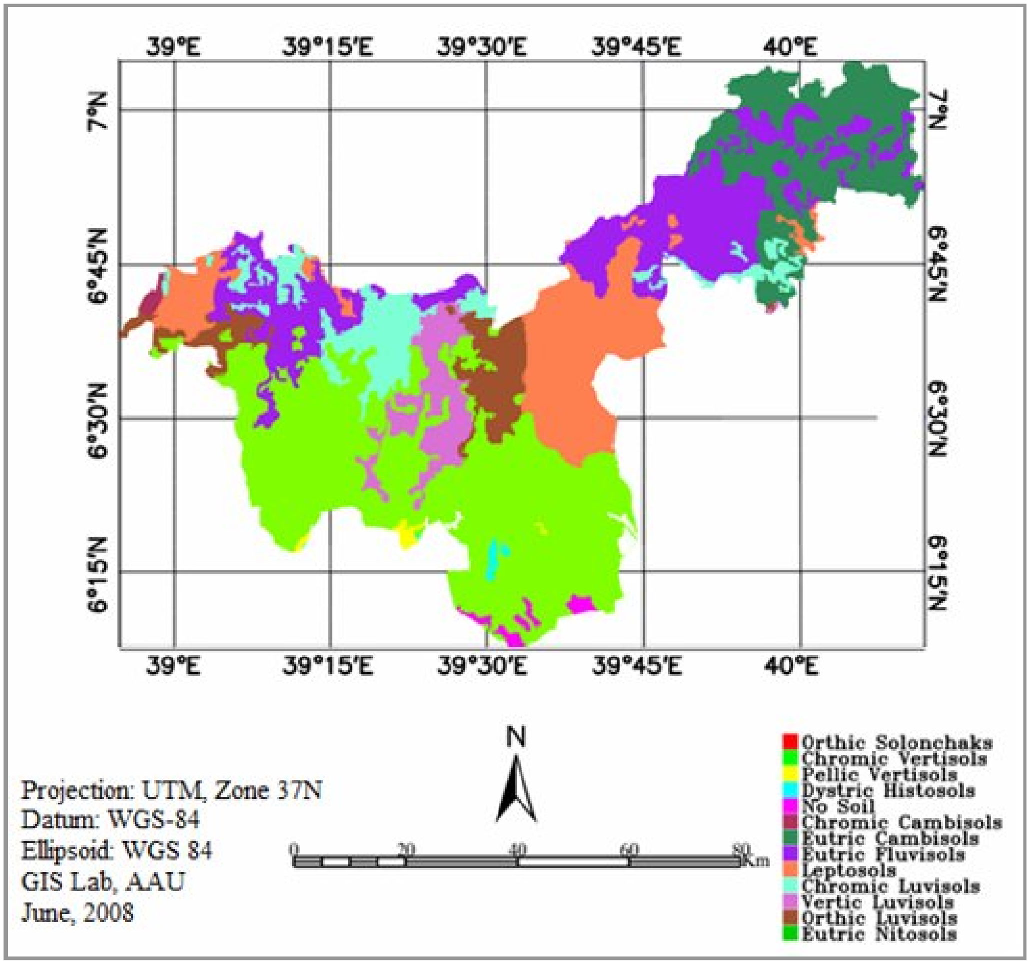

Figure 4: Dominant Soil types of the study area

3.1.4 Climate

Rainfall

The mean annual rainfall received for the period 1986 to 2007, at Dinsho was 1426 mm. The rainfall, which is bimodal, had the highest mean monthly rainfall during July to October, and was in between 155 to 211 mm. April and May had received the second highest peak. The mean monthly rainfall during these period falls within 135 to 221 mm. During the rest of the months, the mean monthly rainfall received varied between 21 and 95 mm (Figure 5).

Whilst at Robe, for the same time period the average annual rainfall received was 1037.3 mm. The highest mean monthly rainfall was received during July to September and was in between 107 to 195 mm. The second highest rainfall was recorded during April to May with a mean monthly rainfall in between 100 and 142 mm. During the rest of the months, the mean monthly rainfall received ranges from 18 to 62 mm.

Temperature

The mean monthly maximum temperature for Dinsho, as recorded from 1986 to 2007, showed little fluctuation, ranging between 16.1 and 18.5°C throughout the year. The lowest mean monthly minimum temperature from December to February was about 2.3°C, whilst the rest of the months, the mean monthly minimum temperature ranged between 3.5 to 5°C.

In Robe, as opposed to Dinsho, the average monthly maximum temperature varied between 20.5 and 23.6°C throughout the year. Robe received the lowest mean monthly minimum temperature from November to February (between 5 and 6.7°C), while the rest of the months, the mean monthly minimum temperature ranged between 8.3 to 10°C (Figure 5).

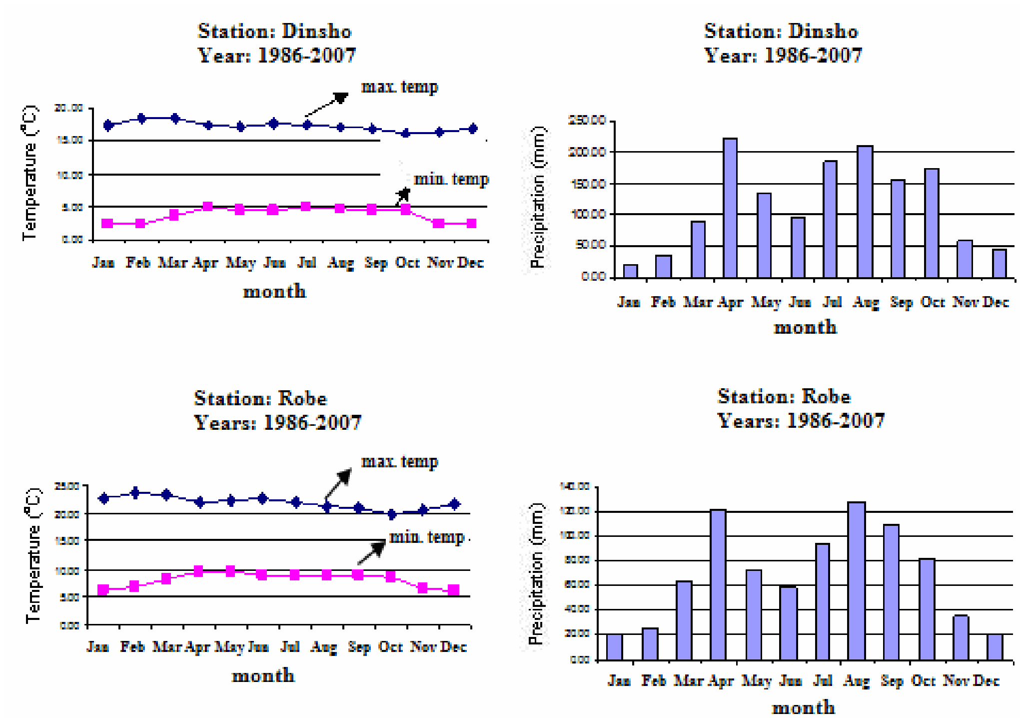

Figure 5: Mean monthly rainfall and temperature as recorded at Dinsho and Robe towns

3.1.5 Flora and fauna

Flora

The total number of taxa for the Bale floristic region is estimated about 1650 species, of which 177, that is 29.5% of the endemic taxa registered in the flora of Ethiopia and Eritrea, are endemic. Thirty one of these endemic species are restricted to Bale floristic region.

CSUMPP (2004) described the vegetation in the northern side of the Bale Mountains as dry evergreen montane forest and does not follow a clear pattern of vegetation zonation. In the lower part (2600 – 3200m) *Juniperus procera* is the single dominant tree species, associated with *P. falcatus, Ekebergia capensis, Pittosporum viridiflorum, Hagenia abyssinica, Buddleja polystachya* and *Maytenus obscura*. The upper part (3350-3500m) is dominated by *Hypericum revolutum. Erica arborea* is dominant between 3500 – 3800 m.a.s.l. and above 3800m, the central plateau is *Helichrysum citrispinum* and *H. splendidum* moorland. *Artemisia afra, Helichrysum* spp., *Ferula communis* and various grasses and sedges dominate the flat valleys lying between slopes.

Plate 1: Hygenia forest – Bale Highlands (Photo by Author)

The vegetation in the southern side of BMNP falls within the moist montane forest type and are commonly known as Manna-angetu and Harena NFPA (Figure 6). Along the altitudinal gradient (3200-3800m), *Erica* scrub, composed of *Erica trimera* and *E. arborea* and further down (3000-3200m) *E. arborea* trees occur (CSUMPP, 2004) for about 1.2 km altitudinal range, showing difference in range and habitat (Yoseph Assefa, 2002).

In altitudinal range between 2700 and 3000 m.a.s.l., dominant tree species are *H. revolutum*, *Schefflera volkensii, H. abyssinica, Myrsine melanophloeos, Galiniera saxifraga* and *E. arborea. H. abyssinica, S. volkensii, Erythrina brucei, G. saxifrage, Allophylus abyssinicus, Dombeya torrida, Ficus ovata, Prunus africana, Croton macrostachyus, Maytenus addat* and *Canthium oligocarpum* characterize the altitude between 2100 and 2700 m.a.s.l. Dominant tree species of the altitudinal gradient between 1700-2100 m.a.s.l are *Syzygium guineense, Polyscias fulva, A. abyssinicus, E. brucei, C. macrostachyus* and *C. oligocarpum*. The vegetation in the lower part (1450-1500m) of the Harena forest are characterized by Filicium-Warburgia-Podocarpus-Celtis forest. Woodland species like C*ombretum molle, Terminalia brownie* and forest species like *Warburgia ugandensis, Celtis africana* and *Podocarpus falcatus* are among others covering the transition zone between the moist montane and the dry woodland north of Delo mena (CSUMPP, 2004).

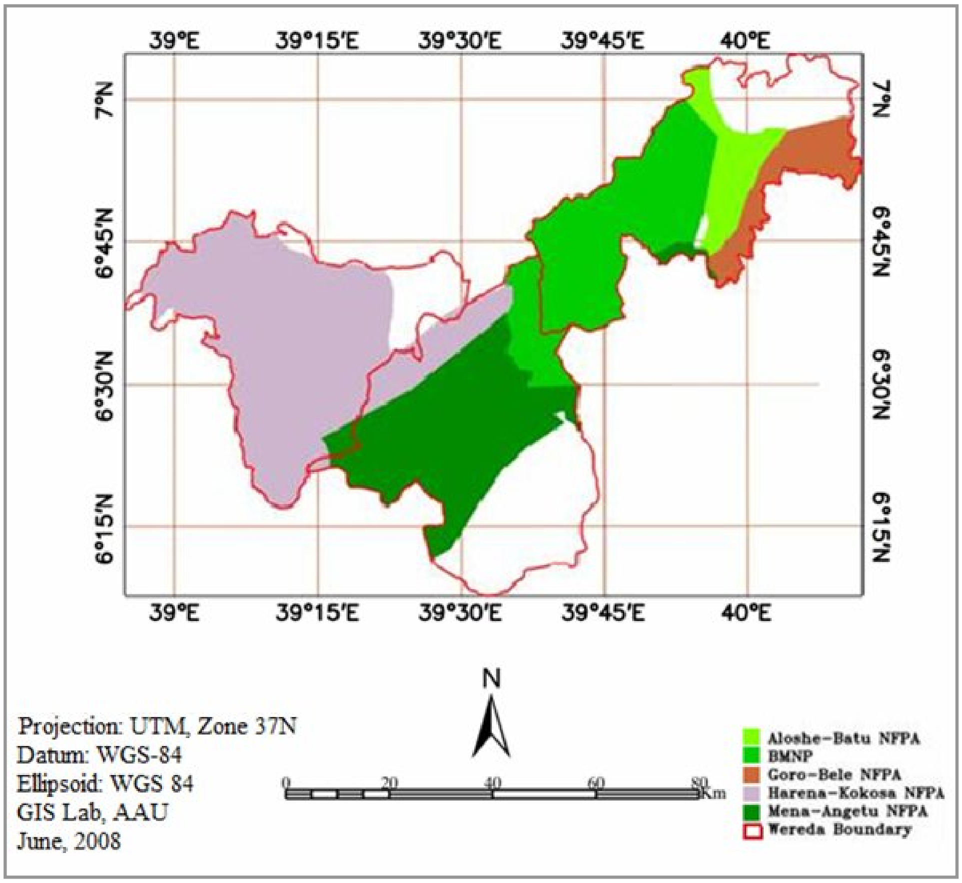

Figure 6: The study area constitutes parts of BMNP and surrounding NFPA's

Fauna

Wren (2007) noted that the Bale Mountain is the habitat for half of the population of the Ethiopian Wolf and the largest population of the Mountain Nyala, both are endemic to Ethiopia. The entire population of the giant mole rat, which is also endemic to Ethiopia, lives solely between 3100-4377m altitude of the BMNP. Among the mammals 26% and birds 6.1% and several species of amphibians that conquered the habitat are endemic to Ethiopia.

3.1.6 Water resource

A total of about forty rivers stream-out from the Bale Mountains, contributing to five major rivers, namely, the Web, Wabe-Shebelle, Welmel, Dumal and Genale and flow to the lowlands (Anteneh Belayneh and Temesgen Yohannes, 2008). More than 12 million people, vast number of livestock and the living environment in the south east of

Ethiopia and further in to Somalia are dependent on the water resources that originate from the Bale Massif (Wren, 2007).

3.1.7 Fire

Fire in the Bale Mountains has a long history and is likely to have been a natural feature of the *Erica* forest/shrub, Harenna forest and *Hagenia/Juniper* woodland (Miehe and Miehe, 1994). The main cause of the forest fire is a deliberate burning to induce sprouting of fresh vegetation for cattle grazing, clearing for cattle track and to ease hunting (Yosef Assefa, 2002).

The forest fire between February and April 2000 had destroyed more than ninety thousand hectares of the country's moist evergreen forest. Recently, another forest fire, recorded as the second severe, had also occurred in nine Woredas (Anteneh Belayneh and Temesgen Yohannes, 2008). Two of the studied Woredas, Goba and Harena Buluq were among the five major Woredas in which the fire was out of control and only extinguished naturally. They had also reported the damage of an area of 1000 ha of bamboo forest by this fire in Goba Woreda.

3.1.8 Administration

The study areas, Goba, Harena Buluk and Nensebo are located in the Oromia National Regional State. Goba and Harena Buluk are under the administration of Bale Zone whilst Nensebo is administered under Western Arsi zone. Goba, Delo-mena and Werka towns are the seat for the administration of Goba, Harena Buluk and Nensebo Woredas, respectively. The study area is bounded by Dodola, Adaba and Dinsho Woredas in the North, Sinana and Berbere in the East, Delomena in the south, and the Sidama zone of SNNPRS in the West.

3.1.9 Population

The present settlers of Bale were animistic cattle breeders who were *Islamized* during the last few centuries. Until recently the highlands of Bale Mountains were less densely populated (Yosef Assefa, 2002). Based on CSA (2008) estimate, the population of Goba has the lowest population profile of the three studied Woredas with a total population of 40,737 of which, 20,134 were females and 20,603 were males.

Harena Buluk, representing 34.4 percent of the total population of the studied Woredas had 40,114 females and 41,368 males, making the population of the Woreda 81,482. The total population of Nensebo Woreda was 114,524 of which 57,570 was females and 56,954 was males. The population of Nensebo Woreda represent 48.4 percent of the total population of the studied Woredas (Figure 7).

As of 2007, some 94 percent of the total population dwelt on rural areas and the average household size was 4.8 (CSA, 2008).

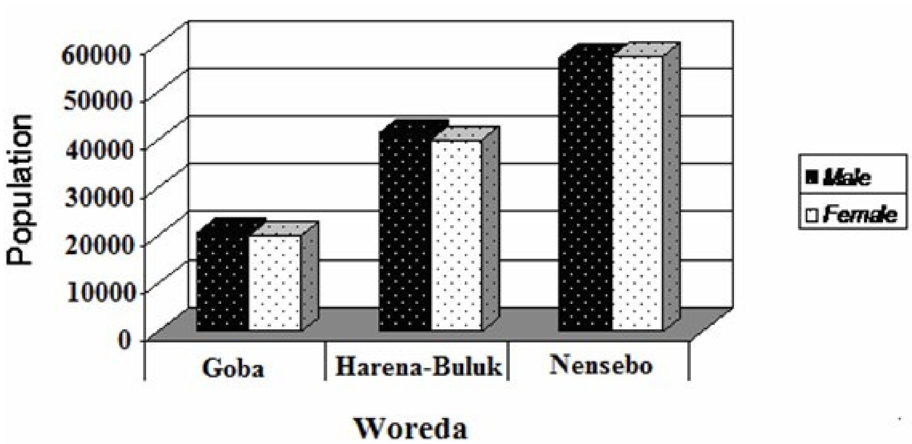

Figure 7: Population size of the studied area by Woreda and sex (source: CSA, 2008)

3.1.10 Economy

Agriculture is the most important sector of the economy for the study areas. Crop production, which is traditional and rain-fed, includes the cultivation of crops mainly Barley during the "mehr" (main) season and the planting of potato, onion, carrot, cabbage and beet during the rest of the months in Shedem area. Livestock is also a major source of livelihood.

3.1.11 Bamboo: tenure and livelihood

Bamboo tenure

In almost all parts of the eastern side of the study area (Goba and Harena Buluk), bamboo is under communal ownership and the planting of bamboo is not practiced. However, in the western part of the study area (Nensebo), bamboo from the remaining natural forests, which once served as a common pool resource, were overexploited, and are now mostly found as private holdings, planted in small patches nearby homesteads, on marginal and agricultural fields.

Resource for livelihood development

Bamboo is extracted to a large extent in the study area for sale and personal use. In Shedem, which is located at the eastern part of the study area, bamboo culms are sold in local markets at a price of 36 - 40 birr per horse load (Plate 2). According to the study of Arsema Andargatchew (2008), income from bamboo constitutes 47% of the average annual income of households in Shedem.

Plate 2: Bamboo transportation (horse load) from Shedem PA (Photo by Author)

Bamboo is mostly send to towns like Robe by carthorse and by lorries from Rira. At the time of data collection, it was observed that most of them pursue extraction and utilization activities that pose heavy pressure on the available resource (Plate 3). Arsema Andargatchew (2008) remarked that the harvesting method causes damages to young shoots, resulting in high disturbance for natural regeneration and growth process.

Plate 3: Non-selective bamboo extraction in Shedem area, (Photo by Author)

DGIS-WWF Ethiopia Project (Forest Conservation in High Priority Areas) in 2001 had provided (and recently the BESMP is also starting) training few local people in selected peasant administrations on new processing technologies. However, failure to provide appropriate production tools as a start on one hand (as exemplified in Rira) and for those who can afford, facilitating market outlets on the other hand, were the short-comings assessed and need to be addressed for the efforts to bear fruits.

3.2 Dataset

3.2.1 Image data sets

Satellite images that have a medium resolution, namely, Landsat-7 ETM+ (Figure 8), with a spatial resolution of 28.5 m in the multi-spectral and 14.25 m in the panchromatic band from the year 2000 (Table 3) were used to determine the extent of bamboo resources in the areas under study. These scenes (Annex 6) were obtained from International Livestock Research Institute (ILRI) and all bands, except band 6, was used during the processing.

Table 3: Description of Landsat 7 ETM+ data used

Satellite	Instrument	Identification number	Date of exposure	No. of spectral bands	Spatial resolution
Landsat-7	ETM+	p167r55	28/11/2000	8	28.5m
		p167r56	28/11/2000		
		p168r55	05/02/2000		
		p168r56	05/02/2000		

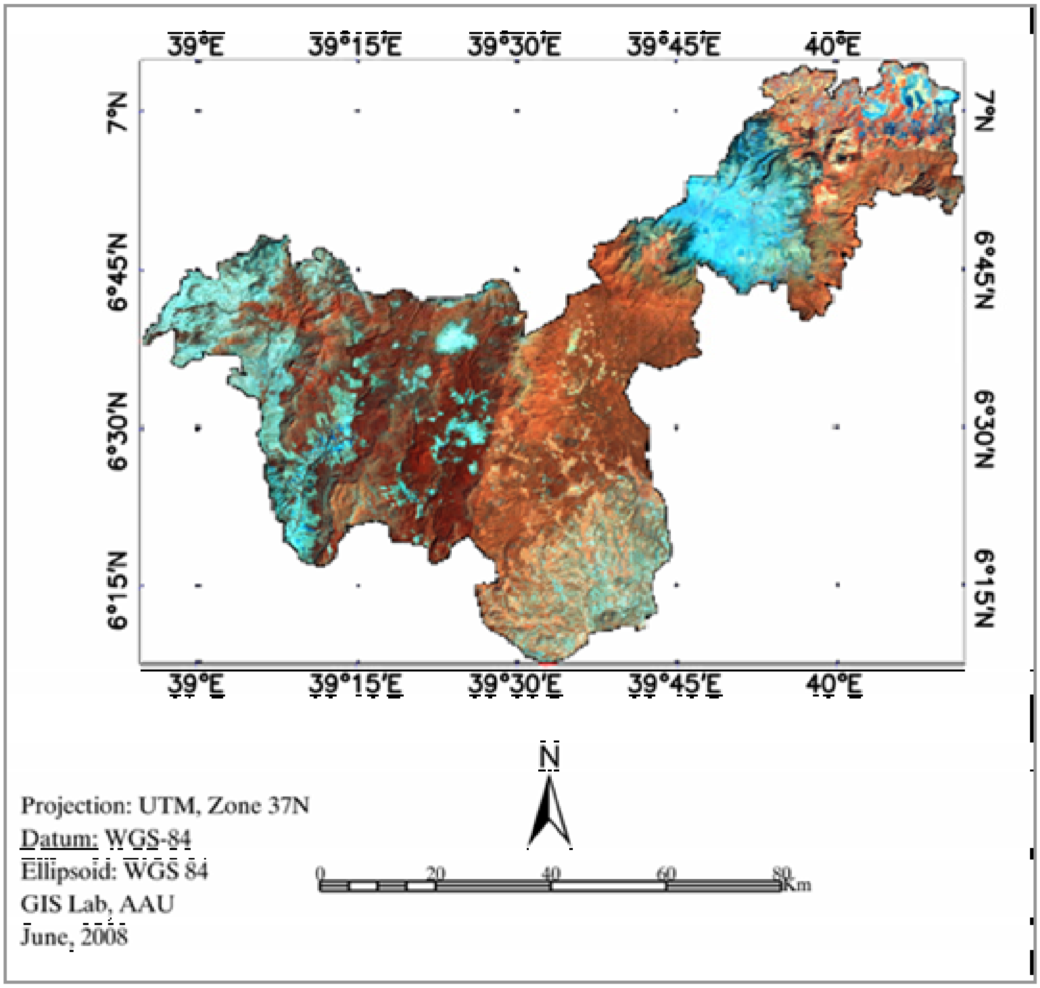

Figure 8: False colour composite Landsat 7 ETM+ image of the study area

3.2.2 Ancillary data sets

Different vector data were used for data merging and GIS integration (Table 4). Temperature and rainfall data of twenty one years (1986-2007) from NMSA, 2007 census data of CSA and 1:50,000 topographic maps of EMA produced in 1976 that cover the study area were also used in this study.

Table 4: List of vector data used

No.	theme	File type	Description	Data source
1	rainfall	shape (polygon)	Mean annual rainfall map of Ethiopia	LUPRD
2	thermal	shape (polygon)	Thermal zones of the country	LUPRD
3	contour	shape (line)	Contour map of Ethiopia	LUPRD
4	river	shape (line)	river map of Ethiopia	LUPRD
5	road	shape (line)	road map of Ethiopia	LUPRD
6	administration	shape (polygon)	administration map of Ethiopia	WBISPP
7	town	shape (point)	town map of Ethiopia	LUPRD
8	Soil	shape (polygon)	Soil map of Ethiopia	EthioGIS
9	Vegetation type	shape (polygon)	Classification by Chaffey	MoA

3.3 Data analysis

3.3.1 Image pre-processing and enhancement

Geometric rectification

The Landsat 7 ETM+ images were geo-referenced to the UTM WGS 84 zone 37N projection. To improve accuracy, it was rectified using several ground control points collected from the field and distributed over the image. For this, well-defined natural features such as river bends and anthropogenic features like road intersections were chosen as GCPs.

Sub-setting and Mosaicking

The Landsat 7 ETM+ image scenes received and the derived data sets were subset to the area of interest to accelerate the processing time. The images were also mosaicked to produce a seamless coverage of the study area.

3.3.2 Image classification and field verification

3.3.2.1 Unsupervised classification

As shown in the conceptual diagram selected for the comparison of the performances of the selected classification techniques (Annex 7) the main aim of this classification was to distingusih the dominant landcover types, as to direct the data collection and the characterization thereof during the field work. Isodata unsupervised classification to a minimum of eight and a maximum of twelve classes with twenty iterations was conducted and a preliminary land cover classes of the study area were developed.

3.3.2.2 Field work

Training data collection

The main aim of the training data collection was to provide adequate and representative data that accurately portray the spectral complexity of the identified land units. This enables the proper execution of the selected classifiers. The field work for training data collection was guided primarily by the unsupervised classification output of Landsat 7 ETM+ image, topographic maps and GPS. The sampling design employed was stratified sampling and data were collected from observation plots that have a size of 90 m^2.

At each plot, the species composition, percent cover of the different physiognomic vegetation types, and other relevant characteristic information were recorded (Annex 8). Furthermore, physical data including elevation, aspect and degree of slope were collected. All collected GPS data were exported to ENVI for the extraction of ROI (sub-title 3.3.2.3). Furthermore, the preliminary land cover units, which were made to have twelve different classes were later modified based on on-site registered data values with supplement of previous land cover classifications (CSUMPP, 2004).

Validation data collection

The main aim of this ground investigation was the acquisition of representative reference data from each land cover category to statistically assess the accuracy of the classification. In consultation with the BERSMP field team as to utilize their knowledge of the area and ensure the capture of the identified land cover classes, a total of 215 GPS points geographically distributed over the different land cover units were collected between June 5 and 22, 2008. These included 48 GPS points for “forest”, 40 for “heath/scrub land”, 51 for “bamboo forest”, 34 for “moore land” and 42 for “others” (including fallow, cultivated, wetland, grass and bare land).

3.3.2.3 Region of interest

Land cover signatures collected from the field were used as a spectral training data in the selected classification techniques. Recognition and delineation (on screen digitizing) of a group of pixel (ROIs) was made by superimposing the GPS points on the image. The spectral separability of each training class on the images were tested and modified for lower separability values by categorization of the ROIs and re-digitizing as to approach the highest level of separability. This ensured the accuracy of classification and the true interpretation of the results.

To visually identify and distinguish the purest pixels in the image, in which the purest pixels always form the very tip of a corner in the data cloud corresponding to one spectrally unique material in the image (ENVI, 2005), check on the statistical separability between category response pattern for all pair of classes (Leillsand and Kiefer, 2000) had been done through different band combinations using the n-D visualizer of ENVI (Figure 9).

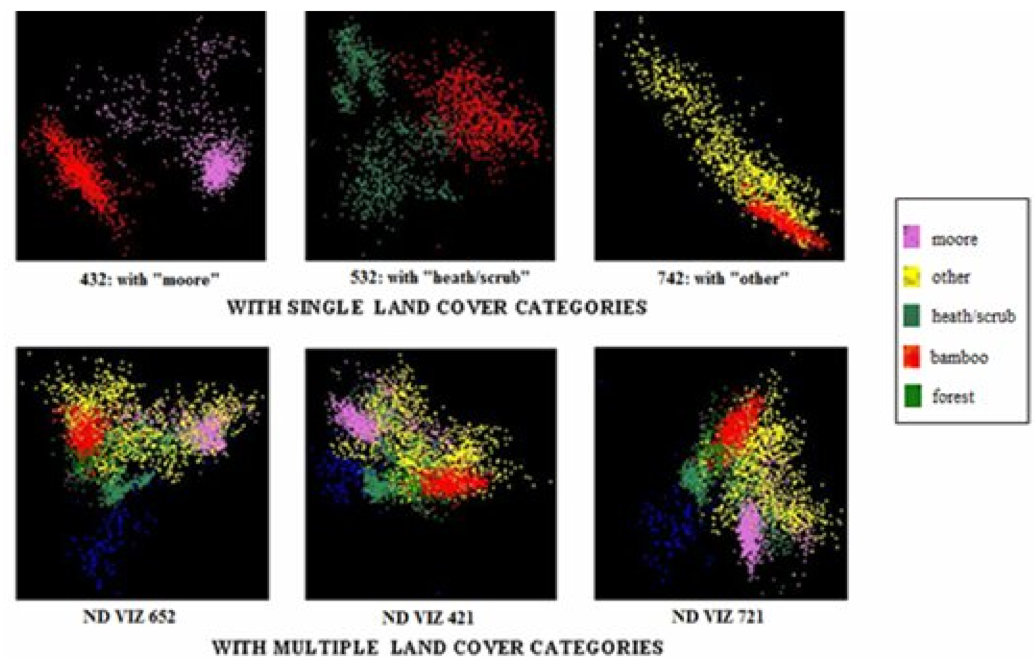

Figure 9: Identifying end members using n-D visualizer

The depiction of statistical separability suggested, which training data added confusion, were spectrally similar to other classes and should be dropped before classification of the full image. This information indicated which areas of the spectrum were most helpful in the separation of the classes (Laba *et al.* 2006).

3.3.2.4 Maximum likelihood classification

One of the images classification technique considered for comparison was Maximum likelihood. The classification process involved the use of the previously defined training classes (subtitle 3.3.2.3), as a means of estimating means and variances of the classes, which were then used to estimate probabilities - the probability that a pixel belongs to one of the five particular classes. After the implementation of the classification using ENVI, comparison was made with the colour composite image and the unsupervised classification as to its efficiency and statistical results were derived.

3.3.2.5 Decision tree classification

A decision tree was built using ENVI decision tree tool and the process involved tree structuring based on decision rules. Inputs were characteristics of the data set such as the spectral response in the different bands of the image (derived from the same training data set as used for Maximum likelihood) and image derived data sets: the tasseled cap. Tests made include use of ancillary data such as the produced potential growing map of the area and DEM.

At each branch of the partitioning, the variables were evaluated as to find the best spectral break points that separate the data groups into one of two possible classes or group of classes. Thresholds were identified using the basic statistical report of the specific bands of the input data. These were utilized separately and /or in combination with others as to determine the correct category for each pixel.

After decision rules were entered and associated pairing of variable and bands were made, the properties of each node were edited in a way that depicts the parameters assigned. In the same manner, additional decision rules were entered in the path from the root node to the terminal nodes to enable the segmentation of the image into the different identified land units. In this way the hierarchal structure of the tree was created to perform the image classification (Figure 10).

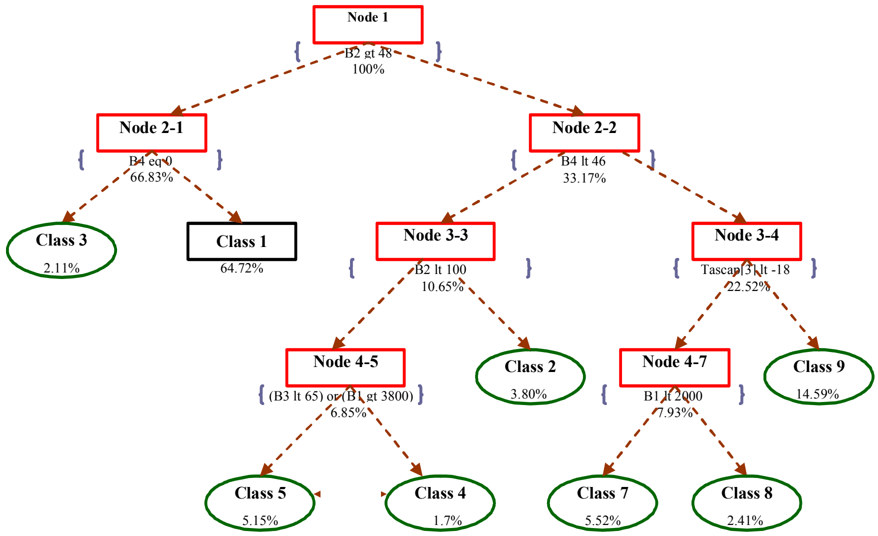

Figure 10: The structure and variables used for decision tree classification

A spectral reflectance greater than 48 in the green band (0.53-0.61µm) allowed to distinguish some of the forest areas intermingled with the boundary. The latter was masked as it had a value of zero in the near infrared band (0.75-0.9µm). From the survivors of the previous node (the root node), a general distinction of the moore, heath / scrub land, and a large amount of the "other" class on one hand, and the major part of "forest", "bamboo", and a small part of "other" class on the other hand was made by employing a threshold of 46 in the near infrared band.

The "heath / scrub land" was segregated (from the previous pixels with values higher than 46 in the infrared band), as it had a reflectance value lower than 100 in band 2. On this same branch, separation of the "moore" class and the large amount of "other" class was made possible by filtering the remaining pixels with a threshold value lower than 65 in band 3 (0.63-0.69µm), and an elevation higher than 3800 m.a.s.l., which was also a characteristics of the "moore" class.

Distinction between the major portion of the "forest" class from the few "other" and "bamboo" units was made by applying the tasseled cap transformation. Values exceeding the threshold of -18 in the wetness (band 3) of the Tasseled Cap were further extracted into "bamboo" and "other" by differentiating those pixels with elevation lower than 2000m into the "other" class.

3.3.3 Accuracy assessment

The purpose of the accuracy assessment was to determine the reliability of the classification and to understand the nature of map errors (Laba *et al.*, 2006; Congalton, 1991).The performance results of Decision tree and Maximum likelihood classification techniques in discriminating *Y. alpina* from other land cover categories were assessed by relying mainly on the error matrix reported for each classification results. This was done by using ENVI's post classification (Confusion Matrix) module.

To assess the accuracy of the classification, a total of 215 observation plots (sub-title 3.3.2.2: *validation data*) were used as a reference data set. The registered geographic coordinate for the center of plots were overlaid on the image and enabled to derive the independent ROI. By comparing the validation data (in columns) with the classification result (in row), the overall, producer and user accuracies and as well Kappa coefficient were also calculated.

3.4 Potential Growing Areas of *Y. alpina*

3.4.1 Purposes

The purpose of developing suitable zones of the species was to provide an indication of the potential areas for the growth and future expansion of *Y. alpine*. Furthermore, it will also help in guiding the establishment of observation plots from which detailed ecological requirements of the species and their influence on the growth of *Y. alpina* shall be investigated (at class or sub-class level) suitability mapping.

3.4.2 Input data

In order to map areas suitable for the growth of highland bamboo, physical and climatic factors from secondary sources were used. Different studies (LUSO, 1997; Kassahun Embaye, 2003) had noted that altitude, rainfall and temperature are the major governing factors for the distribution of *Y. alpina*. Having this as a basic information, the following specific climatic and physiographic parameters were used to develop a map of the potentially suitable areas for the growth of the species (Table 5).

Table 5: Summary of *Y. alpine* environmental requirements

	Parameter	**Range**
Climatic	Temperature (^oC)	10 - 20
	Rainfall (mm)	1500 - 2000
Physiographic	Elevation (m)	2200 – 3500

3.4.3 Description of input data

Rainfall

In Ethiopia, the highest rainfall occurs in the southwestern highlands of Illubabor, near Gore, and in fact all highland areas, above 1000 m elevation, in the southwestern part of the country, receive an average annual rain fall ranging between 1400 - 2200 mm. For much of the remaining highland areas of the country above 1700m elevation, the annual received rainfall vary between 1000 - 1800mm. Generally, higher elevations receive much more rainfall than areas located in lower elevations (LUPRD, 1983).

Kassahun Embaye (2003) and LUSO (1997) noted that highland bamboo requires an average annual rainfall between the ranges of 1500 - 2000mm. Therefore, in consideration of this requirement, meaningful rainfall categories were derived from the existing rainfall map (Figure 11).

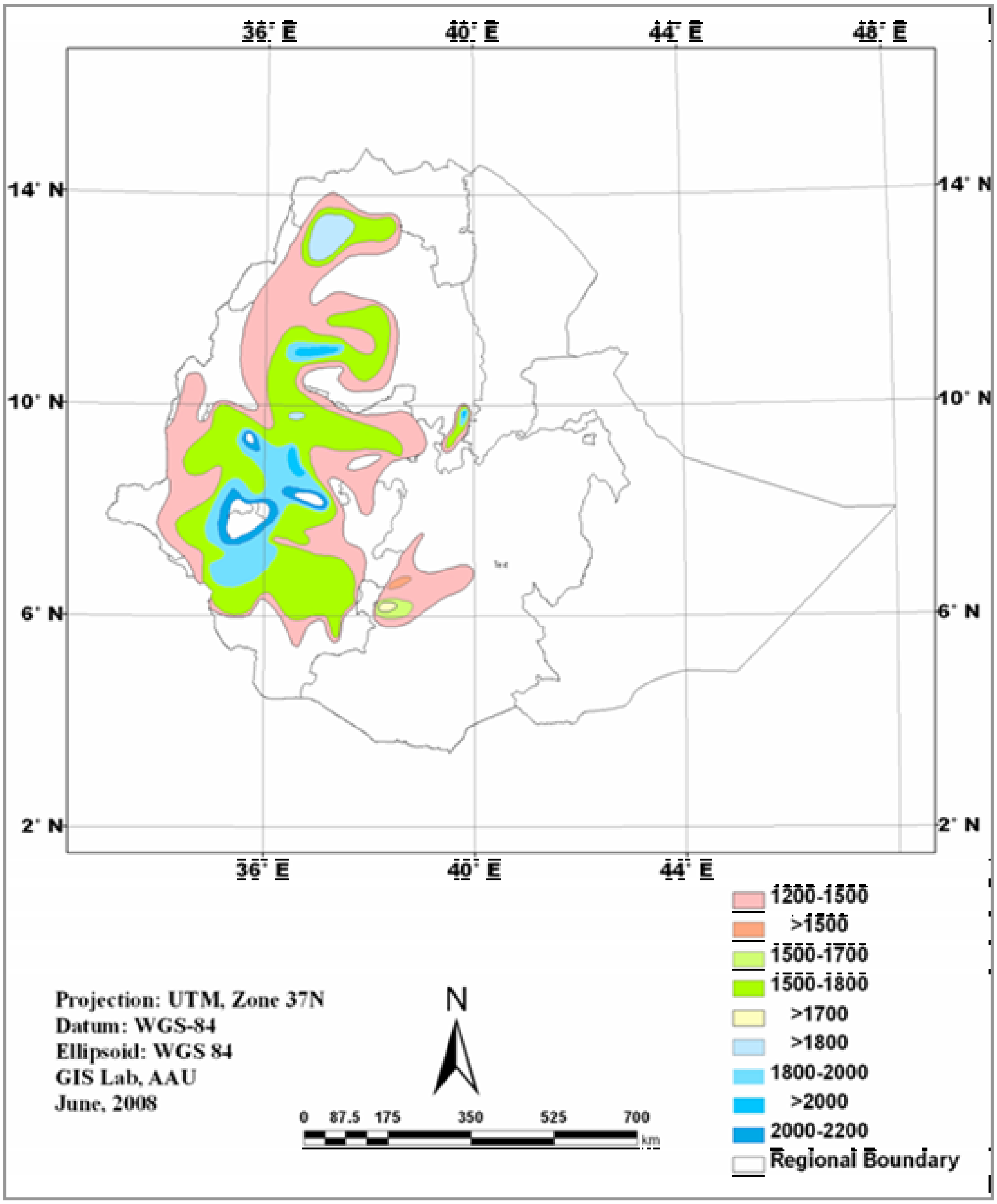

Figure 11: Potential growing areas of highland bamboo –suitable rainfall regimes

Temperature

Temperature is the other basic climatic factor used to develop the potential bamboo growing areas of the country. Extremes in temperature in Ethiopia range from the Danaki depression (about 125m below mean sea level) with a mean daily temperature of 34.5°C for the year to mountain slopes over 4000 m.a.s.l., where minimum temperature fall below zero, overnight. Between these extremes are vast areas of highland plateau and marginal slopes where the average temperatures range in between (LUPRD, 1983).

The temperature requirements of *Y. alpina* is between 10 to 20^{o}C. Therefore, areas that meet this criterion were selected to identify suitable temperature zones of highland bamboo.

During the reclassification of the thermal suitability map, it was found that the minimum temperature was short of covering some identified bamboo areas. Accordingly, further investigation was made to identify the cause and it was found that this is due to the overlapping of the upper and lower temperature range limits. Therefore, adjustment was made by incorporating the thermal zone of 7.5-10, which had the risk of extending the suitable temperature zone of *Y.alpina*. Nevertheless, close visual scrutiny revealed that the addition of this category permits the inclusion of small areas in the central northern and southeastern highlands. Later, with the overlay of the selected environmental requirements, this further diminished the inclusion to a negligible area, but was able to encompass the secluded known bamboo areas in the Bale highland (Figure 12).

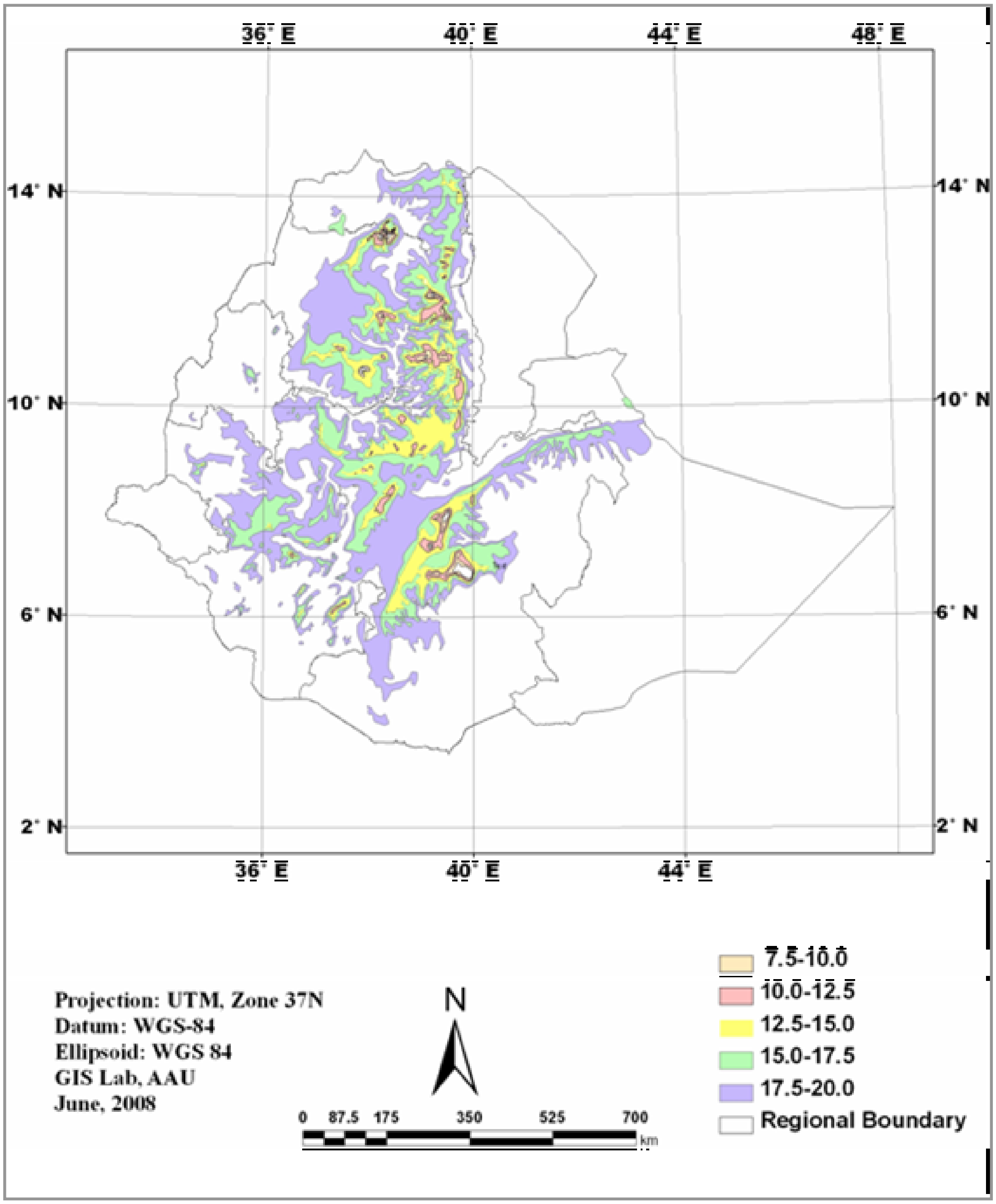

Figure 12: Potential growing area of highland bamboo - suitable temperature zones

Altitude

The single physiographic parameter used in this study is altitude. Most of the Ethiopian plateau lies above 2000m altitude and comprises extensive areas of structurally horizontal table land (LUPRD, 1983). The suitable altitudinal zones cover the ranges between 2200 and 3500 m.a.s.l. (Figure 13).

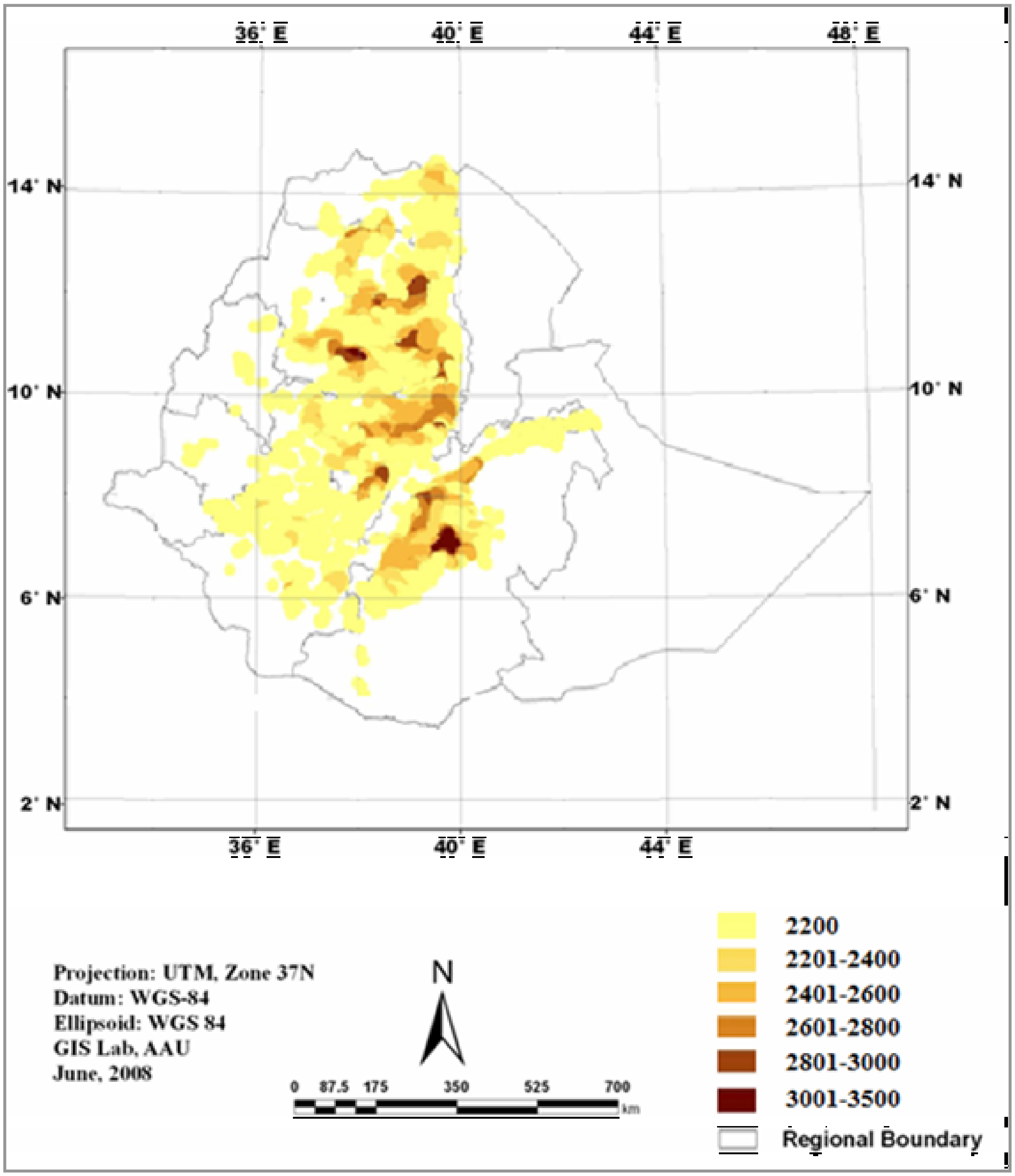

Figure 13: Potential highland bamboo growing area – suitable altitude zones

3.4.6 Analytical framework

A framework (Figure 14) was developed to identify potential bamboo growing areas from the available input maps that match the environmental requirements.

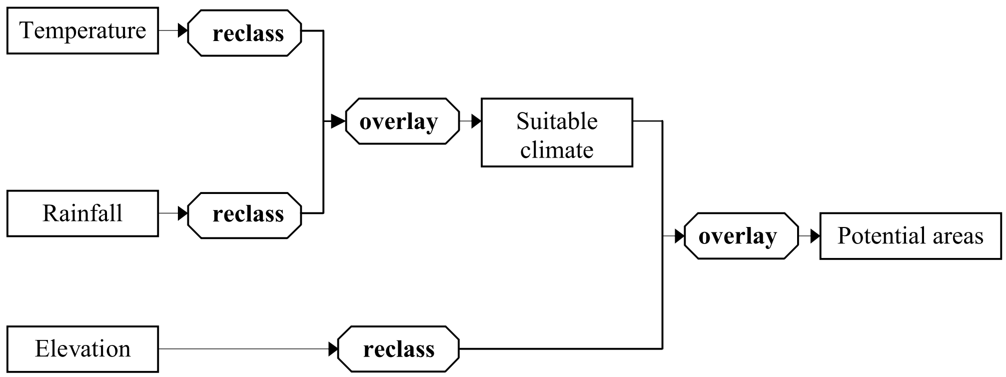

Figure 14: Cartographic model used in the identification of potential Bamboo zone

Steps followed include the production of suitable temperature, rainfall and elevation maps by reclassifying as per the required suitable range. Later on, these data sets were overlaid in order to derive the potential areas. At each step of the process, the outcomes were inspected for inconsistencies in reference essentially to existing publications and consultation.

3.5 Image Processing Software and Equipment used

3.5.1 Image processing software

ENVI 4.3, a software for the visualization, analysis, and presentation of all types of digital imagery, was used to conduct the image processing and analysis of this study. Further more, ArcGIS 9.1, a product of ESRI, had also been used for data manipulation, editing and viewing of the geographic and the tabular data.

3.5.2 Data processing software

Microsoft Office Excel 2003, part of Microsoft Office Profession Edition 2003, was used for the analysis and presentation of collected data.

3.5.3 Equipment

Garmin 12 GPS and Silva-compass were used during the field survey for identification, verification of land cover units, marking of training areas and to locate ground control points. Furthermore, desktop and notebook computers were also used for entry, processing and analysis of different input data.

4. RESULTS AND DISCUSSION

4.1 Classification

4.1.1 Potential growing areas of *Y. alpina* in Ethiopia

Taking into account the climatic and physiographic conditions of the country, the potential suitable areas for the growth of *Y. alpine* had been mapped. Furthermore, the integration of soil data and as well vegetation types have allowed a more comprehensive assessment of the identified units. Tested with reference to published materials and in consultation with experienced field workers, the derived units are considered fairly good in accuracy by comparison with existing bamboo resources.

Against a background of poor knowledge of bamboo distribution (Jinhe, undated) and as a first step in improving the information available, the International Network for Bamboo and Rattan (INBAR) and the UNEP-WCMC had jointly produced regional distribution maps of all species of woody bamboos occurring in Africa, North, Central and South America. This was done by combining qualitative data on the distribution of woody bamboos with global data on existing forest cover to determine the distribution, and to estimate the total area of forest containing bamboo.

LUSO (1997) had attempted to map the potential bamboo growing areas of Ethiopia. Input data were average annual rainfall (deduced from the mean annual rainfall map prepared in 1982 by EMA) and altitude (extracted from general road map by the same and revised in 1992). However, the mapping had a repercussion on the distribution as it was not able to identify the entire south eastern bamboo growing areas of Ethiopia and some known places of the central highland. In spite of this, no subsequent refinements had been made.

The identification of the potential growing area is useful for a wide variety of users ranging from bamboo researchers to end-users engaged with planning, implementation and assessment of bamboo development activities. The information would be useful for the expansion of future plantation activities to become restricted to these areas in order to be successful. It also provides projects involved in improving the livelihood of the local people an alternative to evaluate the environmental and economic returns from introduction of bamboo on the landscape.

The analysis has revealed the mapped potential highland bamboo (*Y. alpina*) growing areas cover 7,632,788ha, constituting about 6.74 percent of the area of the entire country (Figure 15). Among the mapped areas, about 3% is in the Oromia NRS, 2.33% in the Amhara NRS and some 1.2% in the SNNPRS (Table 6). Tigray, Benshangul, Gambella, Harari NRS and Addis Abeba Administration have a potential growing area ranging from 200 to 120,000 ha. Whereas, Dire Dawa Administration, Afar and Somali NRS have no potential highland bamboo growing areas.

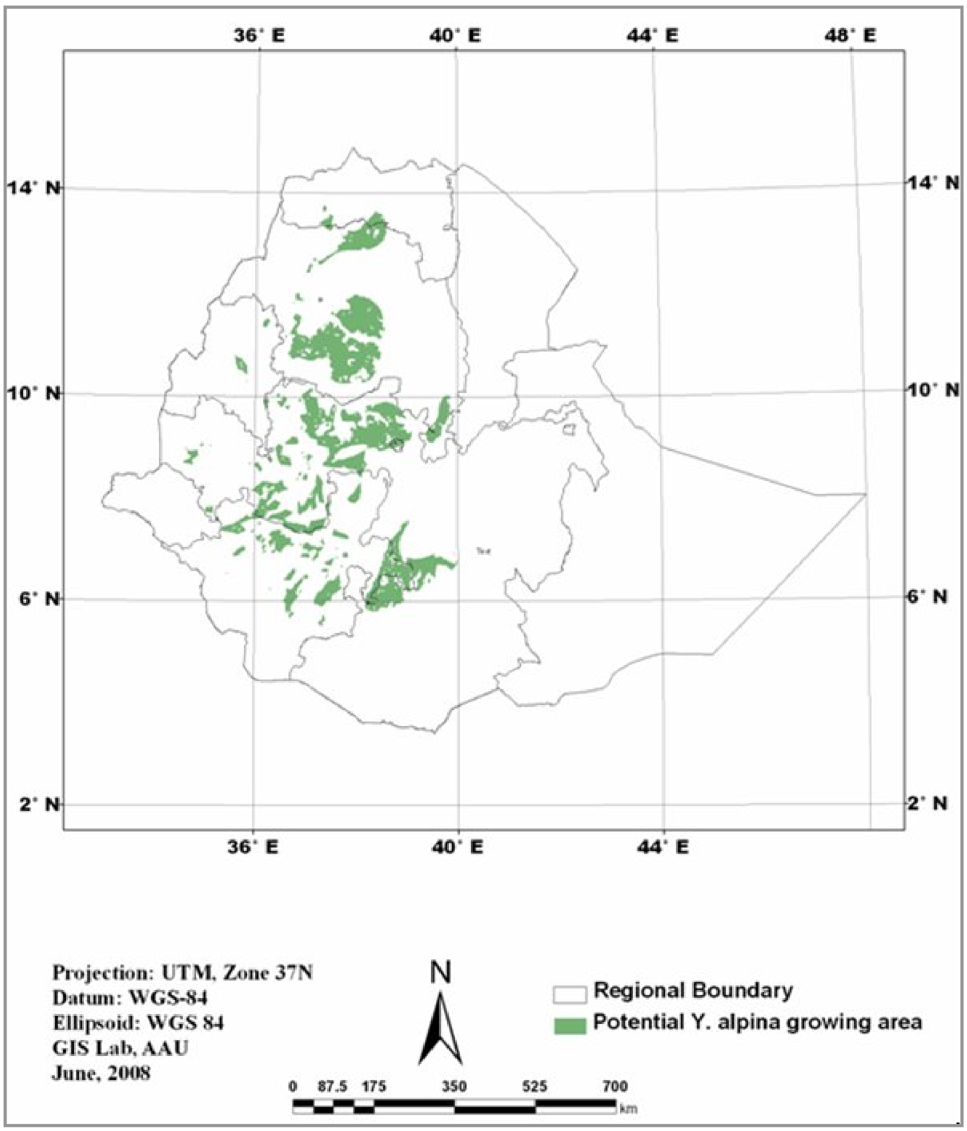

Figure 15: Potential Highland Bamboo (*Y.alpina*) Growing Areas in Ethiopia.

Table 6: Distribution of potential highland bamboo growing area by Regions

Region name	Total area (in ha)	Potential area (in ha)	% potential from country
Addis Abeba	51,997	35,348	0.0312
Afar	9,524,289	0	0
Amhara	15,344,358	2,641,859	2.3320
Benishangul-Gumuz	4,888,917	78,335	0.0691
Dire Dawa	150,709	0	0
Gambella	2,564,936	247	0.0002
Harari	39,968	567	0.0005
Oromia	35,542,348	3,399,094	3.0004
Somali	27,807,358	0	0
SNNPRS	11,726,315	1,357,073	1.1979
Tigray	5,645,153	120,267	0.1062
Total	**113,286,348**	**7,632,790**	**6.7376**

The extent of the potential highland bamboo growing areas within the studied Woredas are given in Figure 16.

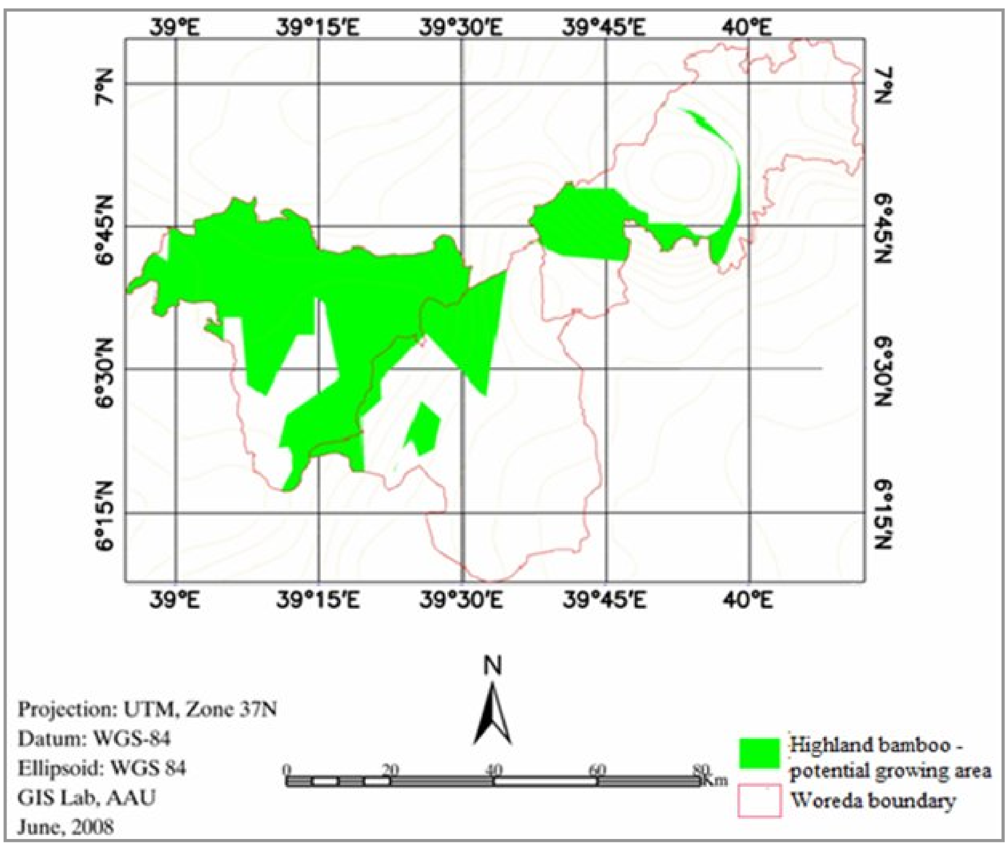

Figure 16: Potential highland bamboo growing areas of the study area.

In these Woredas, the potential highland bamboo growing area covers an area of about 200,524.00 ha (38.07 percent of the study area). Of these, about 25.89% is found in Nensebo Woreda and some 5.87% in Goba and 6.32% in Harena buluk (Table 7). The total calculated figure for the study Woreda constitutes some 2.63 percent of the country's potential growing area.

Table 7: Potential highland bamboo growing area distribution in the studied Woredas

Woreda	Total area (in ha)	Potential area (in ha)	% potential from study area total
Goba	163,733	30,912	5.87
Nensebo	169,854	136,344	25.89
Harena buluk	193,117	33,268	6.32
Total	**526,704**	**200,524**	**38.07**

The overlay of the potential highland bamboo growing area over the soil map of Ethiopia shows approximately half of these areas are dominated by only four types of soils (Figure 17), namely Dystric Nitisols (16.34%), Eutric Cambisols (14.41%), Chromic Luvisols (11.12%) and Pellic Vertisols (10.82). The superimposition of the current classification over the soil map further revealed highland bamboo are dominantly associated with Orthic Luvisols and Chromic Luvisols and with not less correlation with Eutric Cambisols, Eutric Fluvisols and Eutric Nitosols within the study area.

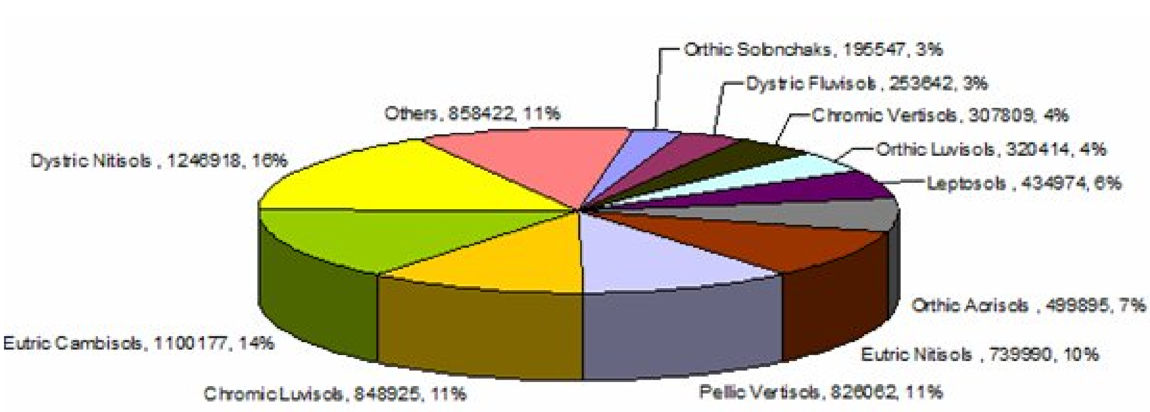

Figure 17: Soil types of the national potential *Y.alpina* growing areas.

4.1.2 Existing land cover classification

The unsupervised classification of Landsat 7 ETM+ had generated twelve land cover classes (Figure 18). Later on, these land cover types were generalized into five broad land cover categories. The major driving factor for this aggregation was the results of analysis of on-site registered data values, the similarity in the spectral reflectance exhibited toward separation from bamboo lands and with supplement of previous land cover classification outcome. These classes were forest, heath/scrub land, bamboo forest, moore and others (comprising grassland, fallow, cultivated lands and other land cover types). The description of the identified land cover classes (Annex 10) gives the minor land cover classes incorporated, the mapping symbol used and their general distribution within the study area.

During the field survey, it was noted that the unsupervised classification had mapped the “moore” and “heath/scrub” in a good way and to a certain extent the “other” and “forest” land. However, it was not able to separate the bamboo from the “forest” class.

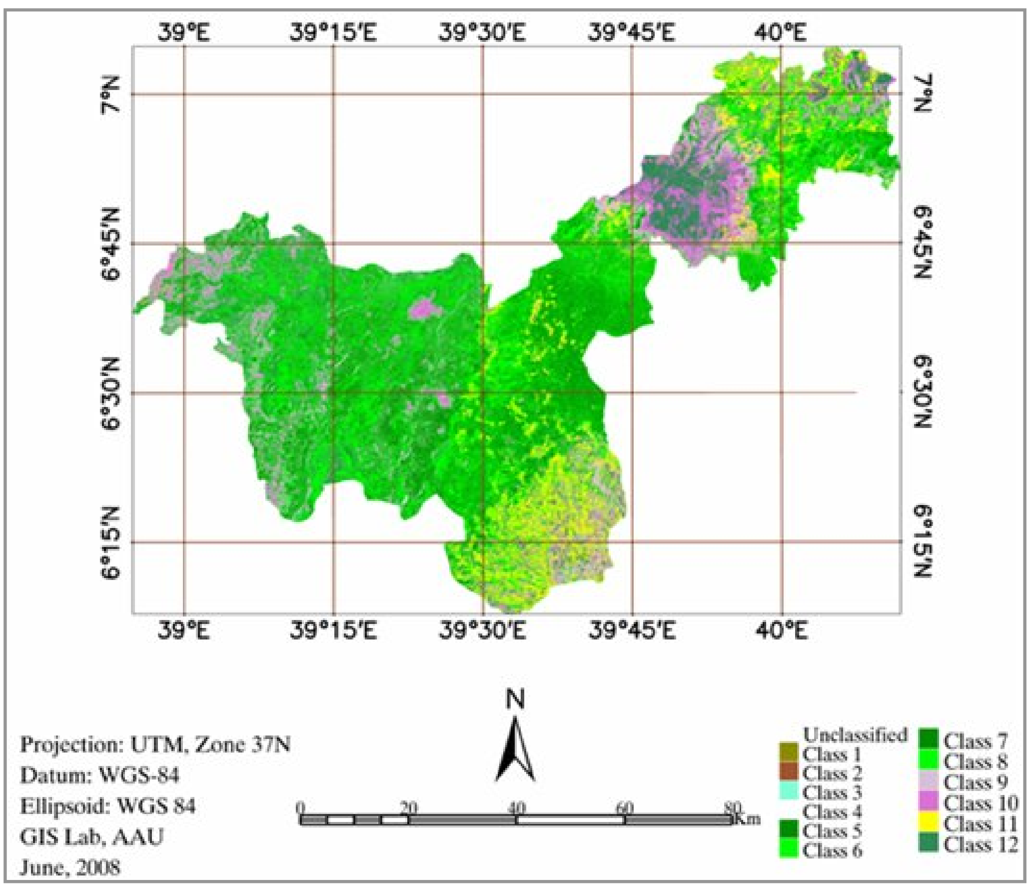

Figure 18: Unsupervised classification result of Landsat 7 ETM+ data

4.1.3 Maximum likelihood supervised classification

The maximum likelihood supervised classification method had made distinction and mapped all the identified five broad land cover classes (Figure 19). Based on this classification, the “forest” class occupied the majority of the study area and had an area of 264, 691.32ha (50.25%). The “heath/scrub land” had an area of 31,229.14ha (5.93%) and was predominantly located in the side slopes of Sanetti plateau.

The “bamboo” was found along the north eastern part creating a belt at the foot slopes of Sanetti and also in the middle top of the classified image. This unit covered an area of 63,407.32ha (12.04%). The “moore” was mainly restricted to Sanetti plateau and had an area of 28,842.02ha (5.48%). The “other” class had an area of 126,772.73ha (24.07%) and is typically found in the southern, western and north eastern part of the study area.

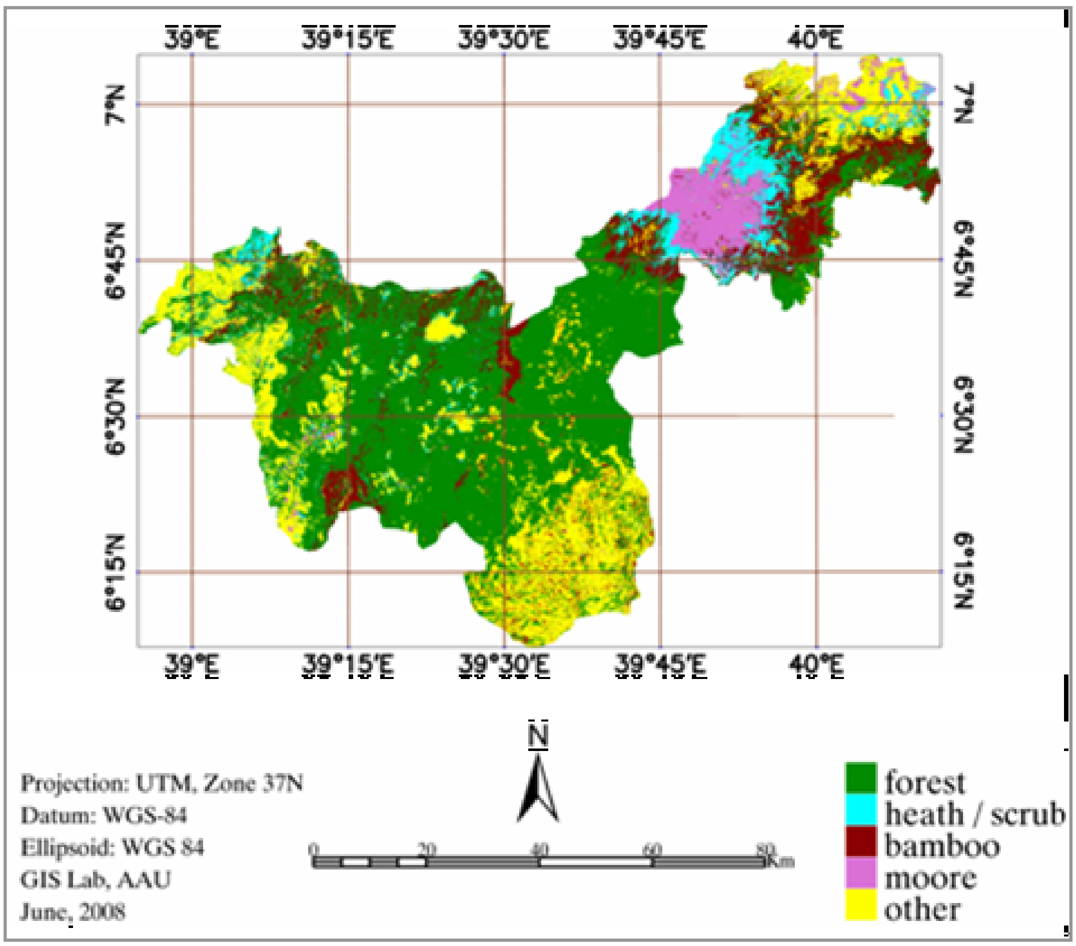

Figure 19: Maximum likelihood classification

Even if good approximation was made on the spectral separability of classes, there were limited visible bamboo units on the western side of the study area. This was attributed to the occurrence of highly fragmented (mostly having an area size lower than $25m^2$) in comparison with the spatial resolution of the image used ($28.5\ m^2$). Moreover, as it was a private holding bamboo plantation on agricultural fields, nearby homesteads and marginal lands in small patches, it was found dispersed on the landscape.

4.1.4 Decision tree classification

The decision tree classification algorithm as applied to Landsat 7 ETM+ had also mapped the five identified land cover classes (Figure 20). The classification had made use of band 2, band 4 and potential zone twice, and wetness band of tasseled cap and band 3 only once. The tasseled cap transformation and parameters used in the potential bamboo growing areas were the strong identifiers in the extraction of bamboo from other land cover categories of Bale highlands. The tasseled cap enabled separation of the bamboo unit from the forest class as the latter exhibited a structural complexity.

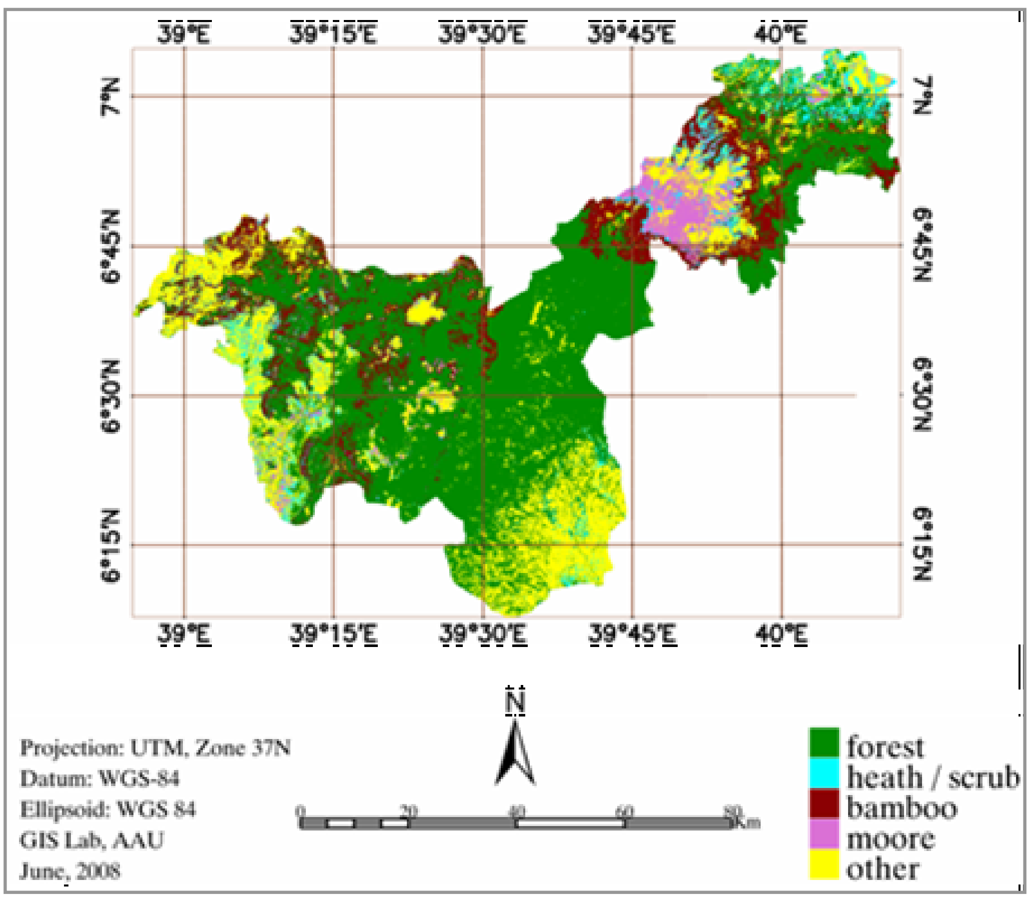

Figure 20: Decision tree classification

Accounting for 52.86% of the total study area, the “forest” (F1) class is the major unit and had an area of 278,394.30 ha. The “heath/scrub” land constitutes 6.36 % of the study area and had an area of 33,503.85 ha. “Bamboo” had an area of 68,550.00 ha and “moore” some 21,794.45 ha, making up 13.01% and 4.14% of the study area, respectively. Being the second major unit, the “other” category had an area of 118,720.98 ha, constituting 22.54% of the study area. A simple ocular investigation shows a similarity in the general distribution pattern of all land cover categories with the supervised classification result. Discrepancies, however, exist and will be discussed in detail in sub-title 4.2.

4.2 Accuracy assessment

4.2.1 Accuracy of the decision tree classifier

The overall accuracy of the Decision Tree classification was estimated to be 66.7% and the Kappa statistics was 0.55 (Table 8).

Table 8: Error matrix for single class decision tree classification

		Reference Data (pixel)							
	Class	Forest	Heath/ Scrub	Bamboo	Moore	Other	**Total**	Users Accuracy (%)	Error of Commission (%)
Classified Data	Forest	**1020**	165	1	0	328	1514	**67.37**	**32.63**
	Heath/ Scrub	0	**275**	0	13	50	338	**81.36**	**18.64**
	Bamboo	66	63	**62**	0	78	269	**23.05**	**76.95**
	Moore	0	38	0	**335**	0	373	**89.81**	**10.19**
	Other	0	41	56	270	**794**	1161	**68.39**	**31.61**
	Total	1086	587	121	618	1255	3667		
Producers Accuracy (%)		**93.92**	**46.85**	**51.24**	**54.21**	**63.27**			
Error of Omission (%)		**6.08**	**53.15**	**48.76**	**45.79**	**36.73**			
Overall Accuracy = (2486/3667) 67.7938%									
Kappa Coefficient = 0.5619									

The ability of the decision tree classification method in discriminating bamboo from other land cover categories was only 62 from the reference 121 pixels, resulting in a user's accuracy of only 23.05 and producer's accuracy of 51.24. The inaccuracies were resulting mainly from confusion with the "other" land cover category, as shown by the fact that 56 pixels that are truly bamboo were misclassified as "other" (N). The reason for this might be attributed to the inclusion of grassland vegetation and within it, particularly in northeastern part of the study area and as well Nensebo Woreda, the occurrence of evergreen herbacious species into "other" unit, which can significantly contribute to the confusion.

Unlike the other identified land cover types, the high error of commission for the bamboo class are caused by misassignment of most other categories, with the exception of "moore" to the "bamboo" class.

A Kappa value of 0.5619 was reported with the decision tree classification technique. This showed a probability of 56 percent better accuracy with the employed classification than if the classification resulted from a random, unsupervised, assignment.

Comparison was also made by merging other land cover units to a class "non-bamboo" (Table 9). With this, an overall accuracy of 94.6 was achieved, but as the chance agreement increases, a lower Kappa value of 0.33 was registered.

Table 9: Error matrix for merged classes decision tree classification

	Class	Reference Data (pixel)			Users Accuracy (%)	Commission (%)
		Bamboo	Non-Bamboo	Total		
Classified Data	Bamboo	56	133	**189**	**29.63**	**70.37**
	Non-Bamboo	65	3413	**3478**	**98.13**	**1.87**
	Total	**121**	**3546**	**3667**		
Producers Accuracy (%)		**46.28**	**96.25**			
Omission (%)		**53.72**	**3.75**			
Overall Accuracy = (3469/3667) 94.6005%						
Kappa Coefficient = 0.3345						

4.2.2 Accuracy of the maximum likelihood classifier

The Maximum likelihood classification had an overall accuracy of 87.75% with a Kappa coefficient of 0.8370 (Table 10). User's and producer's accuracy results for bamboo were 40.56% and 83.47%, respectively. The low user accuracy resulted mainly from confused pixels to "other" and "forest" classes. The confusion with the "other" category might be related to spectral similarity exhibited towards "bamboo" as the former class had encompassed different land cover units including grassland and wetlands. Compared to other land cover classes, the bamboo class has the lowest user's accuracy, but had a relatively similar producer's accuracy with other classes that range between 80 and 95%. Single class error of omission ranges between 4 and 20%.

Table 10: Error matrix for single class maximum likelihood classification

	Class	Reference Data (pixel)							
		Forest	Heath/ Scrub	Bamboo	Moore	Other	**Total**	Users Accuracy (%)	Error of Commission (%)
Classified Data	Forest	**1007**	2	4	0	164	1177	**85.56**	**14.44**
	Heath/ Scrub	0	**559**	8	20	23	610	**91.64**	**8.36**
	Bamboo	63	10	**101**	4	71	249	**40.56**	**59.44**
	Moore	0	7	2	**552**	4	565	**97.7**	**2.30**
	Other	12	5	6	42	**985**	1050	**93.81**	**6.19**
	Total	1082	583	121	618	1247	3651		
Producers Accuracy (%)		**93.07**	**95.88**	**83.47**	**89.32**	**78.99**			
Error of Omission (%)		**6.93**	**4.12**	**16.53**	**10.68**	**21.01**			
Overall Accuracy = (3204/3651) 87.7568 %									
Kappa Coefficient = 0.8370									

Moreover, there exists more error of commission in the bamboo class than omission. As Milliken et al. (1998) noted, from this it can be inferred that this class was probably over mapped. And as most of these errors of commission occurred with the "other" and "forest" classes, these units were probably under mapped and misidentified as bamboo.

Comparison was also made by merging other land cover units to a class "non-bamboo" (Table 11) and an overall accuracy of 95.39, which was almost similar with Decision tree, was achieved. However, a lower Kappa value of 0.52 was registered.

Table 11: Error matrix for merged classes maximum likelihood classification

	Class	Reference Data (pixel)			Users Accuracy (%)	Commission (%)
		Bamboo	Non-Bamboo	Total		
Classified Data	Bamboo	101	148	**249**	**40.56**	**59.44**
	Non-Bamboo	20	3382	**3402**	**99.41**	**0.59**
	Total	**121**	**3530**	**3651**		
Producers Accuracy (%)		**83.47**	**95.81**			
Omission (%)		**16.53**	**4.19**			
Overall Accuracy = (3483/3651) 95.3985%						
Kappa Coefficient = 0.5247						

4.2.3 Comparison of the performance of the selected classification techniques

The overall accuracy of the Maximum likelihood classification was 87.75% whilst the overall accuracy of the Decision tree classification was 67.79% (Table 12).

The single class user's accuracy value for bamboo by the Maximum likelihood classification showed that there were 101 pixels correctly classified as bamboo. This informs the user of the classified data to be 40.56% certain that a pixel classified as bamboo is correctly classified relative to the same type on the ground. Whilst the decision tree correctly classified only 62 pixels from the same reference data, indicating the user of the classified image can be 23% sure of the bamboo pixels as being truly bamboo on the ground. Unlike the decision tree the confusion with other classes was lower in the Maximum likelihood classification.

Table 12: Summary of class user's and producer's accuracy

Class	Decision Tree		Maximum Likelihood	
	Producer's accuracy	User's accuracy	Producer's accuracy	User's accuracy
Forest	93.92	67.37	93.07	85.56
Heath/Scrub	46.85	81.36	95.88	91.64
Bamboo	**51.24**	**23.05**	**83.47**	**40.56**
Moore	54.21	89.81	89.32	97.7
Other	63.27	68.39	78.99	93.81

Moreover, the Kappa statistic for maximum likelihood (0.84) is significantly higher than that of decision tree classification (0.56). It can thus be said that the maximum likelihood classification technique had relatively worked well in discriminating bamboo areas from other land cover categories as compared to the decision tree classification technique.

The percentage distribution for each land cover type (Table 13) shows that the decision tree algorithm had reported a higher value for "forest", "heath/scrub", and "bamboo" and a lower value for "moore" and "other" by the Decision tree classifier as compared to the Maximum Likelihood Classifier.

Table 13: Summary of classified land cover area

Land cover class	**Maximum Likelihood**		**Decision tree**	
	areas (ha)	**percentage**	**areas (ha)**	**percentage**
Forestland	264,691.32	50.25	278,394.30	52.86
Heath / scrub land	31,229.14	5.93	33,503.85	6.36
Bamboo	63,407.32	12.04	68,550.00	13.01
Moore	28,842.02	5.48	21,794.45	4.14
Other	126,772.73	24.07	118,720.98	22.54
unclassified	11,761.87	2.23	5,740.82	1.09
TOTAL	**526,704.41**	**100**	**526,704.41**	**100**

A number of technical considerations might have reduced the classification accuracy reported in this study. Important error sources might be the time gap between the reference data and the date of image acquisition and positional error during the registration of the Landsat image and / or during reference data collection, which was primarily based on GPS (spatial accuracy).

4.3 Comparison with previous bamboo mapping work

Chaffey (1979) had made a reconnaissance inventory of forests, woodland and thicket of SW Ethiopia. The delineation and area estimation of his studies were based on the interpretation of aerial photographs of the 1960's and 1970's, to locate forests, woodlands and thickets, including highland bamboo, and estimated the area coverage of highland bamboo as 109,700.00ha.

According to his study, the total area of pure bamboo stand within the studied Woredas (Figure 21) was 34,612.00ha, which accounted for 6.57 percent of the estimate he made at national level. Furthermore, he also identified the existence of woodland with bamboo thicket that cover an area of 115,021.00 ha, constituting some 21.84 percent of the total study area.

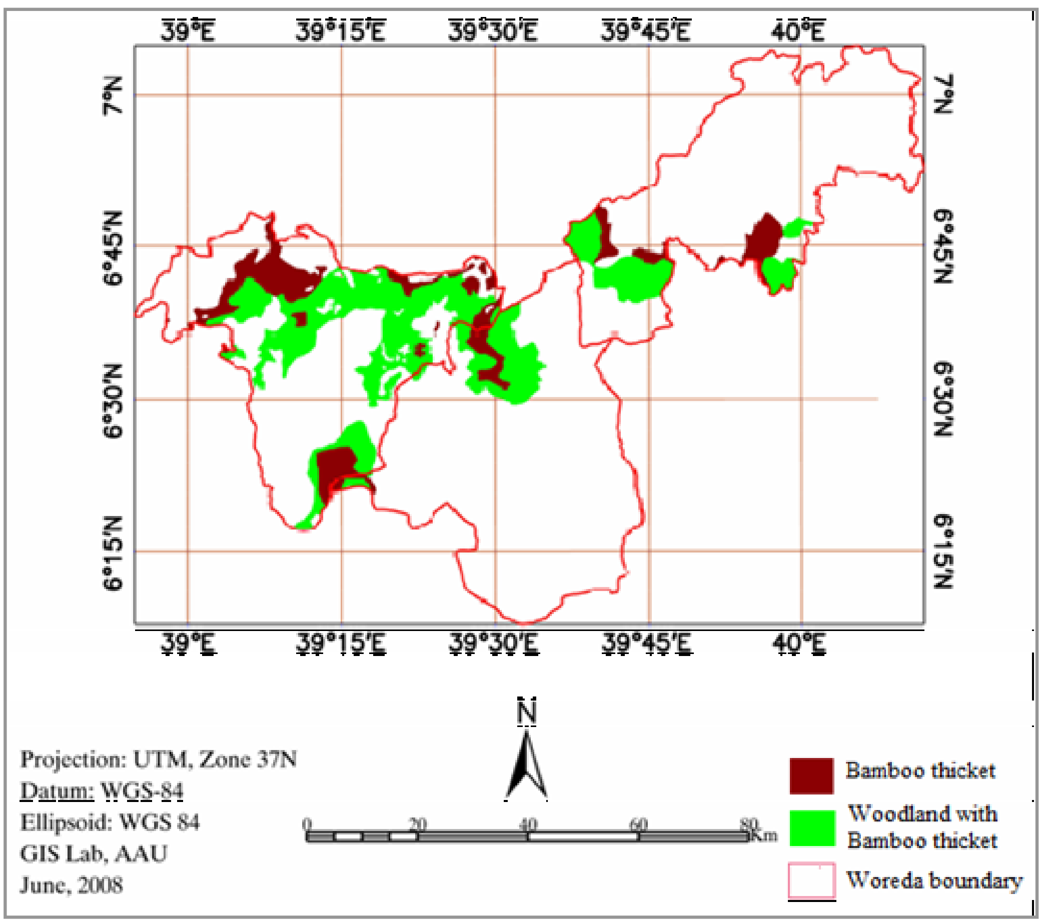

Figure 21: Chaffey's map of highland bamboo in the study areas

An overlay of the potential and the current Landsat 7 ETM+ image classification on the bamboo areas defined by Chaffey (1979), made possible to analyze the differences and similarities. Similarity in delineating the bamboo areas between the two classification approaches was significant in terms of location of pure bamboo stands. However, the most noticeable discrepancy between the two classifications was observed in the central SE of Sanetti and East and Central of Nensebo Woreda. The area estimate of Chaffey for pure bamboo stand in the presently studied Woredas was 34,612.00ha and that of this study 63,407.32 ha. The less extent of the former can be ascribed to the inclusion of more bamboo thicket as mixed with woodland, as might had been found non-mapable by the output scale Chaffey had used (1:250,000).

Taking into consideration the time gap (30 years) of the map work, the difference in mapping of the bamboo resource in eastern and central part of Nensebo Woreda can admittedly be related to the significant waning of pure bamboo stand from the western part of the study area. As described earlier, the bamboos in the remaining natural forests of this area once served as a common pool resource and were overexploited, to be found now in small patches of private holding plantation located nearby homesteads, on marginal and agricultural fields.

Nevertheless, the superimposition of the produced potential bamboo growing area over the map (Figure 22) further shows that, the central southeastern part of the study area, which were mapped as pure bamboo stand are outside of the potential growing region (shown by red arrow).

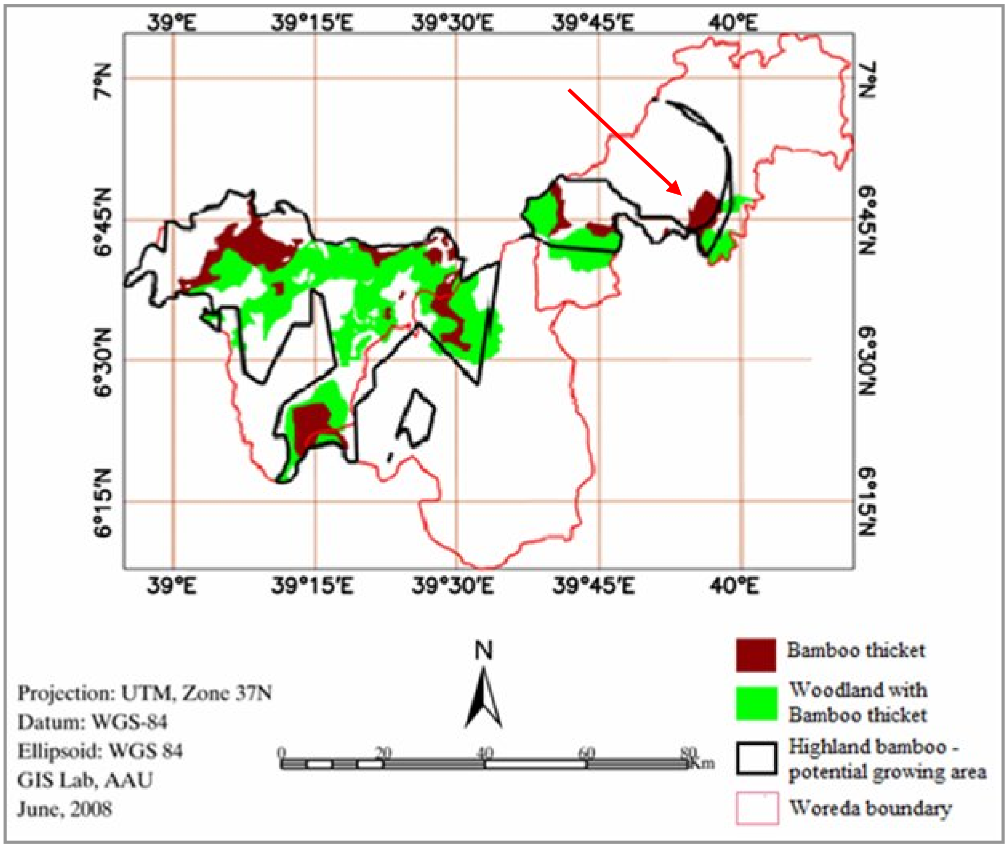

Figure 22: Chaffey's map of highland bamboo in relation to Potential growing areas

As seen in the history of fire incidence (Masresha Fetene *et al.*, 2006), there were wild fires in 1963 in the northwestern escarpment and in 1969, 1971 and 1973 in other areas of the Bale mountains. It was to be remembered that these were the years in which Chaffey had acquired the aerial photo / images his study had based upon. Accordingly, the smooth tone of the resprouting homogenous *Erica* spp. and / or the new emerging grasses might have attributed to the inclusion of the stand to its adjoining bamboo class.

5. CONCLUSION AND RECOMMENDATIONS

The result of this research had demonstrated that the bamboo resource can be mapped at moderate level of agreement from remotely sensed medium resolution images. The Maximum likelihood classification technique can generally be considered adequate to map bamboo areas in the Bale highlands using Landsat 7 ETM+ images. This is due to the comparatively strong consumer (40.56%) and producer accuracies (83.47%) for the Maximum likelihood vis-à-vis 23.05% consumer and 51.24 producer accuracies for the Decision Tree. Moreover, the Kappa statistic, which is a preferred estimate of comparison, for the Maximum likelihood classification technique (0.52) lies between 0.4 and 0.75, which is generally considered to represent a moderate agreement. These suggest that the technique is useful at a reconnaissance level for providing basic information on the extent and distribution of bamboo resources, which can be extensively used for all regions of the nation.

Future Work:

To improve the classification of bamboo resources mapping, the following research areas and surveys are suggested for future considerations:

a) In balance with the rapid development of remote sensing technology such as improvements in image resolution and advancement in ease of acquiring data (both in terms of cost and access), to assess the level of adequacy of such images in satisfying the needs for detail planning at local level;

b) With the improvement and development of classification techniques, to explore other (or same with regard to "a" above) methods that better quantify (increase the accuracy) of the bamboo resource. Emphasize should also be made on different environmental settings;

c) To exert effort towards the implementation of the findings to other identified potential bamboo growing areas; and

d) To build and maintain an effective central data-base that enables to archive, easily access and analyze spatially oriented bamboo data and linked attribute data (by integration of basic information on the bamboo resource such as density of bamboo stock and socio-economic setup).

e) Beyond the currently known influencing factors, as an input to suitability rating, it is also important to establish limit on other important physical, ecological and biological parameters such as soil depth, texture, pH, chemical properties organic matter content, biological and abiotic threats (diseases, pests), etc. that can affect the growth and quality of highland bamboo. In doing so, it would be possible to improve the accuracy of the map.

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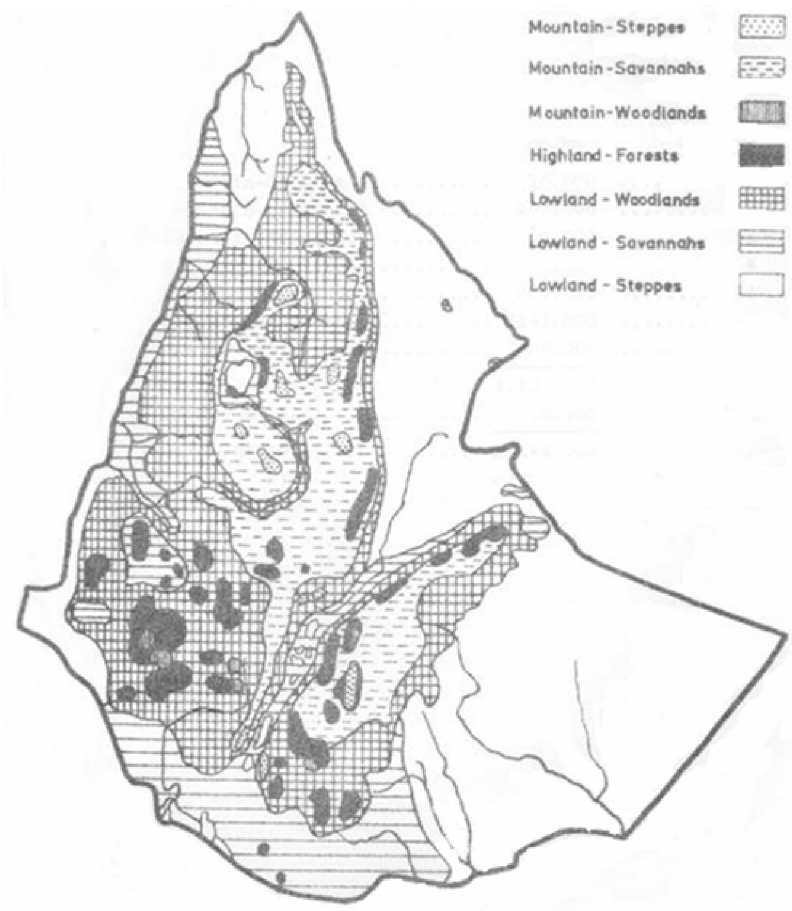
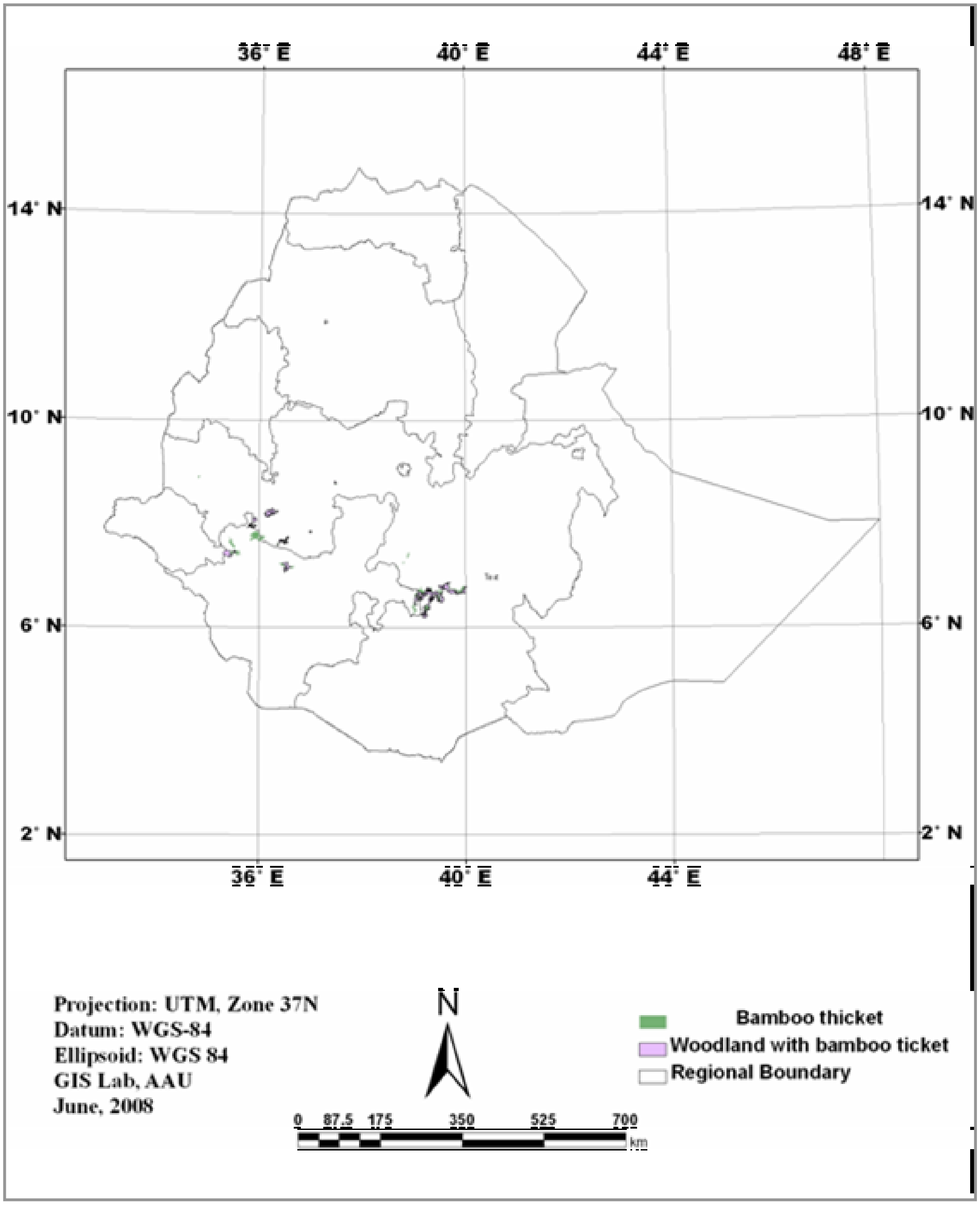
Annex 1: Pichi-Sermolli's (1957) "Una carte Geo-botancia dell Africa Orientale"

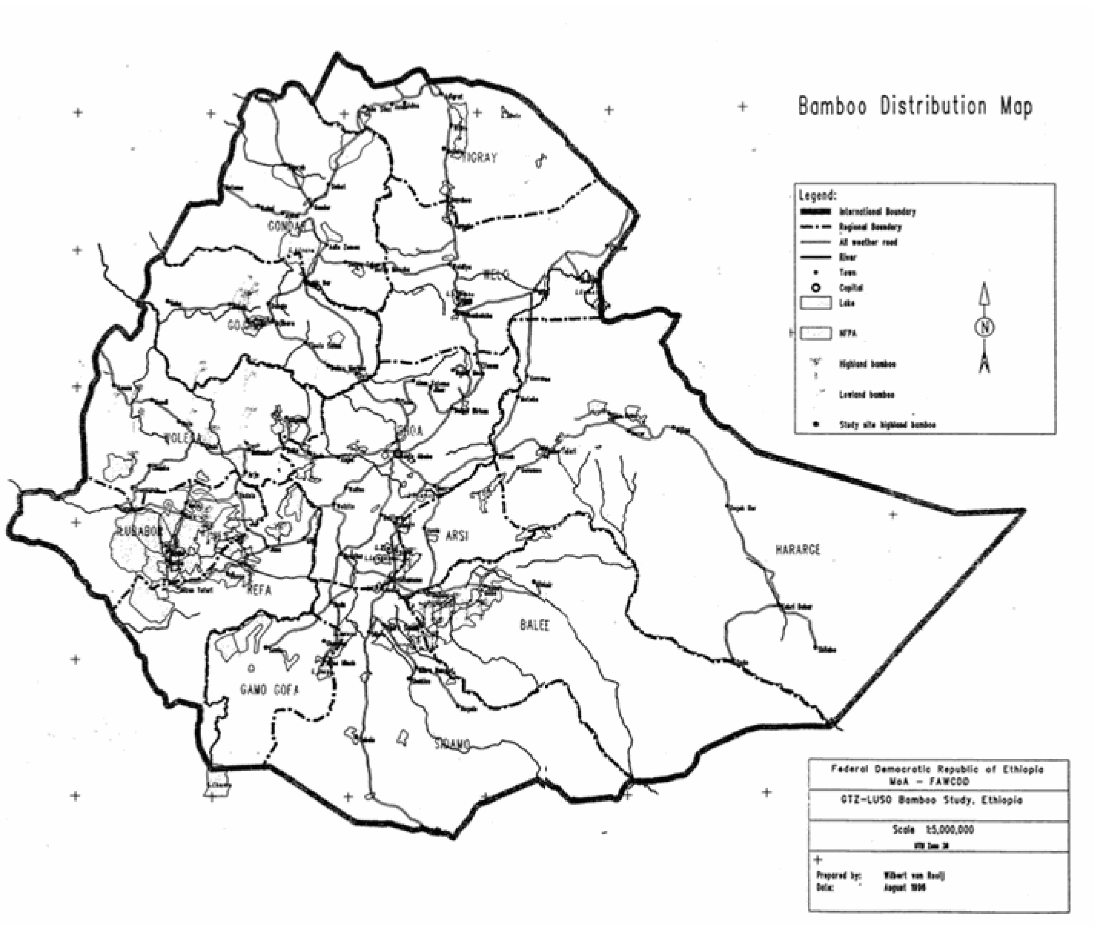
Annex 2: Von Breitenbach's (1961) Vegetation map of Ethiopia.



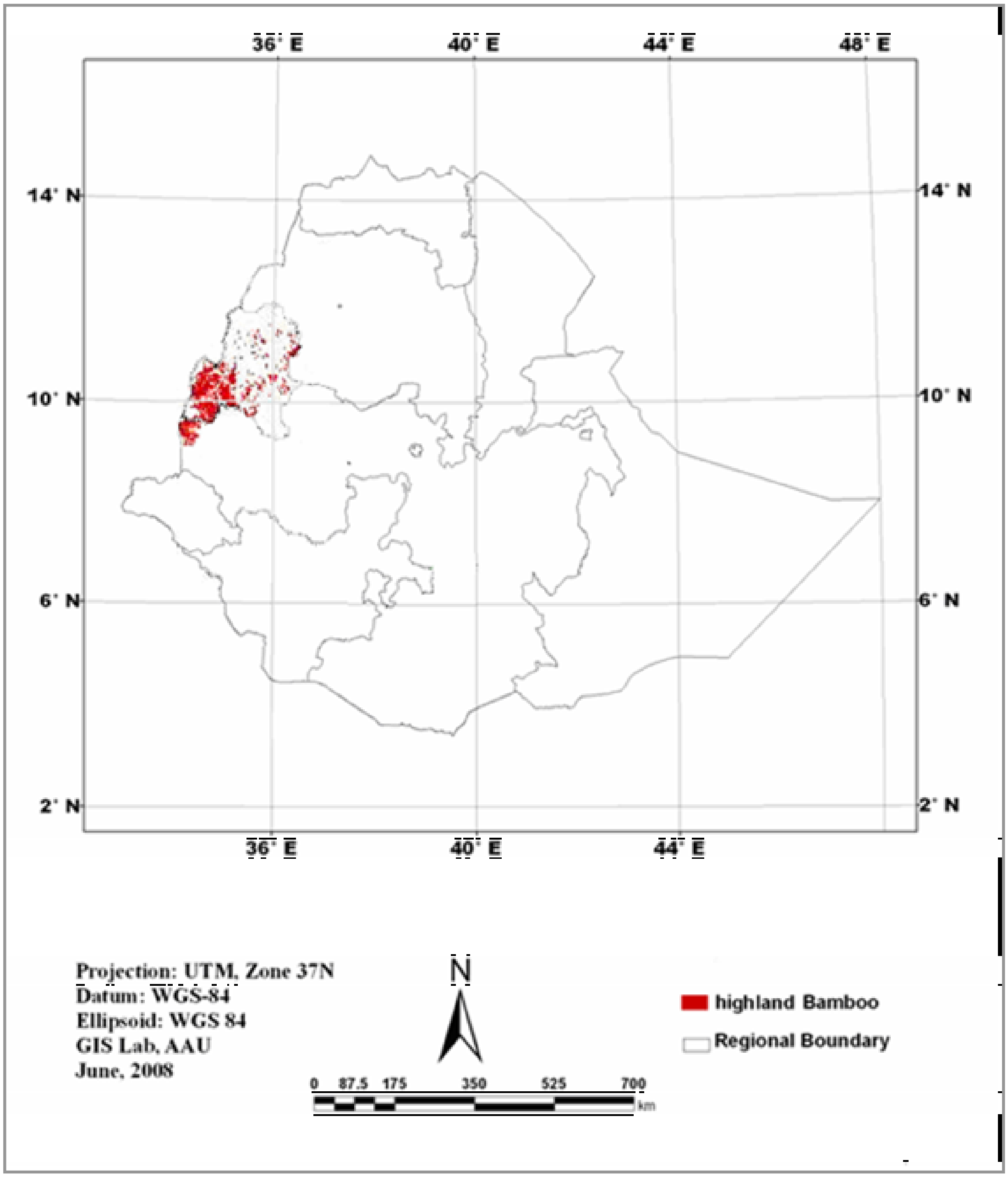
Annex 3: Chaffey's (1979) highland bamboo map



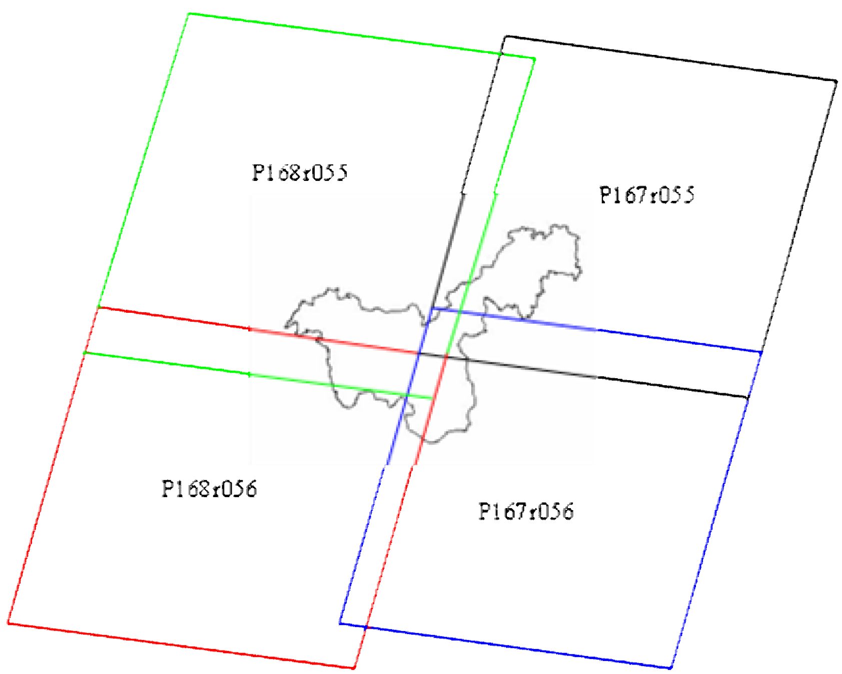
Annex 4: Bamboo distribution map of LUSO (1997)



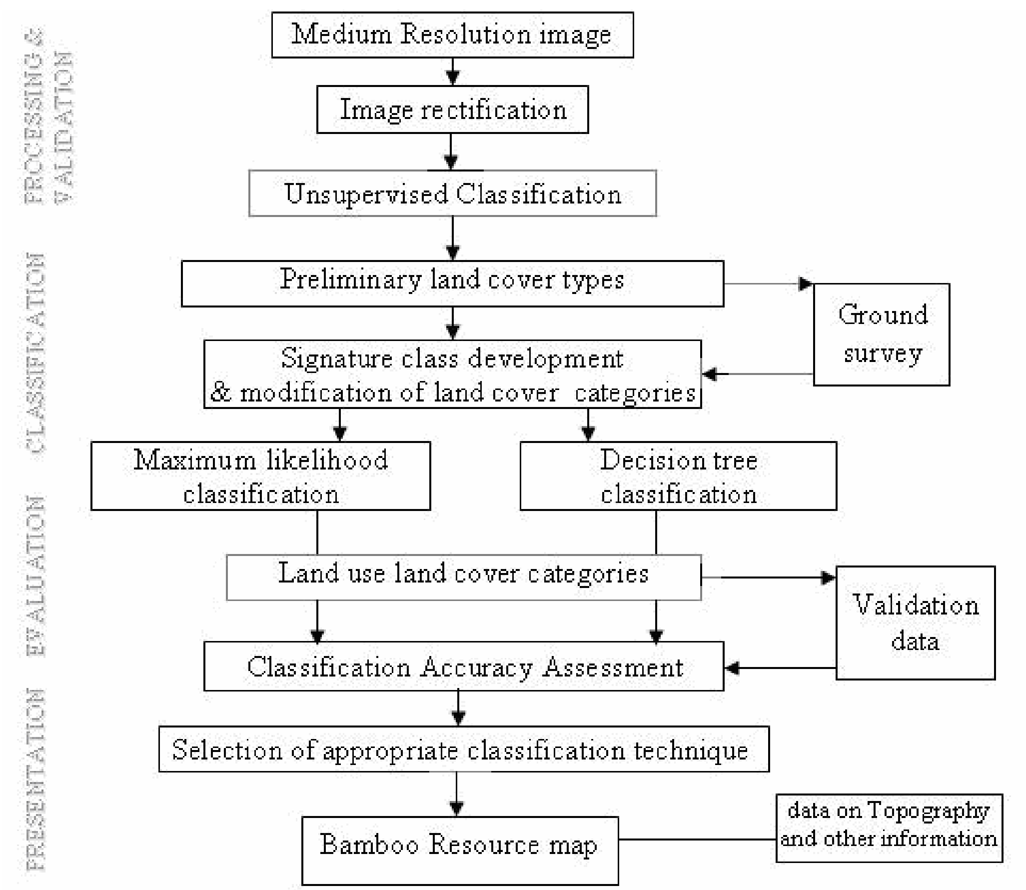
Annex 5: Bamboo distribution map by WBISPP



Annex 6: Landsat 7 ETM path / row index



Annex 7: Conceptual diagram for comparison of classifier's performance



Annex 8: Relevé sheet

Observation number_________

Region_________ Zone__________ Woreda_________ Kebele_______ Locality____________

GPS No. ____: Datum______ Northing__________ Easting__________ Altitude________

Aspect_________ Land form type: __________________ Accessibility_______________

Slope class:__________

Ownership: private ☐ public ☐ other (please specify) ________________

observer_________ Date of observation_____/__/2000

Preliminary sampling unit___________ Observed sampling unit________________

Dominant land cover type___________ % coverage_______ % real cover______

Minor land cover types ____________, ____%. ___________, ___%. ___________, _____%.

____________, __%. ___________, ___%.

Origin / Characteristics

Native ☐ introduced ☐ Natural ☐ Planted ☐

The resource extent

Average number of bamboo in a clump:_________

Average number of clump in the unit (90 * 90m):_________

Average ht.:_________ average DBH:____________

Extent and characteristics of disturbance, if any [high, moderate, low] :________________

Extent of fire burn, pest / disease (occurrence) [H,M,L]: ___________ year:__________

Other observations:

Other Tree and shrub species commonly found in the unit:

local name abundance major use

Village location: name____________ Location : N___________________ E____________________

Annex 9: Dominant soil types of the potential growing area

Code	Soil Type	Area (in ha)	% from total
1556	Eutric Vertisols	16	0
1000	Phaeozems	228	0
1755	Dystric Histosols	837	0.01
261	Mollic Andosols	1114	0.01
1358	Gypsic Yermosols	1889	0.02
551	Calcaric Flubisols	2018	0.03
452	Calcic Cambisols	2206	0.03
353	Cambic Arenosols	3664	0.05
552	Calcic Fluvisols	14221	0.19
9999	Water Bodies	23887	0.31
1459	Haplic Xerosols	31682	0.42
2222	No Soil	40533	0.53
454	Chromic Cambisols	43214	0.57
1156	Eutric Regosols	66629	0.87
1452	Calcic Xerosols	96953	1.27
455	Dystric Cambisols	99768	1.31
462	Vertic Cambisols	110905	1.45
655	Dystric Gleysols	157633	2.07
556	Eutric Fluvisols	161025	2.11
1264	Orthic Solonchaks	195547	2.56
555	Dystric Fluvisols	253642	3.32
1554	Chromic Vertisols	307809	4.03
864	Orthic Luvisols	320414	4.2
700	Leptosols	434974	5.7
164	Orthic Acrisols	499895	6.55
956	Eutric Nitisols	739990	9.69
1565	Pellic Vertisols	826062	10.82
854	Chromic Luvisols	848925	11.12
456	Eutric Cambisols	1100177	14.41
955	Dystric Nitisols	1246918	16.34
	Total	**7632775**	**100**

Annex 10: Descriptions of identified Land Cover Classes

	Symbol	Description
Forestland	F1	This unit is characterized by either dense or open forests regardless of the vegetation composition and is found descending the foot slopes of Sanetti plateau and extending towards the south, south western and western part of the study area.
Heath / Scrub land	F2	E. arborea is the dominating species (>60 %) in parts of this unit mainly along the side slopes of Sanetti plateau. Other parts of this unit are also found in the western part of the study area and are composed of heath / shrub lands.
Bamboo	F3	Represent all areas characterized by highland bamboo. Dense, pure stand of this unit are located on the side slopes of Sanetti plateau and the uplands of the central part of the study area.
Moore	F4	Hypericum spp. with different intensity, and sometimes intermingled with other small shrubs is the dominating vegetation type of this unit. The unit is located in the upper part of Sanetti plateau. Present are also few open grassland and small non-mapable water bodies.
Other	N	This unit is generally located in the south western, northern and south eastern parts of the study area. It includes all other identified land cover types; the dominant of which are agricultural lands (with different intensity levels), fallow lands, permanently and seasonally flooded wetlands, bare lands and grasslands (pure or intermingled with sparse shrub/trees). Categorized under this unit were also other land cover types of anthropogenic origins.

Declaration

This thesis is my original work and has not been presented for a degree in any other university, and that all sources of materials used for the thesis have been duly acknowledged.

candidate:

Tezera Chernet

Confirmed by:

Dr. Dagnachew Legesse, Advisor