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BUSH ENCROACHMENT MAPPING USING SUPERVISED CLASSIFICATION AND SPECTRAL MIXTURE ANALYSIS IN BORANA RANGELANDS: A CASE STUDY IN YABELLO WOREDA

Zemenu Mintesnot

A Thesis Submitted to the School of Graduate Studies of Addis Ababa University in Partial Fulfilment of the Requirements for the Degree of Masters of Science in Remote Sensing and GIS

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Acronyms

Acc.	Accuracy
B	Blue
CSA	Central Statistics Agency
DN	Digital Number
ENVI	Environment for Visualizing Images
EMA	Ethiopian Mapping Agency
ERDAS	Earth Resource Data Analysis System
ETM+	Enhanced thematic Mapper plus
FAO	Food and Agriculture Organization
FAO-SFE	Food and Agriculture Organization Sub Regional Office for Eastern Africa.
G	Green
GIS	Geographic Information System
GPS	Global Positioning System
ILRI	International Livestock Research Institute
m.a.s.l	Meter above sea level
MESMA	Multiple Endmember Spectral Mixture Analysis
MNF	Minimum Noise Fraction
MOA	Ministry of Agriculture
NDVI	Normalized Difference Vegetation Index
NGO	Non-Governmental Organization
NOAA AVHRR	National Oceanic and Atmospheric Administration Advanced Very High Resolution Radiometer
PA	Peasant Association
PPI	Pixel Purity Index
R	Red
ROI	Region of Interest
RS	Remote Sensing
SMA	Spectral Mixture Analysis
TM	Thematic Mapper

Abstract

Bush encroachment has been among the major threats to the livelihood of Borana pastoralists and their ecosystem. A study was conducted in Yabello district to map bush encroachment using supervised classification and SMA (spectral mixture analysis). Landsat Thematic Mapper and Enhanced Thematic Mapper Plus images that were taken in January 1986 and 2003 respectively, 33333were used to assess the land-use/land-cover dynamics, to determine rate of bush encroachment and to spatially locate bush encroached areas. Six land-use/land-cover types were defined for supervised classification. They were forest, woodland, bushland, grassland, crop/cultivated land and bareland. Unconstrained linear SMA was run on the original DN image using woodland, bushland, Savannah grassland, tilled soil and bare surface endmembers. Endmembers collected from the field were tested for their purity by applying pixel purity index and minimum noise fraction transform. Classification result and unmixing were assessed for their accuracy using random samples collected from the field. Overall accuracy and Kappa coefficient for supervised classification of the 2003 image were 82.66% and 0.778, respectively. For the bush fraction image of 2003, they were 72.28% and 0.640, respectively. The study showed that bushland, woodland and crop/cultivated land were increased and forest, grassland and bareland were decreased between the study period. The rate of bush encroachment was 2.54% per year. Bush fraction image showed that in 2003 about 20% of the land was covered by bushy species that had > 40% canopy cover. In Borana rangelands, where heterogeneous vegetation exists, spectral mixture analysis using woodland, bushland, savannah grassland, bare surface, tilled soil and shade endmembers based on Landsat images was found less promising to unmix the land-covers. However, it gave better measure on the status of bush encroachment during 2003 than supervised classification method. Among others, multiple endmember spectral mixture analysis based on high spectral resolution images is recommended to better unmix the land-covers.

Key Words: Bush encroachment, supervised classification, SMA, endmember & Landsat

1. Introduction

1.1. Background

Pastoralism is the mainstay of most people living in the drylands of Ethiopia. About 61-65 percent of the total area of the country is estimated to be occupied by pastoral areas (Biruk, 2007). These areas are home to 12-13 percent of the total population (MOA, 2000). The remnant rangelands where found in these areas and are under tremendous threat from a variety of source (IIRR, 2004). For pastoralists, rangeland has a meaning just more than where they graze their animals. It is a vital resource, open home, which they have struggled to maintain and ensure its existence. The rangeland ecosystem comprises a wide range of biological diversity encompassing the smallest micro-organisms to the largest mammals and trees. Understanding the changes in this system and the interaction between its components helps to manage it on a sustainable basis.

Most pastoralists occupy a naturally dry environment, which is unsuitable for conventional rain-fed agriculture (Save the Children USA, 2007). Yet, this very same land is ideal for extensive livestock production, the kind of life style that pastoralists are so familiar at managing. In such a fragile setting, proper land management is an absolute necessity.

The Borana plateau is one of the best remaining pastoral areas in Africa (Gemedo *et al*., 2005; Leykune Abune, 1991). It occupies an area of about 95 thousand km^2 in southern Ethiopia (Kamara *et al*., 2002). The livelihood of the dominant ethnic group of the area, the Borana, mainly depend on extensive livestock production predominantly cattle and small number of small ruminants, camel and donkeys.

For many centuries, the Borana pastoralists were able to manage their rangeland based on their own experience and knowledge. Their management system involves the interaction between plants, grazing animals, abiotic components and the anthropogenic factors. Since the past three decades, however, the area has been exercising tremendous threats. Reports indicate that the threats are getting more as time goes (UN-EUE, 1996; UN-OCHA, 2008). These threats range from anthropogenic pressures on the environment to catastrophic natural occurrences.

Among the threats occurring in the area, bush encroachment is found on top of the major problems concerning range management (Alemayehu Mengistu, 2006). According to Ward (2005), bush encroachment means the suppression of palatable grasses and herbs by encroaching woody species often unpalatable to domestic livestock. The unpalatability and thorny nature of the bushes prohibits access of livestocks to the underlying grasses. The major factors that are stated as a cause of bush encroachment expansion in the area include overgrazing, ban of rangeland burning during the Dergue regime, neglecting indigenous knowledge and traditional pastoral systems and considering it backward.

Efforts have been made by government and non-governmental organizations to minimize and control the rate at which bush encroachment expands. However, the success rate is very low due to different factors. The repetitive droughts occurring in the area give rise to a favorable condition for the encroachers at the expense of grasslands and herbaceous cover.

Mapping of bush encroached areas helps to plan and strengthen the efforts being made to control and manage this problem. Remote sensing and GIS techniques have a great potential to come up with maps that indicate the rate of bush encroachment and the spatial locations of encroached areas with a minimum cost. Multi-temporal imageries taken at a similar condition are utilized to detect specific changes. There are different methods to assess rangeland condition and cover such as NDVI and Multi-temporal Vegetation Index. One of the most common methods for woody and herbaceous cover analysis of grasslands is Spectral Mixture Analysis (SMA) which involves decomposing image pixels into their constituent surface cover classes.

A single pixel may not contain the reflectance value of a single feature. But it is the combination of the reflectance value of different features contained in the instantaneous field of view of the satellite’s sensor. SMA is a technique based on modeling image spectra as a linear combination of endmembers. It has been used to derive the fractional contribution of endmember materials to image spectra in a wide variety of applications (Philip and Dar, 2004).

SMA has been used in different application areas. Dengsheng and Qihao (2004) used the technique for urban landscape classification. Wessman *et al.* (2004) indicated that SMA is a powerful method to estimate biophysically distinct cover types at the sub-pixel level and it enables woody and herbaceous cover analysis**.** Palaniswami *et al. (*2006) indicated that SMA based approach significantly improved classification accuracy as compared to the maximum likelihood classifier.

1.2. Objectives

1.2.1. General Objective

The general objective of this research is mapping bush encroachment in Yabello Woreda using supervised classification and spectral mixture analysis methods.

1.2.2. Specific Objectives

- To assess the land-use/land-cover dynamics of the area.
- To determine the rate in which bush encroachment had progressed during 1986-2003.
- To spatially locate areas under bush encroachment and to estimate the level of encroachment in the area.
- To assess the suitability of SMA for bush encroachment mapping relative to the supervised classification technique.

1.3. Problem Statement

Bush encroachment is one of the most serious problems in Borana rangelands. The magnitude and location of areas under bush encroachment is not properly determined. As a part, proper management of rangelands requires locating and quantifying areas under bush encroachment. Mitigation and control measures should be based on informed decision making. Although maps play a big role in the attempt to determine the causes of bush encroachment in the area, there were no consistent maps produced so far. Previously undertaken studies were based on small spatial extent. However, most land-use decision and management activities are impacted by regional level policies. Assessment of bush encroachment and land-use change over large area is needed to guide regional policy and land-use management.

2. Literature Review

2.1. Definition of Bush Encroachment

There are different definitions given to bush encroachment. These definitions vary with each other based on the perspectives they are viewed. However, most of them converge to a common central idea. According to Ward (2005), bush encroachment means the suppression of palatable grasses and herbs by encroaching woody species often unpalatable to domestic livestock. Ahmad and Florian (2000) defined bush encroachment as the invasion of shrub and bushes/trees into former grassy rangelands. An expansion of bush land, dominated by unpalatable thorny shrubs, is a common feature of overgrazed pastures in Africa (Rhignos and Hofman, 2003). In semi-arid ecosystems, there has been a general increase in the density of woody plants beyond a critical density, suppressing herbaceous plant production (Oba *et al*., 2000).

The Borana lowlands cover an estimated area of about 50,000km^2, being the major pastoral rangeland in southern Ethiopia (Gemedo *et al*., 2005). Encroachment of woody plants has been the major threat to the livelihoods of Borana pastoralists and their ecosystem (Gemedo *et al.*, 2006; BLPDP, 2004).

2.2. Causes of Bush Encroachment in Borana Rangelands

Grasslands are lands dominated by grass and occasionally herbs sometimes with widely scattered or grouped trees and shrubs (Desta Hamito, 2001). Canopy cover never exceeds 2%. The land is usually subjected to periodic burning. One of the most important aspects of rangeland management is a system of traditional institutions, a system that had been operating successfully for hundreds of years and has only recently been weakened by modern influences (Save the Children USA, 2007).

Borana pastoralists in southern Ethiopia have a well established traditional system of range and water management (Gemedo *et al.*, 2006). Their management system integrates plants, animals, abiotic and human factors. Their range allocation system considers the carrying capacity of the rangelands, rotational grazing system between wet season grazing area, dry season grazing area and drought season grazing reserve areas used to regulate the grazing pressure. Also the Borana pastoralists were obliged by their Gada (traditional and cultural Oromo's management system) to move to other areas when an area is overgrazed. However, this indigenous rangeland management system has been weakened in the near years, by external influences and interventions as well as internal factors (Ahmad and Florian, 2000).

Bush encroachment seems one of the consequences that happened following the depreciation of this indigenous rangeland management system. There are different factors, which are stated as causes of bush encroachment in this area. These factors combined together, resulted in wide bush coverage, which expands through time. These causes include;

a) Overgrazing

Overgrazing is the utilization of rangelands beyond their carrying capacity and optimum grazing frequency. Overgrazing of the rangelands is one of the main causes of bush encroachment. It is associated with the increasing number of both human and livestock population. The degree of grazing strongly affects the structure, composition and quality and productivity of rangeland vegetation (Alemayehu Mengistu, 2006). On the other hand, light to moderate levels of grazing actually maximize both primary and secondary production and encourage perennial grassland at the expense of woody vegetation.

In Borana rangelands, unwise development of new water sources by government and non-governmental organizations without understanding the future effects of it on the rangeland and on the traditional rangeland management system resulted an increase in livestock population (Ahmad and Florian, 2000).

b) Ban of Prescribed Fire

The Borana pastoralists have traditionally used controlled burning as a range management tool. During early growth, the encroachers were treated with fire and killed by repetitive burning. Fire limits tree recruitment, allowing adult mortality to remain low (Ward, 2005). Burning also helps to stimulate the growth of new grass shoots, and destroys unpalatable dried and very mature grasses and undesired bushes.

However, the continuity of this traditional indigenous range management system ceased due to the implementation of the law that prevented rangeland burning (Gemedo *et al.*, 2006). Since 1970, the Dergue regime banned rangeland burning and unpalatable grass/herb/shrub/bush species got the chance to grow. Most of them are not palatable for most livestock, and they suppressed palatable grass species, and began to dominate.

c) Undermining Indigenous Range Management System

Less application of indigenous knowledge of the pastoral community also attributed to conversion of rangeland to bushland (Gemedo *et al.*, 2006). Considering the indigenous knowledge and traditional pastoral system as backward by decision makers and government institutions and neglecting it, weakened the range management system. The "Gada" system of the Borana people is known to control human and livestock population. However, due to internal and external pressures the system has been losing its previous strength and control over the community in the past thirty years.

d) Environmental Stress

Recurrent drought occurring in the area also gives rise to conducive environment for the encroachers. Hence, they do not have a deep root, which traps water from the deep soil, shortage of rainfall limits the growth of grasses. Rainfall frequency is also a necessary condition for bush encroachment (Ward, 2005).

e) Land Tenure

Directly or indirectly land tenure is another factor that has a negative or positive implication on rangeland management. Its negative impact reflected in Borana rangelands is that depreciation of local governance structures to effectively and adequately participate in the management of natural resources and the environment. Land tenure issues have not been adequately addressed to ensure that ownership and utilization of rangelands is clear and effective (Sora Adi, 2007).

f) Land Privatization

The newly emerging trend, privatization of grazing lands by individuals, is another cause that is indirectly related to bush encroachment. To have guaranteed access to grazing and water in times of scarcity, more affluent livestock owners fenced-off grazing lands. Existing along side the no-fenced community grazing land, still is used by all livestock keepers, these areas become depleted. Again, a vicious cycle starts, where only wealthier herders can afford fencing and thus reap the rewards from better animal quality, whereas those who cannot afford the investment overuse the remaining land and are worse-off at the end (Sora Adi, 2007).

The above mentioned factors are not the only factors, which caused and aggravated bush encroachment in the area. There are different factors, which are considered as minor. However, overgrazing, ban of rangeland fire and less application of indigenous knowledge are major factors that most of the pastoralists agreed with and supported by different studies. Land tenure and land privatization are recent trends giving rise to expansion of bushes.

2.3. Effects of Bush Encroachment

Bush encroachment has an adverse effect on the ecosystem and the environment. Herbaceous biomass production and bush encroachment are negatively correlated in the study area (Gemedo *et al.*, 2006). The expansion of unpalatable woody species significantly reduced the rangeland size and availability of grasses. The consequence of the decrease in herbaceous biomass might result in high risk of food insecurity in the area. In addition, the bush prohibits access of livestock to the underlying grass and as the canopy closes the grasses and herbs disappear letting the ground susceptible to water erosion.

Pastoralists in the area perceived that increasing bush coverage is creating well suited environment for harmful wild animals. A study conducted by Borghesio and Gainnetti (2005) suggested that bush crow *(Zavattariornis stresemanni*) population decreased within Yabello Sanctuary could be due to the encroachment of open savannah by dense bush. On the other hand, an increase in bush coverage triggers complete disappearance of wild herbivores, whose browsing is known to favour more open grassland savannah habitats.

Furthermore, encroachment of woody plants may alter soil carbon (C) and nitrogen (N) pools (Hudak *et al.*, 2003). The Borana lowlands soil nitrogen was strongly and positively correlated with both density and cover of woody plants (Gemedo *et al.*, 2006). According to Hudak *et al.* (2003), severely encroached areas had low C: N ratios than less encroached areas. It is evident that land-use/land-cover types have significant impact on the soil chemical and physical properties. Altered carbon sequestration has been reported to be one of the many potential consequences of woody plant encroachment. Progressive growth of bush cover is claimed to alter patterns of livestock grazing and sitting encampments.

2.4. Bush Encroachment Status

Most studies showed that there is an increasing trend in bush coverage. A study undertaken on Bush crow (*Z. stresemanni)* in Yabello Sanctuary and its immediate surroundings, south to the town of Mega showed that 8% increase in dense bush cover between 1986 and 2002 (Borghesio and Gainnetti, 2005). It revealed that dense bush was the most wide spread habitat followed by an open terrain and woodland. According to Ahmad and Florian (2000), the major woody plant species which are considered to be encroachers are *Acacia brevispica (*Hammaresa*), A.bussie (*Hallo*), A. drepanolobium (*Fillensa*), A. melifera (*Saphansa*), A. reficiens (*Sigirsa*), A. seyal (*Wachu*)* and *Commiphora africana (*hammessa*)* in some places. These species are the dominant species that make up major plant communities of the area (Gemedo Dalle *et al.*, 2005).

By the mid 1980s, about 40% of the Borana rangelands had been affected by bush encroachment (Eshete *et al.*, 1986 as cited in Ayana Angassa, 2002). Gemedo *et al.* (2006) reported that in the Borana lowlands (only Yabello, Dire and Hariro), overall mean percentage cover and density of woody plants per hectare was estimated to be 52% and 3014 respectively. They found that woody plants encroachment has been increasing overtime and concluded that in the Borana lowlands both woody plant cover and density have crossed the threshold level and entered in to the encroached condition.

2.5. Efforts Being Made to Control Bush Encroachment

Different government and non-governmental organizations have been trying to reduce bush expansion in the area. The main control mechanism, which has been tried by almost all organizations is clearing through cutting (Ahmad and Florian, 2000). This is executed through food for work and cash for work programmes. After the bush is cleared, it will be piled for burning. So far little attention was given to bush encroachment. Currently, its adverse effect on the performance of the pastoral economy is being acknowledged (Ayana Angassa, 2006). Local and international non-governmental organizations and some governmental departments like Yabello Pastoralist and Dryland Agriculture Research Center are conducting range rehabilitation, involving burning and hand clearing of woody species along highways and near settlements, on an experimental basis.

According to the perception of Borana pastoralists, rangeland burning, bush clearing, and herd diversifications are potential solutions to minimize impacts of woody plants encroachment (Gemedo *et al.*, 2006). Availability of grass temporarily improved in areas where bush clearing is already applied (Ayana and Oba, 2007). However, bush clearing efforts made by development projects in the area did not have significant impact on improvement of rangeland condition (Gemedo *et al.*, 2006).

Application of prescribed fire is suggested as best mechanism by different authors (Ahmad and Florian, 2000; Ayana and Oba, 2007; Gemedo *et al.*, 2006). Using fires with grazing and tree cutting is highly recommended and gave best result for conservation of herbaceous species diversity (Ayana and Oba, 2007), whereas tree cutting and fire seemed superior in terms of herbaceous biomass conservation.

2.6. Remote Sensing and GIS

2.6.1. A Short Glance at RS and GIS

Remote sensing is a science and an art of obtaining information about an object, area or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area or phenomenon. (Lillisand and Keifer, 1994). It utilizes the electromagnetic radiation emitted from objects when natural or artificial radiations strike them. Remote sensing was evolved as the ability of man to observe in regions of electromagnetic spectrum, beyond the range of human vision.

GIS consists of the tools and services necessary to allow one to collect, organize, manipulate, interpret, and display geographic information (Bettinger and Wing, 2004). It helps to solve problems of human and nature for planning and sustainable management of our environment using an organized computer system. GIS is effective at handling spatial data and that, over the years, it has gradually become more effective at handling spatial data analysis. It is a relatively new area of research that has made extraordinary progress in the last few decades (Keith *et al*., 2004).

2.6.2. Role of Remote Sensing and GIS in Rangeland Management

Satellite remote sensing was introduced as an important tool in understanding and monitoring various components of rangeland function and health (Tueller, 1991 as cited in Palmer and Fortescue, 2003). Keeping the limits imposed by scale and image resolution, remote sensing application in rangeland management has got wide acceptance.

One of the primary applications of remote sensing in the rangelands is prediction of production potential of a ranch (Palmer and Fortescue, 2003). Using different imageries that have varying spatial and temporal resolution, it is possible to estimate grass biomass.

Satellite imageries have been used from its earliest times for the preparation of base maps for rangeland inventory. Integrated with GIS, the system provides spatial and temporal information, which are valuable for inventory. Furthermore, range conditions can be relatively easily handled with low cost and effort. Satellite image like NOAA AVHRR have high temporal resolution which can capture information on the condition and health of rangelands on daily basis supported with ground truth.

Satellite derived imageries have provided the opportunity to describe the spatial extent of floristically and structurally defined units (Palmer and Fortescue, 2003). Invasion of rangeland by alien species remains a major problem through out the world. Attempts to monitor the extent of this invasion based on ground investigation and assist with the planning of the control and eradication program, have met with limited success. The development of spectral libraries, which archive the signature of each species, would improve the efficiency of this application.

Change detection using high resolution imagery is another application provided by remote sensing. Ground based change detection is expensive and requires more manpower, resources and time input. In addition, previous data should be available at the appropriate scale and level. However, for example, using Landsat imageries of the past three decades which are freely available, valuable information can be extracted using remote sensing. Rangelands change frequently and their succession favour woody plants domination.

GIS has diverse application in rangeland management. These include selection of suitable site for establishing new livestock water points, access road construction, disease infestation mapping, animal migration mapping, habitat suitability analysis, habitat modeling and the likes (Bettiner and Wing, 2004). The application of remote sensing and GIS is not limited to this level. They are also utilized in complex models used to assess range degradation, net primary production, below and above ground carbon sequestration.

2.7. Image Classification

Application of image classification in thematic mapping is a common process. The overall objective of image classification is to automatically categorize all pixels in an image in to land-cover classes or themes (Lillisand and Keifer, 1994). Land-cover classification uses remotely-sensed reflectances or radiances to determine the category to which a given pixel belongs (Parker and Raymond, 2004). Normally multi-spectral data are used to perform the classification. Classification assumes that similar materials respond to the incoming electromagnetic radiation in a similar manner. Thus, different feature manifest different spectral pattern.

Image classification procedures based on the method used can be classified in to supervised classification and unsupervised classification (Palaniswami *et al.,* 2006). In supervised classification, the image analyst "supervises" the pixel categorization process by specifying, to the computer algorithm, numerical descriptors of the various land-cover types, called training areas, are used to compile a numerical "interpretation key" that describes the spectral attributes for each feature type of interest (Lillisand and Keifer, 1994). Each pixel in the data set is then compared numerically to each category in the interpretation key and labeled with the name of the category it "looks most like". The unsupervised classification in essence reverses the supervised classification process. Spectral classes are grouped first, based solely on numerical information in the data, and are then matched by the analyst to information classes. There are different clustering algorithms, which are used in both cases.

2.7.1. Supervised Classification

Supervised classification, as mentioned earlier, is done based on knowledge of the area to be classified. Three basic steps are involved in typical classification procedure (Lillisand and Keifer, 1994). In the training stage the analyst selects representative training areas of each land-cover types of interest in the scene. These training areas contain numerical descriptions of their specific land-cover type. In the classification stage, each pixel in the image dataset is categorized in to land-cover classes it most closely resembles. Finally, after the entire dataset has been categorized the results are presented in the output stage. In supervised classification, one pixel is categorized as one land-cover type, unless it is insufficiently similar to any training dataset. In such cases, it is usually labeled as unknown.

2.7.2. Spectral Mixture Analysis (SMA)

Usually mapping land-use/land-cover has been accomplished using traditional (supervised and unsupervised) classification techniques. However, it is difficult to find consistent classes with this approach between images taken at different times (David, 2001). In addition, for change detection, availability of information on previous land-use/land-cover types is uncertain. On the other hand, collection of large amount of field data, in particular, is costly (Dengsheng *et al.*, 2004). Therefore, application of historical remote sensing data for land-cover classification is often difficult. It is necessary to develop a method that does not require use of training sample data for classification of historical remote sensing data.

An alternative approach is to use mixed pixel method or spectral mixture analysis. This method recognizes that a single pixel typically made up of varied spectral types (i.e. soil, water, vegetation). In effect, SMA is a technique used to measure the percentage of spectra for each land-cover type in a single pixel.

SMA has become an essential tool for remote sensing vegetation analysis. It has been successfully used to classify successional forest types of varying carbon sink strength (Palaniswami *et al.*, 2006). It has also been used in applications as diverse as monitoring urban environments, measuring water turbidity (Kameyama *et al.,* 2001), mapping land degradation (Haboudane *et al.,* 2002) and analysis of land-cover change detection (Dengsheng *et al.,* 2004). Parker and Raymond (2004) used a new method of spectral mixture analysis, Mixture Tuned Matched Filtering (MTMF) to determine the occurrence of leafy spruge (*Euphorbia esula)*, a noxious perennial weed. Tsagaan and Germino (2005) also successfully used SMA to assess Juniperous encroachment using multi-date Landsat imageries.

SMA is based on the assumption that the reflectance spectrum derived from an air borne or space borne sensor can be deconvolved in to a linear mixture of the spectra of different ground components, frequently referred to as spectra endmembers. Pure features in a mixed pixel are referred to as endmember of that pixel (Palanswami *et al.,* 2004). SMA involves two steps. First defining the spectra for pure selected land-covers and second each pixel is modeled as spatial mixture endmember spectra to determine the physical abundance. The mathematical model is described as follows (Dengsheng and Qihao, 2004);

$$RI = \sum_{K=1}^{n} f_k R_{ik} + \epsilon_i$$

Where,

i is the number of spectral bands used; **k = 1,…,n**(number of endmembers);

RI the spectral reflectance of band **i** of a pixel, which contains one or more endmembers;

f_k is the proportion of endmember **k** within the pixel;

R_{ik} is known as the spectral reflectance of endmember **k** with in the pixel on band **i and**

ϵ_i is the error for band **i**

Based on the type of endmembers selected, the above equation can be constrained to 1

Where,

$$\sum_{K=1}^{n} f_k = 1$$

or remains unconstrained. Takeuchi *et al*. (2002) used vegetation, soil and water endmembers constrained to unity to investigate regeneration condition of fire affected areas in Western Siberia and the method is found effective. The vegetation-impervious surface-soil (V-I-S) model assumes that land-cover in urban environments is a linear combination of three components; vegetation, impervious surface and soil (Dengsheng and Qihao, 2004). Although this model describes the landscape in urban environments the limited endmembers, complexity of impervious surface and omission of shade from the model constrained its application. Shadow is so ubiquitous that it must be included as an endmember within the overall endmember list for most images

The linear mixing model is not strictly applicable for a variety of reasons (Leica Geosystems user's guide, 2000). As described earlier, the assumption underlying linear mixing is that each photon interacts with a single material on the ground. However, this is not always true. Multiple scattering or interaction of a single photon with more than one material is possible, even likely, which violates our assumption and becomes a non linear process.

One of the main advantages of this system over the traditional way of classification is that it simplifies the classification process. In the traditional classification system, to select training areas, it is mandatory to have some information about the land-use/land-cover types existed during the time of image acquisition. However, in SMA based on the spectral characteristics of existing land-use/land-cover types it is possible to classify previous imageries. More than this, the percent cover of each land-cover classes can easily be estimated using this method, which is not possible in the traditional supervised classification system.

2.7.3. Endmember Selection

The selection of appropriate endmember to input in to a linear model is important. Endmember can be obtained from a spectral (field or laboratory) library and from the purest pixel in an image (Leica Geosystems user's guide, 2000; Palanswami *et al.*, 2006). Several spectral libraries are developed for image analysis. One such library is the SPECMIN spectrum library series of minerals and geologic materials, which can be used for all geologic and natural resource application (Leica Geosystems user's guide, 2000). Conventional spectrometers are used to collect spectral reflectance of materials from the field in order to build spectral libraries.

In heterogeneous landscapes, it is exceedingly difficult to locate image pixels containing 100% cover of each pertinent endmember, which is usually required when using image-derived endmembers in a spectral mixture model (Wessman *et al.*, 2004). Thus, library spectra have been widely employed with the recognition that libraries cannot easily capture the full range of endmember variability as is found in nature. This method allows great control over the selection of endmember spectra, but requires that raw image data be correctly converted to reflectance, an often difficult task in remote sensing (Palaniswami *et al.*, 2006). Scene derived endmember selection is simple and accompany the atmospheric effects.

There are alternative options to get relatively pure endmembers. These involve pixel purity index in which endmembers are selected manually by visualizing the PPI results in an n-dimensional visualizer with ENVI (ENVI, 2006) and manual endmember selection, which is a multidimensional visualization technique for interactively exploring the mixing space in search of spectra to designate as endmembers (Dengsheng and Qihao, 2004). The same authors used combination of image and reference endmembers using high-spatial resolution aerial photographs to characterize urban land-use/land-cover classes using SMA.

2.8. Maps as Management Tools

Maps are amazing tools, which, if constructed correctly, have the ability to communicate information quickly and clearly to the audience (Betinger, 2004). They are an effective method of illustrating ideas and representing spatial relationships among landscape features. The level of information obtained from a map depends on the degree of detailness of the map. This is mainly governed by the scale. Large scale maps provide precise description and identification of the mapped object or land plots to appear as a recognizable unit (ECA, 2007). However, they require intensive ground investigation, storage space and compilation. So, it is necessary to keep the trade-off between the intended application of the map and its scale.

In a digital environment, maps provide better information when linked to attribute databases, which is one of GIS functionality. With the help of remote sensing, classification and mapping past land-use/land-cover of an area helps to trace trends in land-use change. Non availability of up-to-date spatial information about the land makes land management weak. This is a common truth in the developing world.

There have been considerable discrepancies among the different maps so far produced in the study area. In addition the low land vegetation in previous maps is differently represented from map to map (Fris and Sebsibe, 2001). Such wide gaps hinder planning and management efforts.

2.9. Land-Use/Land-Cover Dynamics and Change Detection

Land is an important asset in the livelihood and economic activities of human beings. This includes agriculture, livestock production, tourism and extraction of mineral ore and oils. Whether a country is developed or developing, land remains the ultimate source of all materials, wealth and subsistence of life. Since the start of sedentary agriculture, man has been engaged in the transformation of land-use/ land-cover systems.

The earth’s surface is always through a continuous dynamism. Understanding the causes, consequences and direction of changes have paramount importance for proper management and planning of the earth's resources. Land-use/land-cover changes are prominent, but not simple processes. Land-cover refers to the bio-physical state of the earth's land surface and immediate sub-surface including abiotic, soil, topography, surface and ground water, and human structures (Turner *et al.,* 1993), whereas a land-use is the purposes for which human exploit the land and its resources.

A land used at one time for a specific use can be used for another purpose at another time. In the case of pastoralists the use of land for crop production is increasing at the expense of livestock production. In these areas the accumulated effect of population growth, crop cultivation, land privatization and other factors result in the general deterioration of rangelands and livestock production. Population growth is a ubiquitous catalyst of change, along with changes in environmental condition.

Unless they are managed strategically, these factors place significant strain on existing land-cover and natural resources. Changes to the environment can also reflect how the land has been managed, and using established change detection methodologies to monitor these changes can serve as an evaluation of these management practices. Change detection is a technique used in remote sensing to determine the changes in a particular object of study between two or more time periods. It is an important process for monitoring and managing natural resources and urban development because it provides quantitative analysis of the spatial distribution in the area of interest (Sean and Congalton, 2001).

Since the introduction of satellite-based technology in the early 1970's, the Landsat program has made this process possible. With repetitive satellite coverage, the rapid evolution of computer technology, and the integration of satellite and spatial data with GIS, development of environmental monitoring applications such as change detection have become simple.

3. Description of the Study Area

3.1. Location and Topography

The Borana rangeland is found in Oromia Regional State, southern Ethiopia. It lies between $4^{o}0^{'}$-$5^{o}30^{'}$ N latitude and $37^{o}30^{'}$-$39^{o}20^{'}$ S longitude. It covers about 95,000 km^2 which is estimated to be 7.6% of the national area. The Borana zone has 10 Woredas of which six are classified as lowland rangelands. Yabello Woreda is found in this category covering about 5556 km^2. Yabello town, the capital of the Woreda is 570kms far from Addis Ababa. Figure 1 shows the geographic location of the study area.

Most of the lowlands of Ethiopia are characterized by plain topography. According to the Woreda Pastoralist Development Office, about 5% of the district is covered by mountainous topography. Except these few mountains with peak elevation of 2200 m.a.s.l., the landscape is gently undulating across an elevation of 1450-1600 m.a.s.l., which falls with in the Rift Valley system of East Africa (Coppock, 1994; Leykun, 1991).

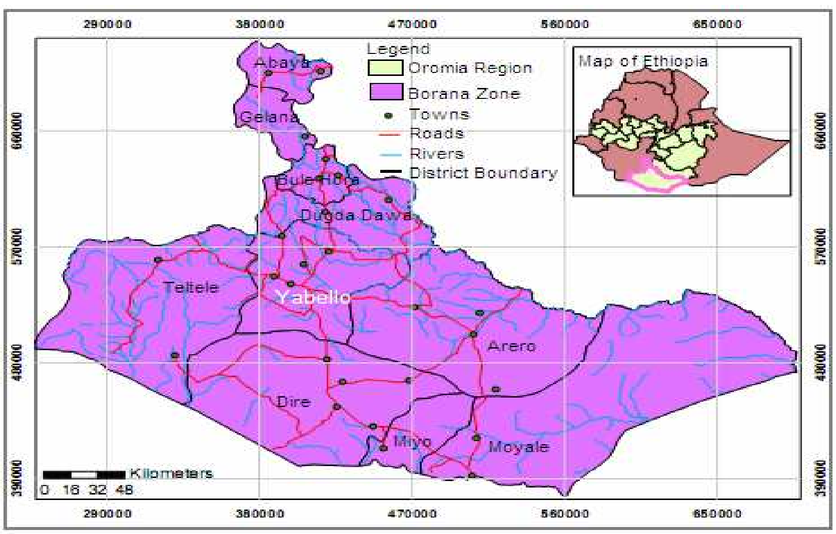


Fig. 1. Map of the Study Area.

3.2. Climate

Climatic condition in the lowlands of Ethiopia is largely a result of altitude. Based on the climatic map of Ethiopia, the climate of the study area falls with hot and semi arid "Upper Kolla" zone (National Meteorological Services Agency, 1989 as cited in Leykun Abune, 1991). The climate of the area is influenced by the relief of high mountain ranges of Bale in the northern and equatorial winds from the south.

The study area comes under the influence of a bi-modal monsoon rainfall type, where 60% of the 300-900mm annual rainfall occurs during March to May (Ganna) and 40% between September and November (Hagaya) (BLPDP, 2004). The period from June to September is characterized by heavy cloud cover, mist and occasionally short showers, while the main dry season (Bonna Hagaya) occurs from November to March with high evaporation (BLPDP, 2004). Seasons in the study area are classified by the local people in to five sets according to climatic variation and the uses of the range.

The overall average temperature ranges from an annual mean minimum of 13.3^{o}C to annual mean maximum of 25.1^{o}C (Sintayehu Mesele, 2007). The area has an absolute monthly minimum temperature of 12.1^{o}C and an absolute monthly maximum temperature of 26.9^{o}C.

3.3. Soil and Geology

The geology of the whole system is basement complex and soils developed on precambrian basement complex rock formations (Coppock, 1994). According to Ayana Angassa (2006), soils of the study sites are shallow red sandy loam in the uplands and vertisols in the bottomlands. The area is notable for its red soils, which have little organic matter. The rangeland soils of Yabello are regarded as having low fertility probably due to the inherent fertility of the parent material (Getachew *et al.,* 2007).

3.4. Vegetation

The pastoral rangelands of Ethiopia are mostly characterized by sparse vegetation composed of mainly grasses, bushes, shrubs, small trees and bareland (Alemayehu Mengistu, 1998). Soil type and topography are among the main factors that control the vegetation type of an area. As the altitude increases from sea level, the vegetation type changes accordingly. This is evident in Yabello district. Most of the central mountain vegetation was composed of *Juniperus procera*, *Olea europaena* sub-spp. *cuspidata* and *Podocarpus falactus*, whereas, the lowland vegetation is mainly composed of Acacia spp.

The general vegetation type of the study area is Acacia savannah, the major trees being *A. drepanolobium* in black cotton soil, and *A. brevispica* and *A. horrida* on the slopes. According to Gemedo (2005), *Commbertum-Terminalia* and *Acacia-Commiphora* woodlands characterize the lowlands of Borana zone. Bushlands and thickets, which cover major parts of the lowlands are dominated by *Acacia* and *Commiphora* species. Besides, species of the genera *Boscia, Maerua, Lannea, Balanites, Boswellia* and *Aloe* are common in the study area (Gemedo, 2006).

3.5. Water Resource Potential

Water is one of the most important natural resources, which the Borana pastoralists depend up on. The Borana rangelands in general and Yabello Woreda in particular are characterized by a general scarcity of surface water and perennial rivers. The main water sources for human and livestock consumption in the Woreda are deep wells (Eellas) and hand-dug ponds (Haros). There are nine major wells in the district. Ponds are found in greater concentration than wells. Harobeke is the largest pond found in the Woreda which is the main water source for livestock during dry seasons. The pond is also utilized by pastoralists in neighboring Woredas when there is sever water scarcity.

3.6. Socio-economy

3.6.1. Human Population and Settlement Pattern

The dominant ethnic group of the study area is Borana Oromo amalgamated with a few Guji Oromo, Amhara, Somali, Geri and Konso. The production and livelihood system is based on traditional Gada system, an approximately 550 year's democratic, economic and socio-political system, which is more or less common for all Oromo tribes (BLPDP, 2004).

The Gada council, which divides the entire rangelands in to traditional grazing based administrative units called "madda". The madda on their part are centered around permanent water sources, usually traditional deep wells (Kamara *et al*., 2002). All economic and social life revolve around the wells. The madda is further sub divided in to sub-grazing units called "arda", which consists of a few encampments that have jurisdiction over some form of grazing area, cultivated land and to a lesser extent, on water resources (Kamara *et al.,* 2002). The encampments or ollas, which comprise about ten households, are the smallest administrative units in the traditional system.

The Borana household unit consists of one household head, one wife or more depending on the number of animals one has, and three to seven children depending on the number of wives (BLPDP, 2004). According to the Woreda Pastoralist Development Office, the total population of the Woreda in 2007 was 116,436 of which 98,688 reside in rural areas and 17,748 live in urban area.

3.6.2. Livestock Population

The Borana pastoralists traditionally depend mainly on cattle, but also on goat and sheep for household food security and a few donkeys and camels for transport. The local Zebu known as the Borana cattle breed is bred and kept in Borana rangeland and plays a major role in the traditional Borana pastoralist production and livelihood system (BLPDP, 2004). This breed has good milk and meat production potential besides adapting adverse environmental condition under arid and semi-arid environmental conditions, which is developed through time and selection. Cattle take the largest number being 232,949. Goat, sheep and camel were 97,794, 29,073 and 22,972, respectively, in 2007.

3.6.3. Farming System

It is known that agriculture is the basis of Ethiopian economy. In Borana rangelands livestock production is the main source of food and money. Beyond this, it plays a major role as being a symbol object of a Borana identity and culture as well as being a central element of their social and political organization, the Gada system (BLPDP, 2004).

According to Yabello Woreda Pastoralist Development Office, out of 23 PAs in the district, 7 are identified as agro-pastoralists. The rest of them are classified as pastoralists. In some of the pastoralist PAs, there are small tracts of lands which are tilled only to satisfy household grain requirement. Cultivated land is estimated to cover 11971 ha, which is 2.02% of the Woreda. Agropastoralism is a newly emerging phenomenon in Borana rangelands. Agropastoralism could be described or defined as an activity based on a gambling system spearheaded by those individuals who had lived in the pastoral areas and due to one reason or the other became destitute and are forced to cultivation of lands as opportunistic farmers (Sora Adi, 2007).

According to Sintayehu Mesele (2004), the observed trends of increasing cropland areas in Borana rangelands could be attributed to a substantial proportion of the grassland were lost in response to environmental change and the recurrent drought forced the pastoralist to till their land in greater extent than before to cope up with the conditions.

4. Materials and Methods

4.1. Data Collection

Field investigations either to collect training data for digital classification or for ground verification or validation is part and parcel of applied remote sensing (Bedru Sherefa, 2006). Accordingly, primary data on the dominant land-use/land-covers of the study area were collected in April 2009. The collection procedure included defining the dominant land-use/land-cover types in the area and selecting sample Kebelles and relevant areas to be visited.

Based on their abundance and coverage the main land-use/land-cover types were identified as forest, woodland, bushland, grassland, farmland and bareland. Since they cover very small area as compared to other classes, urban or built-up areas were not considered in the data collection. The following definitions were applied as a baseline for the classification.

Forest refers to an area naturally covered by closed stands of large trees of indigenous species like *Juniperous procera, Olea european* sub-spp. *cuspidata* and *Podocarpus falcatus* with more or less a continuous canopy cover and 7 to 30m height.

Woodland is an area covered by open stands of relatively large trees of *Acacia, Balanites, Comiphora,* C*ombertum, Juniperous, Olea* and *Podocarpus* species with more than 20% canopy cover, taller than 5m and frequently do not exceed 20m. The ground is dominantly covered by grasses and herbs.

Bushland refers to open to closed stands of mainly Acacia trees 2 to 5m tall and canopy cover greater than 20%. This land-cover class dominantly refers to those species identified by the local people as invasive and mostly unpalatable to livestock. Most of them are thorny Acacia species forming a patch that prohibits human and livestock movement. The dominant species belonging to this category are *A. brevispica* (Hammaresa), *A. bussie* (Hallo), *A. drepanolobium* (Fillensa), *A. melifera* (Saphansa), *A. reficiens* (Sigirsa), *A. seyal* (Wachu) *and Commiphora africana* (hammessa).

Grassland is an area dominated by local or introduced grasses and forbs species, including grass-like plants such as sedges and rushes, and small flowering and non flowering plants or herbal vegetation with trees found scattered along the landscape and canopy cover not exceeding 2%. Savannah type of grassland is included in this category.

Crop/Cultivated land refers to agricultural lands that are seasonally cultivated by the local people for the production of mainly grains like wheat, sorghum, maize and teff. This category mainly includes fragmented or scattered areas that are cultivated mainly for subsistence. Perennial crops and irrigatedlands are not significant and thus were not included in this category.

Bareland refers to an area that has neither significant vegetation cover nor utilized for crop production. This category includes lands which were formerly grasslands, but now due to overgrazing and/or erosion, they become less worthy. Areas that are naturally non-vegetated were included in this category.

Having defined the land-use/land-covers of the study area, the geographic location of a total of 131 random sample points which were found at the center of a single land-use/land-cover type that was greater than $900m^2$ were collected using 10m accuracy Garmin GPS. The percent cover and the extent of the land-use/land-cover surrounding the reference point was estimated visually and recorded. The abundance of bushy species based on canopy cover was defined as sever (>80%), high (60-80%), medium (40-60%), low (20-40%) and very low to none (<20%). Another 60 points were collected from a 1:50,000 scale topographic maps of the study area produced by EMA. These maps were originally prepared from an aerial photo series acquired during 1986 and 1987. Thus, they are to some extent comparable to the January1986 TM data set in this study. In the absence of other historical land-use/land-cover information these maps proved to give an important insight about the historical situation in terms of land-cover in better details than the historical imagery (Bedru Sherefa, 2006).

Further, collection of reference points for the classification of 1986 image were aided by local people who know the area very well during the specified time period. It was assumed that a land covered by forest or grass during field survey, was also covered by forest or grass during 1986, respectively, and used to train both images. This assumption was based on the existing trend that forests and grasslands are diminishing. Informal discussion was made with key informants from visited Kebelles, concerned government and NGO workers. Keeping the limit imposed by time relevant information such as tree species local name, rate of invasion, and local people perception were also collected informally.

Secondary data were collected from Yabello Woreda Pastoralist Development Office. Information on human and livestock population, farming system and level of bush encroachment was collected from Kebelles (Peasant Association).

4.2. Image Acquisition and Calibration

Two date cloud free Landsat TM and ETM+ imageries (path 168; row 56 and 57) that were acquired on January 1986 and 2003 respectively, were analyzed to classify the land-use/land-covers of the study area. Both of the satellite images were obtained from ILRI. The mosaics of the two scenes (row 56 and 57) covering the whole extent of the study area were prepared for both years. Landsat TM and ETM+ data have 7 and 8 bands, respectively. The additional band on the ETM+ is a panchromatic band with 15m spatial resolution. The thermal bands and this panchromatic band were not utilized in the analysis. All image processing and analysis tasks were done by ENVI 4.3 and ERDAS IMAGINE 9.1 image processing softwares and maps were produced using ArcGIS 9.2.

For change detection application using multi-temporal remote sensing data, accurate geometric rectification and atmospheric calibration are two important aspects in image processing (Dengsheng *et al.*, 2004). The Landsat images obtained for this study had been already orthorectified by the image supplier. However, the model used for orthorectifying is too broad (global) to be in the state of usable precision. Accordingly, the two images were rectified to Transverse Mercator projection using Clarke 1880 spheroid to fit with the projection of a 1:50,000 topographic map and further georeferenced using 21 points. Then the 1986 TM image was coregistered by the 2003 image with root mean square error less than 1 pixel. Radiometric conversion of the data to at-sensor reflectance was not successful due to absence of information on atmospheric constituents and other ancillary data. Thus, all subsequent image processing were done on the raw DN images.

4.3. Data Analysis

4.3.1. Supervised Classification

Supervised classification method is a well known procedure used to cluster pixels in to their respective classes. Where there is a heterogeneous landscape supervised classification gives best result (Yuksel *et al*., 2008). In this study, this method was applied to classify the land-use/land-cover types of the study area. Initially the image was pre-classified using the unsupervised classification method and features that were not readily identifiable on the images were then identified during field visit. The sample points collected from the field were converted to polygons using ENVI's ROI (region of interest) tool. The extent of the polygons surrounding each point was collected during field survey. About 40% of the polygons were used for training and the rest for accuracy assessment. In addition, the training process was aided by other supplementary training areas that were collected from the scatter plots of the images by comparing their spectral characteristics with the original training areas.

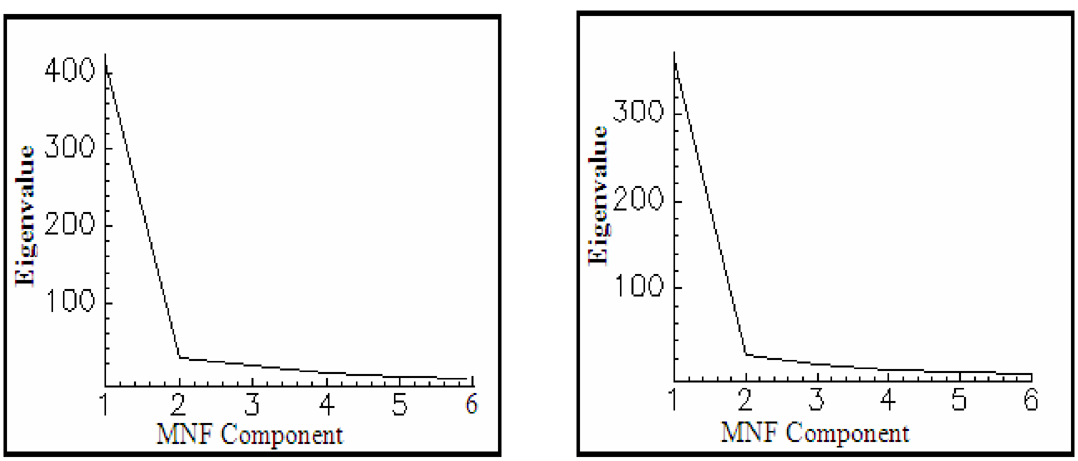
The separability of the ROIs was computed step by step during delineating them on the images. ROIs that significantly reduced the degree of separability of one class from the other were rejected. Both the Jeffries-Matusita and Transformed Divergence separability measures were reported. These values range from 0 to 2.0 and indicate how well the selected ROI pairs are statistically separate (ENVI, 2005). Values greater than 1.9 indicate that the ROI pairs have good separability. For ROI pairs with lower separability values, it was attempted to improve the separability by editing and/or by selecting new ROIs from the scatter plots of the images. ROI pairs with very low separability values (less than 1) should be combined into a single ROI. The separability report of the ROIs is provided in appendix I. Finally, pixels were clustered using Gaussian Maximum Likelihood algorithm.

4.3.2. Spectral Mixture Analysis

As described earlier, development of high quality fraction images depends greatly on the selection of suitable endmembers. Points that represent pure land-use/land-cover classes that were converted to polygons for supervised classification were again used in the SMA. However, these points were not enough to construct a spectral library of each land-use/land-cover. Thus, other mechanisms were applied to determine the degree of purity of each selected endmembers and to collect other pure pixels from the images. The MNF (Minimum Noise Fraction) transform and PPI (Pixel Purity Index) and scatter plots were applied.

The MNF transform (Green *et al*., 1988) is an algorithm consisting of two consecutive data reduction operations. The first is based on an estimation of noise in the data as represented by a correlation matrix. This transformation decorrelates and rescales the noise in the data, by variance. At this stage, the information about between band noise has not been considered. The second operation accounts for the original correlations, and creates a set of components that contain weighted information about the variance across all bands in the raw data set. The algorithm retains specific channel information because all original bands contribute to each of the components weighting. MNF transform is used to determine the inherent dimensionality of image data, to segregate noise in the data, and to reduce the computational requirements for subsequent processing.

First the Landsat TM and ETM imageries were transformed into new components using MNF transform and the first four components were selected for the analysis based on their eigenvalues. The other two were discarded due to their low eigenvalues. Bands with large eigenvalues (greater than 1) contain data, and bands with eigenvalues close to 1 contain noise (ENVI, 2005). The MNF transformed images of 1986 and 2003 are shown in Appendix-IV. The first MNF components of the 1986 and 2003 MNF images contained about 87.4% and 87.5% of the variation respectively. The second components contained 5.96% and 5.83% of the variance. Figure 2 shows the eigenvalues for each component. Using the dominant components the MNF transformed image was again transformed back to its original spectral space, resulting in the same number of transformed channels as the original data provided.



a) b)

Fig. 2. MNF plots of Forward MNF Transformed Images of 2003(a) and 1986(b).

In this study scatter plots of the first and second components of both the 1986 and 2003 MNF images were examined. The pixels that were found at the extremes of the scatter plots were assumed to be pure relative to other pixels in the image. The scatter plots of band 3 and band 4 of the original images were also examined to get pure pixels of bush species and woody species from the images.

The Pixel Purity Index, as the name indicates, is used for defining potential image endmember spectra for spectral unmixing. When image spectra are treated as points in n-dimensional spectral space, endmember spectra should lie along the margins of the data cloud. The PPI creates a large number of randomly oriented test vectors anchored at the origin of the coordinate space. The spectral points are projected onto each test vector, and spectra within a threshold distance of the minimum and maximum projected values are flagged as extreme.

The PPI was run on the inverse MNF transformed images by testing the optimum number of iterations. One thousand iterations were made on both images with a threshold distance of three and the PPI images were produced.

For most remote sensing applications using linear SMA, the image-based endmember selection method is often used because the endmembers are easily obtained and represent spectra measured at the same scale as the image data. In this study five types of endmembers were identified for the unmixing. They were savannah grassland, bushland, bareland, woodland and shade. According to Dengsheng *et al.* (2004), the number of endmembers should be less than or equal to the spectral bands used. On the other side other author argues that the number of endmebers should be less than the spectral bands. Takeuchi *et al.* (2002) used constrained endmembers one less than the bands in the image to unmix NOAA AVHRR image for detection of fire affected area. However, it is clear that the number of endmembers is dependent on the degree of heterogeneity of the landscape and number of available relevant bands.

The selection of pure endmembers for developing the spectral library of the land-covers should be looked thoroughly. Selection of inappropriate or incorrect endmembers adversely affects the accuracy of the unmixing. Finally, to avoid such undesirable outcomes and to get the best endmember, five dependent selection criterions were set.

Thus, to be selected an endmember should meet the fifth criteria unless it did not meet one of the first four criterions. The criterions are described here under according their order of importance;

I. Endmembers that have high PPI value, found at the extreme sides of the MNF scatter plots and that were collected from the field.
II. Endmembers with high PPI value and found extreme on the MNF scatter plots.
III. Endmembers that were collected from the field and have high PPI value.
IV. Endmembers that were identified from the field and found extreme on the MNF scatter plot.
V. Endmembers that were found on the extreme sides of the scatter plots of band 3 and band 4 and have high PPI value.

The fifth criteria was mainly applied for the selection of endmembers that represent bushes and woodlands.

For each class, endmembers that fulfill the above set criterions were compared to each other by plotting their spectral reflectance. One endmember per class which mostly resemble the other was finally taken and spectral libraries were constructed for the 1986 and 2003 images. The unmixing was tested by combining different endmembers to get the best result. Combination of woodland, bushland, savannah grassland, bare surface, tilled soil and shade was examined first. Then woodland was omitted, next bushland was omitted and woodland was incorporated. Again savannah grassland and tilled soil were omitted. Then bare surface was omitted and tilled soil was incorporated. And finally combination of bushland, soil and shade was tested. Unconstrained unmixing was applied to produce the final fraction images. The bushland fraction image was then stretched to 100% and classified in to five classes based on canopy cover.

4.4. Postclassification Accuracy Assessment

The outputs of both the supervised classification and SMA were assessed for their accuracy using field collected random samples. For the former, ground truth data of each land-use/land-cover classes collected from the field was used. But for the later the bush fraction image was assessed based on canopy cover of ground truth data collected from the field. The accuracy assessment was only limited to bush fraction due to the limit imposed by time to collect and analyze field data for each class. Collection of verification samples assumed that there was no significant vegetation cover change between image acquisition time and data collection time. This assumption was made due to unavailability of other better options. The accuracy of the 1986 classified image produced by both methods was not assessed due to lack of appropriate data.

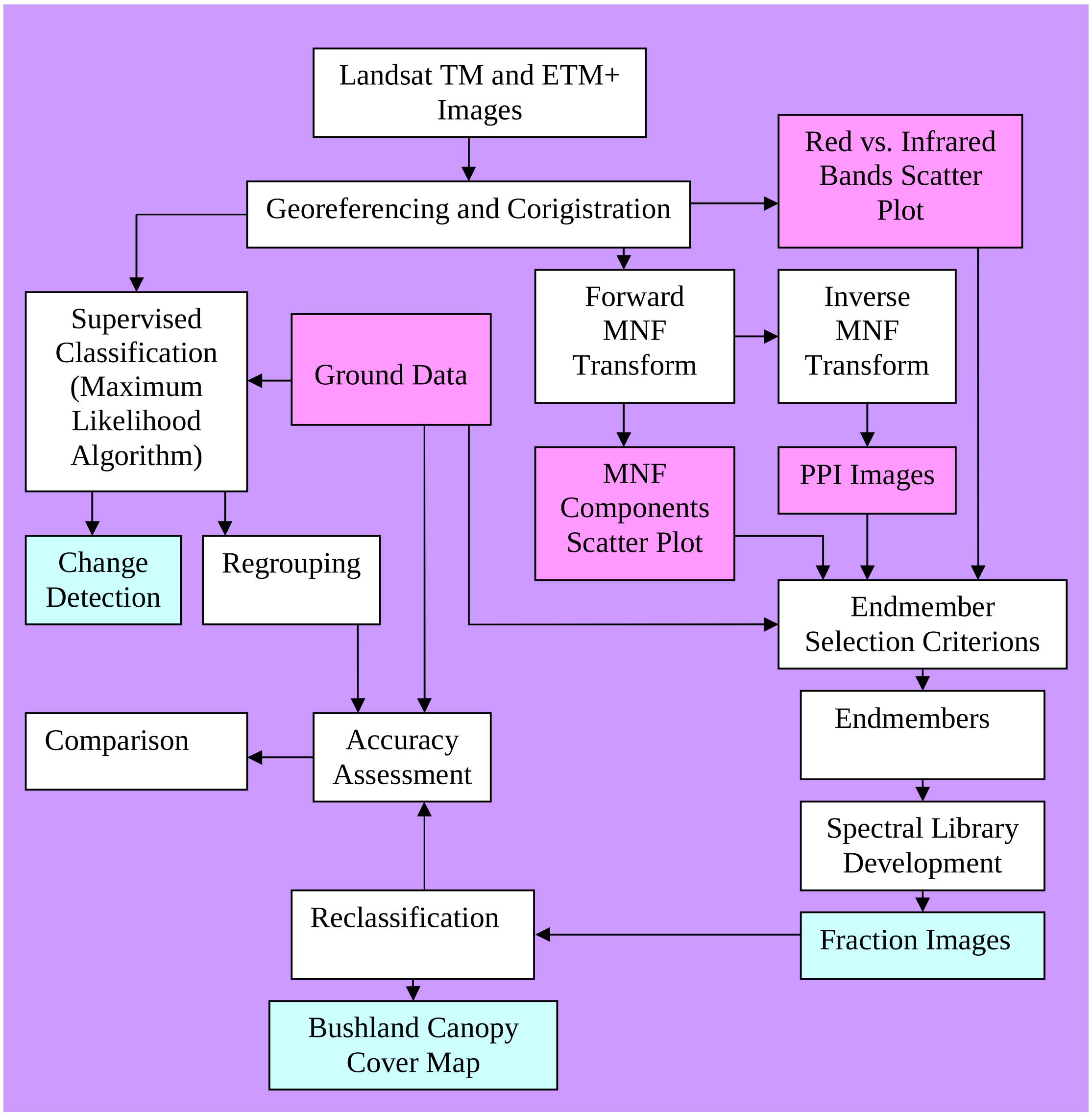


Fig. 3. General Methodology Flow Chart.

Comparison of classification outputs obtained from supervised classification and SMA was made by regrouping the classified images in to bushland and no-bush classes. In the supervised classification all land-use/land-cover classes except bushland were grouped in to one class; no-bush. In the SMA bushland canopy cover <20% was considered as no-bush based on the definition of bushland and other classes that have >20% canopy cover were regrouped to a single class; bushland. Accuracy of the regrouped images obtained from both methods was assessed using about 100 random points collected from the field that represent bushland and no-bush classes. Overall accuracy, Kappa coefficient, User and Producer accuracy were reported.

5. Results and Discussion

5.1. Outcomes of Supervised Classification

Change in land-use/land-cover has important consequences on the management of natural resources including soil and water quality, global climatic systems and biodiversity. Thus, classification of dominant land-use/land-covers should be done first to evaluate the trends in the system.

As described earlier in the supervised classification method, pixels are assigned to their respective classes based on their spectral characteristics. In the central mountain ranges, where remnant forests and woodlands are relatively prominent, classification of pixels to these classes was found difficult. This is due to similar composition of the forests and the woodlands and the spectral variability between these two classes was masked by the presence of shade from adjacent mountains and cliffs.

On the other hand, grasslands and farmlands conveyed similar radiance, where there were residues of corn and sorghum left on the farmlands. Beside, relatively moist grasslands were observed to have similar reflectance with tilled soils. The images were acquired during dry season and this gave better room to separate woodlands and forests from grasslands. During the wet season, grasslands and forests have nearly similar spectral characteristics. Barelands were readily separable from other classes except with a little confusion with croplands. This land cover type gave very distinct white colours on the false colour composite images (Appendix-III) showing high (>1.90) separability index for the two year images.

Generally, crop/cultivated land and grassland (1.30), bushland and woodland (1.62), forest and woodland (1.64), forest and bushland (1.82) and crop/cultivated land and bareland (1.83) for the 1986 image and bushland and woodland (1.28) and forest and bushland (1.69) for the 2003 image showed lower (<1.9) Jeffries-Matusita separability measures. Both Jeffries-Matusita and Transformed Divergence separability measures for all of the training areas are provided in appendix-I.

User and producer accuracy for each land-use/land-cover classes of the 2003 classified image is shown in Table 1. The overall accuracy and Kappa coefficient were found to be 82.665% and 0.778, respectively.

Table 1: Producer and User Accuracy of the Classification of 2003 ETM Image.

Class	Producer accuracy (Percent)	User accuracy (Percent)	Producer accuracy (Pixel)	User accuracy (Pixel)
Forest	44.41	86.11	155/349	155/180
Grassland	79.16	74.19	319/403	319/430
Bareland	80.72	94.23	490/607	490/520
Bushland	90.50	85.43	1038/1147	1038/1215
Woodland	91.00	79.67	435/478	435/546
Crop/cultivated land	94.19	69.23	243/258	243/351

A land-use/land-cover classification system which can effectively employ orbital and high-altitude remote sensor data should meet an interpretation accuracy of at least 85 percent in the identification of land-use/land-cover categories (Anderson *et al.*, 1976). However, this threshold is put regardless of the next application of the classification output. It is clear that different applications require different classification accuracy. To get such result, however, the classification should be done repetitively and interpretation of the remotely sensed data should be aided by other high resolution maps.

Relatively good user and producer accuracy was achieved for the bareland and bushland categories. Despite the fact that bushlands showed lower separability from woodland and forest, they are classified with better accuracy. This may be due to their presence in abundant. User and producer accuracy and confusion matrix were shown in Appendix-II.

5.2. Land-Use/land-Cover Change Between 1986 and 2003

Postclassification comparison method was used to detect the change from 1986 to 2003. The land-use/land-cover maps of the study area for 1986 and 2003 are presented in Figure 5 and 6, respectively. Change in land-use/land-cover is a natural process that cannot be stopped. But changes induced by anthropogenic factors will aggravate or divert the direction of change. In Borana rangelands, according to this study, there is a tremendous change during 1986-2003. Table 2 shows the changes in each land-use/land-cover classes in km^2 and in percent. This result shows that crop/cultivated land, bushland and woodland increased whereas, forest, grassland and bareland decreased over the study period.

Table 2: Statistical Results of Land-Use/Land-Cover Change Detection Between 1986 and 2003.

	1986		2003			
	Area in km^2	Area in %	Area in km^2	Area in %	Change in km^2	Change in %
Forest	66.04	1.192	46.86	0.84	-19.18	-29.04
Woodland	483.35	8.75	665.97	12.06	182.62	37.78
Bushland	1549.37	28.05	2418.46	43.80	869.09	56.09
Grassland	2661.16	48.18	1580.28	28.82	-1080.88	-40.61
Crop/cultivated Land	335.12	6.06	453.23	8.20	118.11	35.24
Bareland	427.46	7.74	356.97	6.46	-0.49	-16.49

The above table only shows the extent and percent of vegetation cover change. Even if vegetation cover is determined by the structure of the vegetation, supervised classification output tells nothing about the vegetation structure. Figure 4 shows the change between 1986 and 2003.

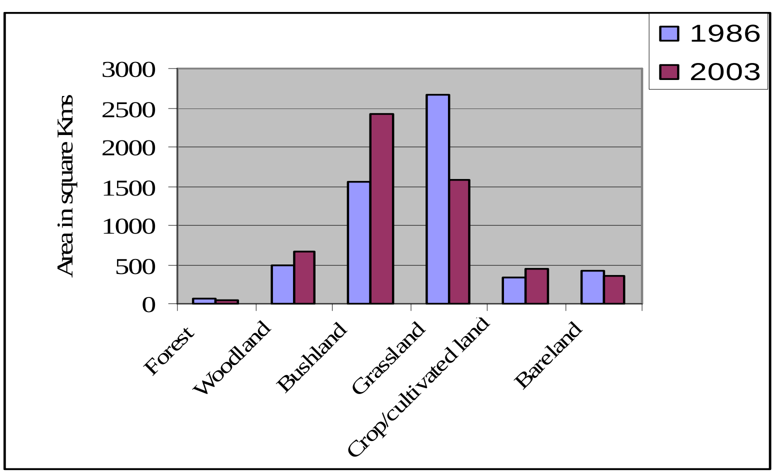


Fig. 4. Comparisons of Change in Land-Use/Land-Covers Between 1986 and 2003.

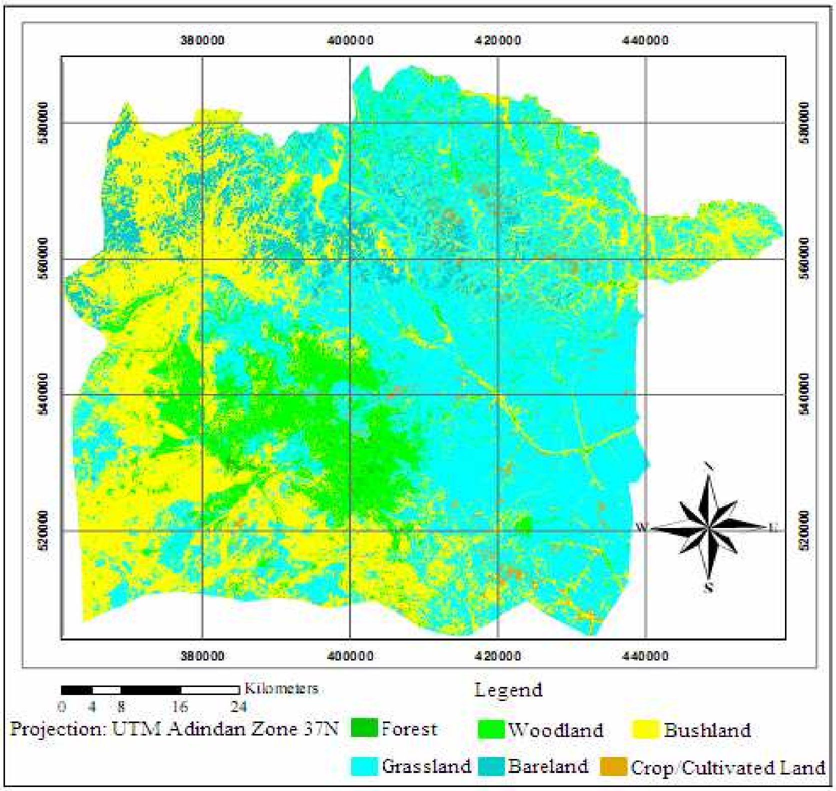


Fig. 5. Land-Use/Land-Cover Classes of Yabello District in 1986.

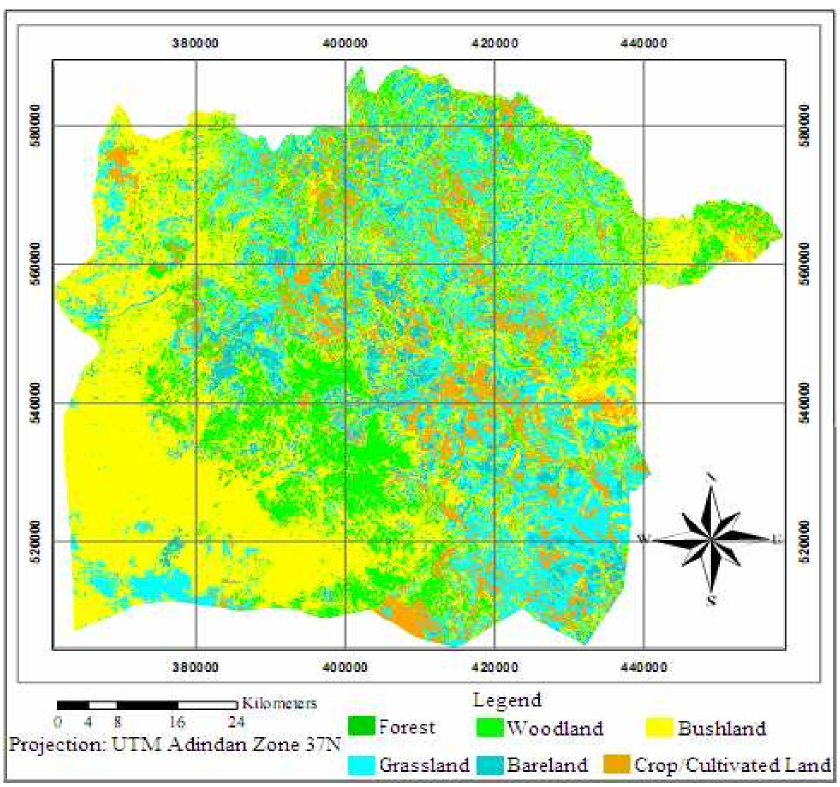


Fig. 6. Land-Use/Land-Cover Classes of Yabello District in 2003.

5.2.1. Forest

It is known that the extential quality of forest habitat have been dwindling from time to time all over Ethiopia. Table 3 shows the initial and final state of each land-use/land-cover classes and direction of change in each class in percent during 1986-2003. The existing trend is also similar that the forests of the central mountain ranges of Yabello district were declined by 29.04% during 1986-2003. These forests are mainly composed of indigenous species that are found on top of the list of endangered species. The main threat to these forests is illegal cutting. Almost all Borana traditional mud houses have been constructed mainly by *Juniperous procera* (Yeabesha Tid). This is due to its durability by resisting decay and termite attack that are very prominent in red soils of Borana rangelands forming blocks of soil by churning up the sub soil to the top. Absence of fast growing, straight-truncked multipurpose trees species put strong pressure on the indigenous species. Besides, these species are transported more than 100kms up to Moyale town and sold illegally.

Areas that were initially covered by forest were largely converted to woodlands and bush lands. This indicates that there existed selective cutting of trees. Conversion of forests to farmland is not significant as compared to the woodland and bushland. This may be due to the restricted coverage of forests. The conversion of forests to farmlands is a rapid process and if it were existed it could be seen clearly.

Table 3: Land-Use/Land-Cover Change Matrix.

	Initial State in percent						
		Forest	Wood land	Bush land	Grass land	Crop/ Cultivated land	Bare land
Final State	Forest	7.29	1.344	1.95	0.19	0.12	0.05
	Woodland	58.33	29.74	13.81	8.73	6.74	3.46
	Bushland	31.47	48.54	65.53	34.90	23.91	32.49
	Grassland	1.44	11.75	12.68	36.32	46.57	47.59
	Crop/cultivated land	1.18	4.09	5.02	11.06	14.79	2.59
	Bareland	0.29	4.55	0.99	8.80	7.84	13.81

5.2.2. Woodlands

Woodlands are the main components of rangelands. They bear fodder and shade for both wild and domestic animals beside other ecological significances. In the study area, about 665.97km^2 was covered by woodland in 2003. There is a net increase in this class. Mainly bushlands were converted to woodlands next to forest.

The change matrix shows a 6.74% conversion of crop/cultivated lands to woodlands. Crop/cultivated land confuses with grassland. Thus, those grasslands that were burned before the fire ban would have similar reflectance with crop/cultivated land before they were overtaken by woody species. However, this change also indicates that there was a confusion between crop/cultivated land and other classes during classification. There was also a conversion of grasslands and barelands to woodland. This conversion is possible due to privatization of communal grazing lands and better conservation in some places like enclosures. On the other hand, this may show that bushlands would be wrongly classified as woodland.

5.2.3. Bushland

The natural succession of vegetation in East Africa is towards woody vegetation unless it is restricted by very low rainfall and/or unfavuorable soil-water condition (Alemayehu Mengistu, 2006). The major constraints to woody vegetation completely dominating the rangelands of Eastern Africa are burning and clearing. In Yabello district, bushlands were increased significantly between the study periods. This result agrees with the findings of other authors (Nigusse Bekelle, 2008; Sintayehu Mesele, 2007; Ayana Angassa, 2006 and Gemedo *et al*, 2006).

The percent cover of bushland in 1986 was 28.05%. But in 2003, it reached about 43.8% which is 56.09% increas in seventeen years. This is about 2.57% increase per year. Woodlands are mainly converted to bushland. Grassland and forest were converted to bushland next to woodlands. The conversion of woodlands to bushlands may be due to high resistance of bushes to the prevailing drought and illegal cutting. However, conversion of woodlands was offset by the conversion of forests and grasslands to woodland and thus, there is no a general decrease in the woodland category. Bush clearing activities and conservation of communal grazing lands in some places resulted in conversion of bushland to grassland.

There is an increasing pattern in bush cover since 1979 after the ban of rangeland burning. Overgrazed and degraded lands give rise to bush invasion due to their low moisture content and low competition exerted on bushes by grass. Bush encroachment decreases grass biomass yield and cause shortage of fodder. It also increases migration for feed and reduces animal productivity and hosts predators (Nigusse Bekelle, 2008).

5.2.4. Grassland

Grasslands were shrunk by 40.61% during 1986-2003. This was the largest value among the classes that were reduced. They were converted largely to bushland, followed by woodland, crop/cultivated land, and bareland. Similar justifications were given for the disappearing of grasslands in Borana rangelands. Overgrazing, bush encroachment, population pressure (both human and livestock) and climate change are the top reasons. In dominant pastoralist groups of Borana, cattle production is favoured than browsers. So, imbalance between browsers and grazers also contributed for the expansion of trees and shrubs into the grassland in the study area (Nigusse Bekelle, 2008).

Similarly, Joing (2004) stated that increase in domestic livestock (grazers) and a decrease in browsers number increases the pressure on the grass layer, the competitive advantage of a vigorous perennial cover declines, and it creates favourable environment for the woody component. Another factor is that successive ethnic conflicts displaced portion of the population and brought additional pressure on the grazing land.

5.2.5. Crop/Cultivated Land

As discussed earlier, crop cultivation was restricted to a few Peasant Associations in Borana lowlands generally, and Yabello district particularly. However, starting from a few years back, crop production has been practiced for commercial purpose beyond producing for household subsistence. In this study, expansion of crop land at the expense of other classes indicates a general shift towards crop production. About 11.06% of the grassland was converted to crop/cultivated land. Bushland (5.01%), woodland (4.07%), bareland (2.58%) and forest (1.17%) were converted to agricultural land. According to Sintayehu Mesele (2007), there was a big shift in the land use pattern of the lowlands during this period because of farmers' attractions towards cropping mainly teff, maize, sorghum and wheat on valley bottom lands. More recently, teff cultivation for commercial purposes has gained momentum on the lowlands mainly due to improved access to local markets. Also the recurrent drought forced the pastoralists to till their land in greater extent than before to cope up with the conditions.

5.2.6. Bareland

The very striking result of this study is that barelands were decreased between the study period. They are mainly converted to grassland and bushlands. This change is visible from the false colour composites of the two date images shown in appendix-III. Initially very white pixels were changed to red to bluish. Bushes can grow on degraded lands if little moisture is available. But this does not imply that bush encroachment reduced soil erosion. Because bush encroached sites have low grass and herbaceous cover due to light and moisture competition. Thus, the underground surface, which is formerly covered by grasses and herbs will be subjected to soil erosion than before. Bush invasion increases evapotranspiration and surface run-off by intercepting high amount of rainfall that infiltrates to the sub soil. Ayana *et al*. (2006) reported that soil condition is generally good in the study area except in areas where agriculture has been practiced for long period of time.

5.3. Spectral Mixture Analysis

5.3.1. Spectral Library Development

Different methods were applied to explore possible image endmembers. The scatter plots of the first MNF and second MNF components of the 1986 and 2003 MNF images are shown in Figure 7. In the scatter plots bare surface, shade and tilled soil have distinct spectral limits. However, the bushland and woodland were not readily separable and found mixed with other classes. This created a big trouble to get endmembers of bushland particularly for the 1986 image. The presence of shadow on the central woodlands seriously reduced the spectral variability contained in the images.

Endmembers for bushland and woodland were finally obtained from the scatter plot of band 3 and band 4 of the two original images and from the PPI image. Vegetation has high value in the near infrared region and low value in the red reflectance region. Although the original scatter plot gave better separation between the bushes and woodlands than the MNF scatter plots, there was a difficulty to separate the two land-covers.

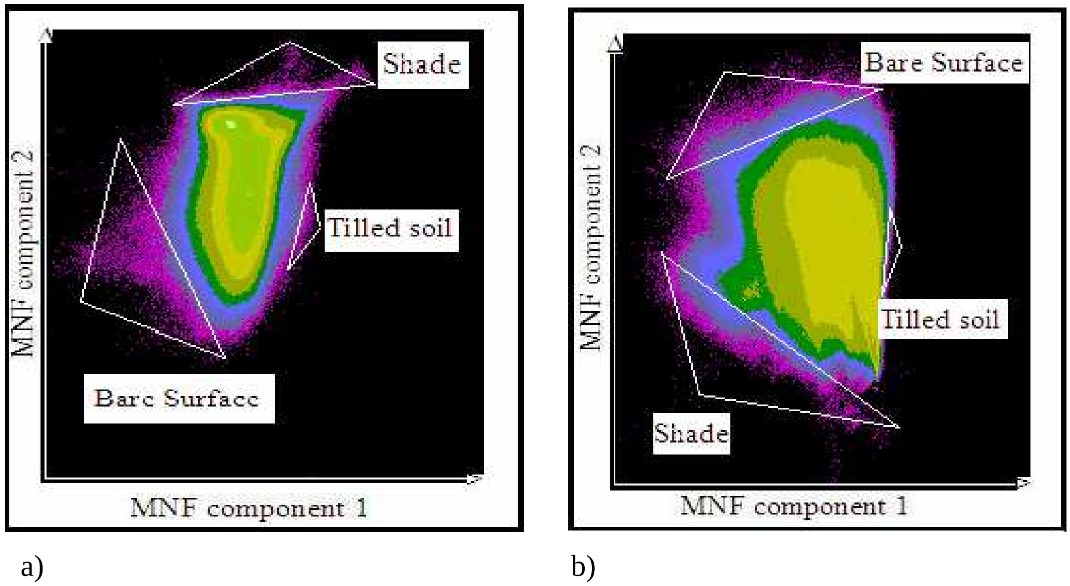
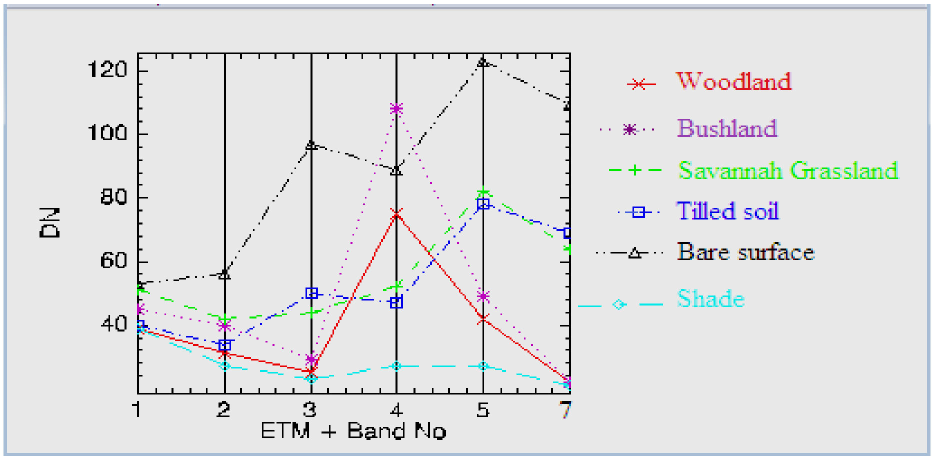


Fig. 7. MNF Scatter Plots of Forward MNF Transformed Images of 1986(a) and 2003(b**).**

Bushy species have relatively higher DN value than the woodlands in the infrared region. This is due to the greater effect of seasonal moisture stress on the woodlands. As stated earlier, most of the bushlands are composed of Acacia species and can resist moisture stress than the woodlands. However, this did not clearly segregate the two classes due to the presence of large Acacia trees that are found under the woodland category that have similar leaf structure with the bushes. Variation in leaf chemistry and structure has a great importance in the identification vegetation types.

The spectral libraries of both years shown in Figure 8, developed from the selected endmembers, exhibited better separation at the infrared and mid-infrared regions for all of the land-use/land-cover classes. Savannah grassland, tilled soil and bare surface depict nearly similar pattern through out the spectral bands. Woodland and bushland were separated at the near infrared and mid infrared regions of the spectrum. All the land-use/land-cover classes follow nearly similar pattern at the blue band. This is mainly due to high atmospheric scattering at this band. This pattern may be reduced by using spectral libraries that are developed from images initially radiometrically converted to at-sensor reflectance.



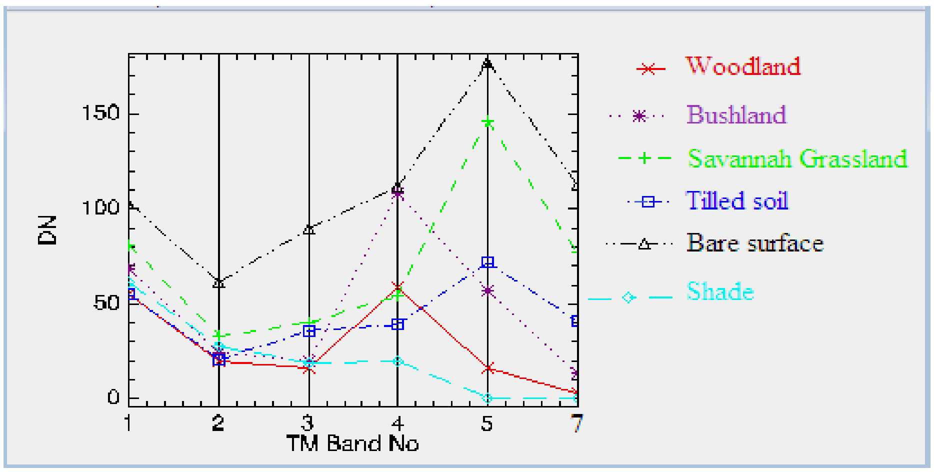


Fig. 8. Spectral Library Plots of Endmembers from 2003 ETM+ (Top) and 1986 TM (Bottom) Images.

5.3.2. Characteristics of Produced Fraction Images

Using the constructed spectral libraries fraction images of each land use land cover classes were produced. The unmixing was iteratively tested for the best result. The combination of bushland, savannah grassland, tilled soil, bare surface and shade endmembers clearly segregated bushlands from other classes on the 2003 image.

Fraction of images produced from combination of endmembers where both bushlands and woodlands were present did not capture both the woodlands and the bushland satisfactorily. However, the root mean square error decreased as the two classes were used separately. Bare surfaces tend to enter to the bushland category as the two endmembers used together. This problem was prevalent in the 1986 image, where combination of bushland and woodland endmembers did not unmix bushlands. Thus, this study suggests that selection of bushland and woodland endmembers based on Landsat images requires further investigation and analysis.

Visual analysis of fraction images is useful for understanding the characteristics of different land-cover types. Figures 9 and 10 provide comparisons of the multi-temporal fraction images derived from 1986 TM and 2003 ETM images for the best combinations. A high abundance of each endmember is indicated by brighter pixels and a low abundance by the darker pixels. Figure 9a and Figure 10a show the vegetation fraction and bush fraction, respectively. The increasing trend in vegetation cover is visualized clearly on the images. The brightness of vegetation varies due the relative abundance and canopy cover variation along the landscape. Areas that have high vegetation or bush fraction have low soil or bare surface fraction. Savannah grasslands are found in greater concentration on the 1986 fraction image than the 2003 fraction image. Also, on the later image, savannah grasslands convey parcel formation trend, which shows the restriction of this land-cover from time to time.

On the tilled soil and bare surface fraction images of both years, vegetation appeared darker owing to lower exposure of soil and bare surface under the canopy. The shade that was existed on the central mountains is clearly displayed on the shade fractions.

Different fraction images have their own characteristics in representing land-cover types, and different vegetation stand structures and land cover-types have different area proportional compositions of the endmembers (Dengsheng *et al.*, 2004). For example, vegetation and non-vegetation have significantly different soil fractions; very low soil fractions for vegetation covers and high values for non-vegetation cover except water. Thus, soil fraction differencing image from two dates can be used to detect vegetation deforestation or reforestation. However, in this study image differencing was not attempted due to the unsuccessful unmixing of bushland fraction for the 1986 TM image and due to time limit.

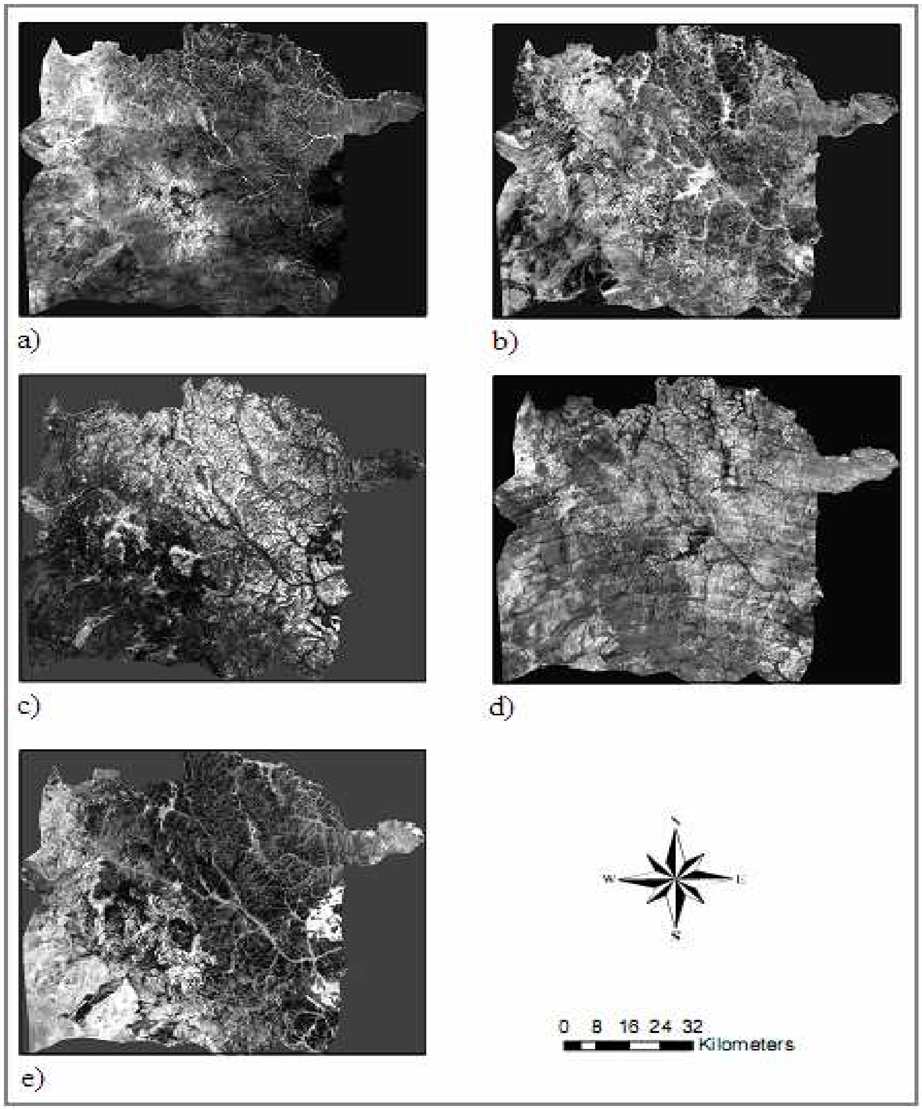


Fig. 9. Fraction Images of 1986 a) Vegetation, b) Savannah Grassland, c) Bare Surface, d) Tilled Soil, e) Shade.

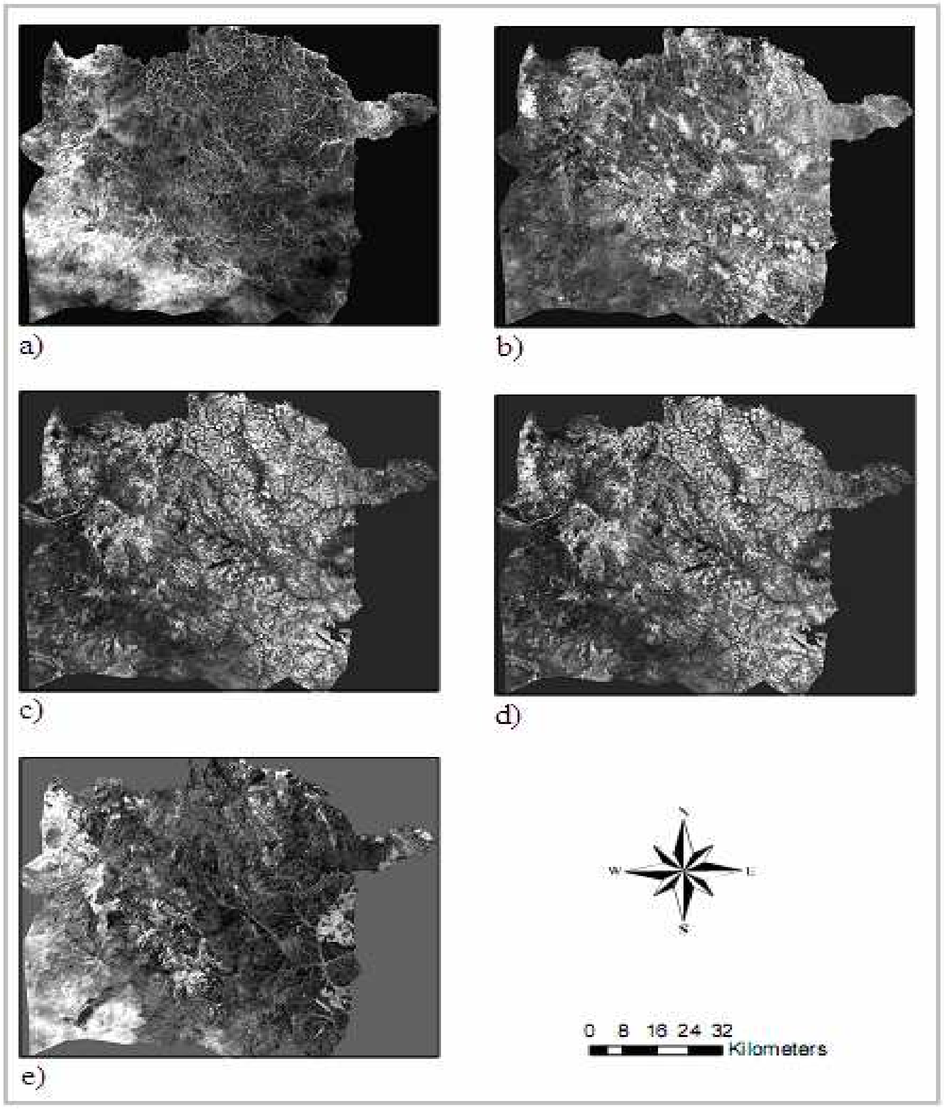


Fig. 10. Fraction Images of 2003 a) Vegetation, b) Savannah Grassland, c) Bare Surface, d) Tilled Soil, e) Shade.

The vegetation-impervious surface-soil model using bare surface as impervious material was also tested and showed high root mean square error. This model works better for urban environment, where soil fraction is low and impervious surface is prominent.

5.3.3. Mapping Bush Encroachment from Fraction Images

Linear spectral unmixing was found suitable for mapping homogeneous vegetation cover (Palanswami *et al.*, 2006). In this study, due to the limitation of radiometric and spectral resolution, it was difficult to greatly improve the SMA classification accuracy for the fraction images. The heterogeneity and composition of the vegetation in the study area combined with the limited number of bands in the Landsat TM and ETM+ images utilized in this study also reduced the quality of fraction images produced.

The overall accuracy and Kappa coefficient of the classification of bushland fraction image were found to be 72.00% and 0.64, respectively. It is well recognized that Landsat ETM data are hampered by the low spectral dimensionality and by low spatial resolution, which limits the selection of a few pure non-mixed pixels (Meer and Jong, 2000). In a standard application of SMA, a fixed number of representative endmembers, usually between two and five, are selected. However, this procedure is limited because the selected endmember spectra may not effectively model all elements in the image, or a pixel may be modeled by endmembers that do not correspond to the materials located in its field of view. Both cases result in decreased accuracy of the estimated fractions (Sabol *et al*., 1992).

Table 4: Statistical Result of User and Producer Accuracy for the 2003 Bush Fraction Image.

Class	Producer Accuracy (%)	User Accuracy (%)	Producer Accuracy (Pixels)	User Accuracy (Pixels)
<20%	68.76	99.49	590/858	590/593
20_40%	59.47	59.55	424/713	424/712
40_60%	79.20	58.37	537/678	537/920
60_80%	86.31	83.08	599/694	599/721
>80%	54.69	71.43	70/128	70/98

Based on the produced fraction image, bush cover was estimated. Table 5 shows the percent cover of bushes based on canopy cover.

Table 5: Bush Cover of Yabello District Based on Canopy Cover in % in 2003.

Canopy cover in %	Area cover in km^2	Area cover in %	Severity
<20	2037.53	36.90	Very low
20-40	2374.3	43.07	Low
40-60	932.6	16.89	Medium
60-80	161.78	2.93	High
>80	10	0.18	Sever

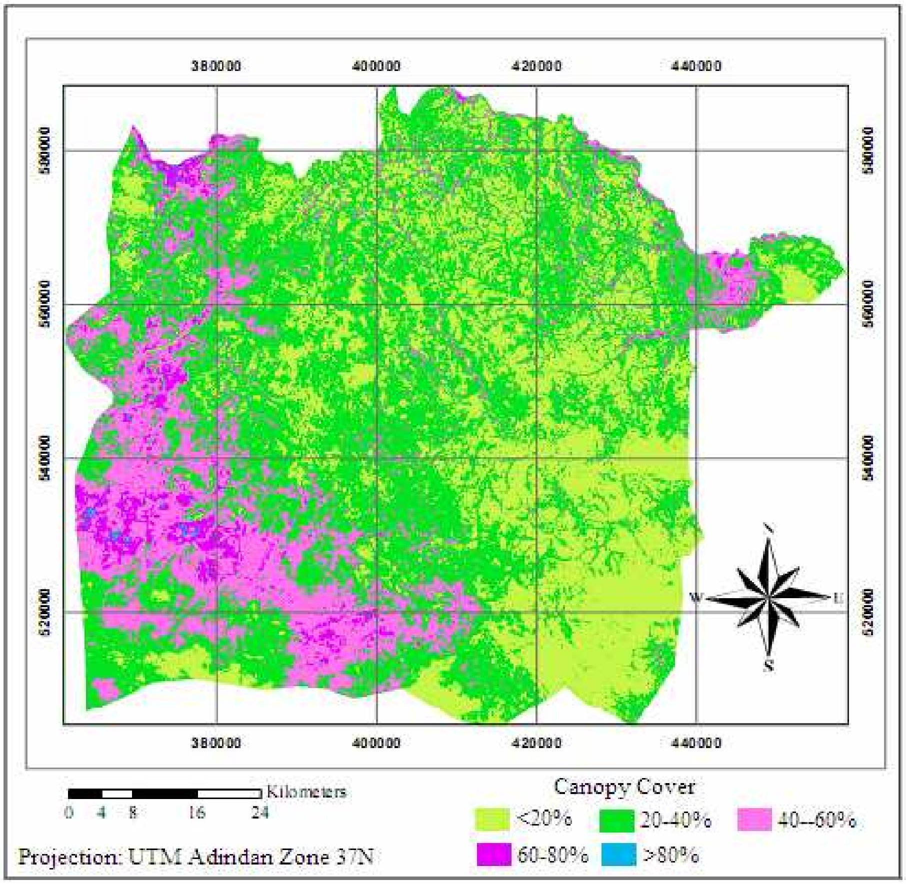


Fig. 11. Map of Bush Encroachment During 2003 Based on Canopy Cover.

Figure 11 and 12 show bush coverage and vegetation coverage in 2003 and 1986, respectively. Majority of the land was covered by bushy species that have 20-40% canopy cover in 2003. Severely encroached area covered about 0.2% of the district. According to Gemedo *et al*. (2006), shrub cover of 40% and/or 2400 woody plants per ha was considered as a border line between non-encroached and encroached condition. Thus, 20% of the district is encroached only by bushy species. This figure is excluding contribution of other woody species that were not considered as encroacher in this study. Vegetation cover existed during 1986 was estimated from the fraction image. Hence, it was not possible to segregate bushlands and woodlands using the SMA, comparison was made with total vegetation cover that was existed during 1986. Table 6 shows the percentage cover of vegetation in 1986.

Table 6: Vegetation Cover of Yabello District in 1986 Based on Canopy Cover.

Vegetation canopy cover in %	Area cover in km^2	Area cover in %
<20	4460.5	80.78
20-40	1023.74	18.54
40-60	35.34	0.64
60-80	1.65	0.03
>80	0.08	0.0015

From Table 5 and Table 6, it is clear that there was a tremendous increase in vegetation cover. In 1986, 80.78 % and 18.54% of the land was covered by vegetation that had less than 20% and between 20 and 40% canopy cover, respectively. Areas that had >40% vegetation cover were rare (0.67%). However, in 2003 about 20% of the land was covered by bushy species that had > 40 canopy cover. It showed that the 1980s and 1990s were the transitional periods from grassland to bushland. After the ban of rangeland burning these periods give rise to the expansion of woody species.

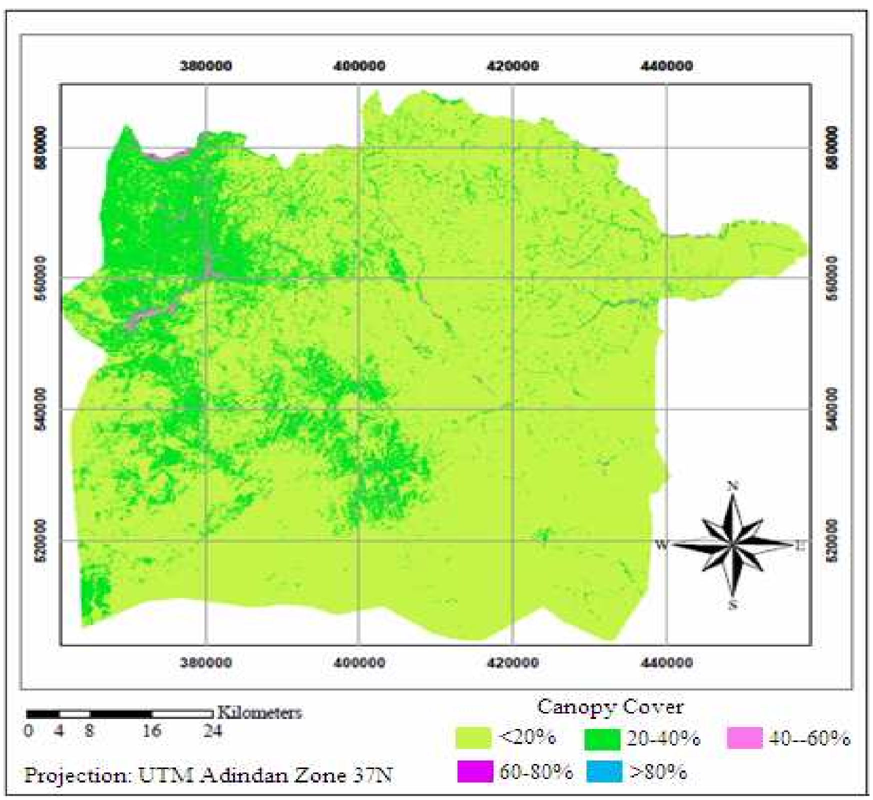


Fig. 12. Map of Vegetation Cover During 1986 Based on Canopy Cover.

5.3.4. Bush Encroachment at Peasant Associations Level

According to discussions made with local people, District Pastoral Development Office experts and non-governmental organization workers, level of bush encroachment varies from place to place and from one Peasant Association to the other. Gemedo *et al.* (2006) indicated that cover of woody plants was significantly different across different land-use units and sites. Density also significantly varies across different land-use units. Based on the level of bush encroachment, the Pastoral Development Office of the district divided Peasant Associations in to none encroached, low, medium, high and severely encroached classes. Figure 13 and Table 7 shows the level of bush encroachment in each Peasant Association.

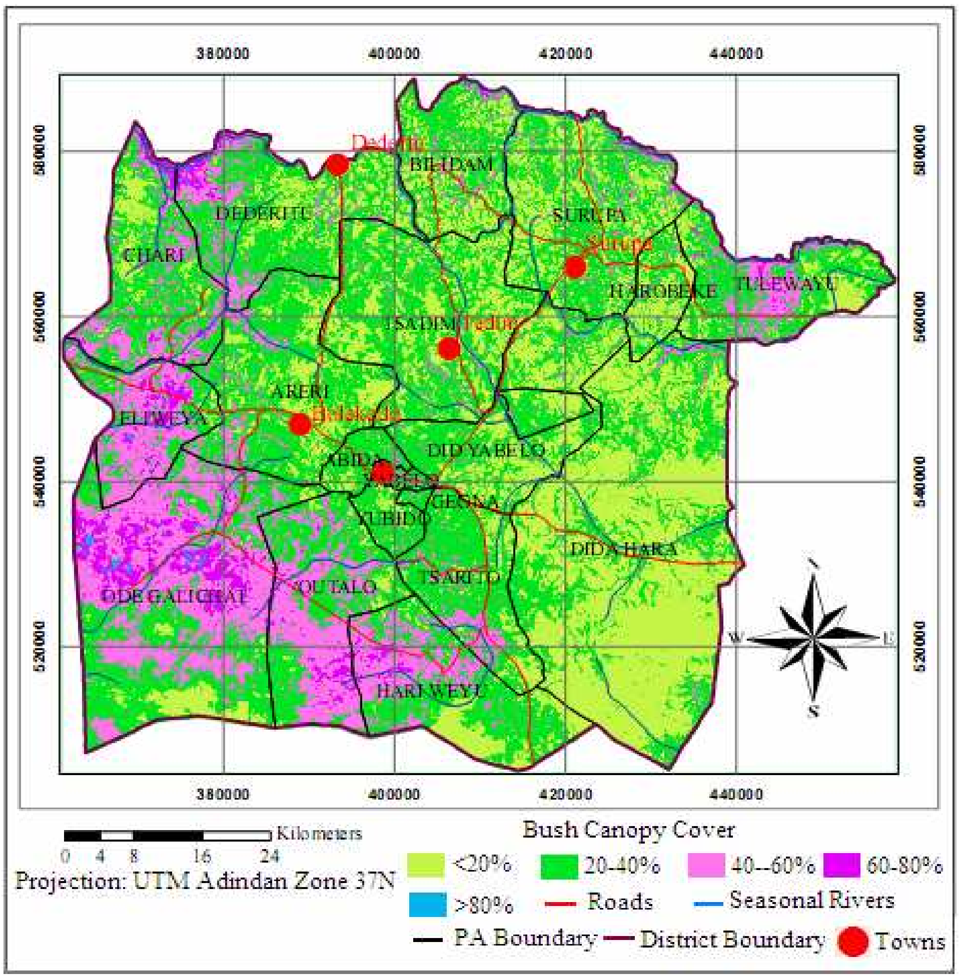


*Fig. 13. Map of Bush Encroachment Status of Peasant Associations in Yabello District.

*The names of peasant associations in the map are not correctly spelt. The right naming is the one that is followed on table 7.

Table 7: Bush Encroachment Status of Peasant Associations in Yabello District (source: Yabello District Pastoralist Development Office).

No	Peasant Association	Level of bush encroachment				
		None	Low	Medium	High	Sever
1	Adegelchet				√	
2	Areri			√		
3	Bildimraso				√	
4	Cheri			√		
5	Cholkasa			√		
6	Dedertu			√		
7	Dedim			√		
8	Derito				√	
9	Deed Hara				√	
10	Deed Yabello			√		
11	Elweya			√		
12	Ganya	√				
13	Harobeke				√	
14	Haroweyu					√
15	Obda		√			
16	Surupa		√			
17	Tula Weyu				√	
18	Utalo				√	
19	Yubdo	√				

Gemedo *et al*. (2006) found that the mean cover of woody plants in Deed Hara Peasant Association was 50% in 2006. The major contributors were *A. drepanolobium* and *C. africana*. *A. drepanolobium* mainly grows on black cotton soils and it has nearly dry canopy with thorny black to dark brown swellings. Both supervised and SMA classification outputs exhibited lower level of bush encroachment at Deed Hara. The spectral characteristics of the underlying black soil confuses with the signature of *A. drepanolobium.*

Figure 13 shows some agreement with the classification of the Pastoralist Development Office. For example, in Haroweyu and Adegelchet Peasant Associations, there exist sites which have > 80% canopy cover. Peasant Associations that are found in the highly encroached category in the classification also have canopy cover between 60% and 80% on the map. The map shows that Adegelchet, Areri, Haroweyu, Tula Weyu, Cheri, Elweya, Dedertu and Utalo are Peasant Associations that have >40% canopy cover.

5.4. Comparison of Supervised Classification Method and SMA

According to this study, both supervised classification and spectral mixture analysis methods showed the level of bush encroachment in the district. Comparison results showed that bush encroachment was mapped with greater accuracy using the supervised classification than SMA. As described earlier, Palaniswami *et al. (*2006) indicated that SMA based approach significantly improved classification accuracy as compared to the maximum likelihood classifier. However, in this study supervised classification performed better than the standard SMA application. The overall accuracy and Kappa coefficient for the supervised classification based on no-bush and bushland test samples were 90.38 and 0.80, whereas, SMA exhibited 84.61% and 0.69 overall accuracy and Kappa coefficient, respectively.

Independent of the endmember selection technique, Landsat-type instruments tend to provide sufficient spectral information to broadly discriminate between green vegetation and non-photosynthetic materials such as litter and soil (Asner *et al*., 1998). However, they do not typically provide the spectral resolution necessary to delineate species, functional groups, or greenness conditions within the “green vegetation” class using spectral mixture models unless seasonality enables such separations (Wessman, 2004).

Qualitatively, the main advantage of the supervised classification method over the SMA is its higher flexibility in selecting the number of classes considered in the classification. Since in SMA the number of endmembers that are used for unmixing should not exceed the number of spectral bands in the image, incorporating one endmember enforces omission of the other. Beside, where there are different species of bushes under a single bushland category readily separations of bushes require selection of the best endmember that represent all species in the class. SMA does not account for spectral variations present within the same material, as it permits only one endmember per material (Dennison and

Roberts, 2004). Also uncommon materials, which may not merit their own endmember, may be poorly modeled by SMA. However, in the supervised classification selection of training areas that represent similar species that are found under one category was found more simpler.

Regarding the requirement of training areas for classification, the SMA method was found simpler if ones the representative endmembers are defined. In the supervised classification adequate number of pixels should be provided to get sound classification. Also the final output does not tell us anything about the percentage cover of the class in a specific area. A pixel is classified to only one dominant land-use/land-cover. However, SMA provided an opportunity to estimate the abundance of each endmember in a pixel and gives room to asses the accuracy of each fraction images based on coverage.

6. Conclusion and recommendations

6.1. Conclusion

The Borana rangelands are among the remnant rangelands in Eastern Africa. However, bush encroachment is found to be a threat to the ecosystem among others. Satellite based remote sensing application was found suitable to map the level of bush encroachment and study the land-use/land-cover dynamics of the study area.

Better classification accuracy was achieved for supervised classification than SMA. Change detection results showed that there is a tremendous change between 1986 and 2003. Bushland, woodland and crop/cultivated land were increased by 56.09%, 37.78% and 35.24%, respectively, between the study period, whereas, grassland, forest and bareland were decreased by 40.61%, 29.04% and 16.49%, respectively. The annual rate of bush expansion was found to be 2.57%.

In 2003, areas with bush canopy cover <20%, 40-60%, 60-80% and >80% were found 36.9%, 43.07%, 16.89%, 2.93% and 0.18%, respectively. Generally speaking, vegetation cover increased significantly between the study periods.

For Yabello district, where heterogeneous vegetation exists, spectral mixture analysis using woodland, bushland, savannah grassland, bare surface, tilled soil and shade endmembers based on Landat images was found less promising to unmix the land-covers. However, it gave better flexibility in measuring the level of bush encroachment during 2003 better than the supervised classification method.

6.2. Recommendations

Change in land-use/land-cover is an inevitable process that has been operated since the creation of man kind. However, once gone its restoration needs a tremendous effort and/or may not be possible at all. Thus, assessment of land-use/land-cover change should be done earlier, to get better information and set viable plans.

Increase in woody species cover in Borana rangelands is a threat to the livelihood of the pastoralists. Controlling mechanisms which do not affect the trade-off between the ecosystem and the social welfare should be considered as early as possible before things get harsher. On the other hand, bush encroachment should be seen with the prospect of carbon credit/offset programmes. Bush encroachment may become an income-generating commodity because of its potential to sequester more carbon above and below ground relative to the grasslands it replaced. Thus, the gain and perverse outcomes with respect to livestock production, wildlife habitat, grassland biodiversity, aquifer/stream recharge should be studied in depth and compared.

The study area is composed of different vegetation types. Application of high spectral resolution remote sensing satellite images to study and map bush encroachment at species level using Multiple Endmember Spectral Mixture Analysis (MESMA) should be considered and tested for its result.

In this study, the SMA was run on a raw DN image. Atmospheric effects reduce the level of information contained in the image and may lead to inappropriate decision. Thus, the study better tested using images that are radiometrically converted to at-sensor reflectance.

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Appendices

Apendix I: ROI Separability Report

Report I-A: Separability of ROIs Used for Classification of 1986 Landsat TM Image.

ROI Name: (Jeffries-Matusita, Transformed Divergence)

Cultivated land [Red] 733 points:
Forest [Green] 446 points: (1.99999237 2.00000000)
Bareland [Yellow] 3611 points: (1.82915417 1.99997961)
Grassland [Cyan] 1775 points: (1.30254259 1.65056305)
Bushland [Maroon] 2236 points: (1.99036192 1.99999840)
Woodland [Magenta] 650 points: (1.99971303 1.99999996)

Forest [Green] 446 points:
Cultivated land [Red] 733 points: (1.99999237 2.00000000)
Bareland [Yellow] 3611 points: (2.00000000 2.00000000)
Grassland [Cyan] 1775 points: (1.99959835 2.00000000)
Bushland [Maroon] 2236 points: (1.82487879 2.00000000)
Woodland [Magenta] 650 points: (1.64882496 1.99440709)

Bareland [Yellow] 3611 points:
Cultivated land [Red] 733 points: (1.82915417 1.99997961)
Forest [Green] 446 points: (2.00000000 2.00000000)
Grassland [Cyan] 1775 points: (1.90066771 1.99744701)
Bushland [Maroon] 2236 points: (1.99911746 1.99999867)
Woodland [Magenta] 650 points: (1.99999931 2.00000000)

Grassland [Cyan] 1775 points:
Cultivated land [Red] 733 points: (1.30254259 1.65056305)
Forest [Green] 446 points: (1.99959835 2.00000000)
Bareland [Yellow] 3611 points: (1.90066771 1.99744701)
Bushland [Maroon] 2236 points: (1.96369901 1.99939241)
Woodland [Magenta] 650 points: (1.99612176 1.99995339)

Bushland [Maroon] 2236 points:
Cultivated land [Red] 733 points: (1.99036192 1.99999840)
Forest [Green] 446 points: (1.82487879 2.00000000)
Bareland [Yellow] 3611 points: (1.99911746 1.99999867)
Grassland [Cyan] 1775 points: (1.96369901 1.99939241)
Woodland [Magenta] 650 points: (1.62632192 1.97238652)

Woodland [Magenta] 650 points:
Cultivated land [Red] 733 points: (1.99971303 1.99999996)
Forest [Green] 446 points: (1.64882496 1.99440709)
Bareland [Yellow] 3611 points: (1.99999931 2.00000000)
Grassland [Cyan] 1775 points: (1.99612176 1.99995339)
Bushland [Maroon] 2236 points: (1.62632192 1.97238652)

Pair Separation (least to most);

Cultivated land [Red] 733 points and Grassland [Cyan] 1775 points - 1.30254259
Bushland [Maroon] 2236 points and Woodland [Magenta] 650 points - 1.62632192
Forest [Green] 446 points and Woodland [Magenta] 650 points - 1.64882496
Forest [Green] 446 points and Bushland [Maroon] 2236 points - 1.82487879
Cultivated land [Red] 733 points and Bareland [Yellow] 3611 points - 1.82915417
Bareland [Yellow] 3611 points and Grassland [Cyan] 1775 points - 1.90066771
Grassland [Cyan] 1775 points and Bushland [Maroon] 2236 points - 1.96369901
Cultivated land [Red] 733 points and Bushland [Maroon] 2236 points - 1.99036192
Grassland [Cyan] 1775 points and Woodland [Magenta] 650 points - 1.99612176
Bareland [Yellow] 3611 points and Bushland [Maroon] 2236 points - 1.99911746
Forest [Green] 446 points and Grassland [Cyan] 1775 points - 1.99959835
Cultivated land [Red] 733 points and Woodland [Magenta] 650 points - 1.99971303
Cultivated land [Red] 733 points and Forest [Green] 446 points - 1.99999237
Bareland [Yellow] 3611 points and Woodland [Magenta] 650 points - 1.99999931
Forest [Green] 446 points and Bareland [Yellow] 3611 points - 2.00000000

Report I-B: Separability of ROIs Used for Classification of 2003 Landsat ETM Image.

ROI Name: (Jeffries-Matusita, Transformed Divergence)

Forest [Green] 101 points:
Grassland [Magenta] 1630 points: (1.99999984 2.00000000)
Bareland [Purple] 1531 points: (1.99999998 2.00000000)
Bushland [Yellow] 3239 points: (1.69670294 1.99966718)
Woodland [Cyan] 2543 points: (1.96635910 1.99821027)
Farmland [Maroon] 700 points: (1.99999994 2.00000000)

Grassland [Magenta] 1630 points:
Forest [Green] 101 points: (1.99999984 2.00000000)
Bareland [Purple] 1531 points: (1.96681809 1.99378959)
Bushland [Yellow] 3239 points: (1.98233166 1.99770110)
Woodland [Cyan] 2543 points: (1.99840106 1.99951703)
Farmland [Maroon] 700 points: (1.98981713 1.99288630)

Bareland [Purple] 1531 points:
Forest [Green] 101 points: (1.99999998 2.00000000)
Grassland [Magenta] 1630 points: (1.96681809 1.99378959)
Bushland [Yellow] 3239 points: (1.99898431 1.99999082)
Woodland [Cyan] 2543 points: (1.99967107 1.99999998)
Farmland [Maroon] 700 points: (1.99991619 1.99999986)

Bushland [Yellow] 3239 points:
Forest [Green] 101 points: (1.69670294 1.99966718)
Grassland [Magenta] 1630 points: (1.98233166 1.99770110)
Bareland [Purple] 1531 points: (1.99898431 1.99999082)
Woodland [Cyan] 2543 points: (1.28420627 1.69054050)
Farmland [Maroon] 700 points: (1.99760284 1.99994927)
Woodland [Cyan] 2543 points:

Forest [Green] 101 points: (1.96635910 1.99821027)
Grassland [Magenta] 1630 points: (1.99840106 1.99951703)
Bareland [Purple] 1531 points: (1.99967107 1.99999998)
Bushland [Yellow] 3239 points: (1.28420627 1.69054050)
Farmland [Maroon] 700 points: (1.99875131 1.99990454)

Farmland [Maroon] 700 points:
Forest [Green] 101 points: (1.99999994 2.00000000)
Grassland [Magenta] 1630 points: (1.98981713 1.99288630)
Bareland [Purple] 1531 points: (1.99991619 1.99999986)
Bushland [Yellow] 3239 points: (1.99760284 1.99994927)
Woodland [Cyan] 2543 points: (1.99875131 1.99990454)

Pair Separation (least to most);

Bushland [Yellow] 3239 points and Woodland [Cyan] 2543 points - 1.28420627
Forest [Green] 101 points and Bushland [Yellow] 3239 points - 1.69670294
Forest [Green] 101 points and Woodland [Cyan] 2543 points - 1.96635910
Grassland [Magenta] 1630 points and Bareland [Purple] 1531 points - 1.96681809
Grassland [Magenta] 1630 points and Bushland [Yellow] 3239 points - 1.98233166
Grassland [Magenta] 1630 points and Farmland [Maroon] 700 points - 1.98981713
Bushland [Yellow] 3239 points and Farmland [Maroon] 700 points - 1.99760284
Grassland [Magenta] 1630 points and Woodland [Cyan] 2543 points - 1.99840106
Woodland [Cyan] 2543 points and Farmland [Maroon] 700 points - 1.99875131
Bareland [Purple] 1531 points and Bushland [Yellow] 3239 points - 1.99898431
Bareland [Purple] 1531 points and Woodland [Cyan] 2543 points - 1.99967107
Bareland [Purple] 1531 points and Farmland [Maroon] 700 points - 1.99991619
Forest [Green] 101 points and Grassland [Magenta] 1630 points - 1.99999984
Forest [Green] 101 points and Farmland [Maroon] 700 points - 1.99999994
Forest [Green] 101 points and Bareland [Purple] 1531 points - 1.99999998

Appendix II: Confusion Matrices

Table II-A: Confusion Matrix of 2003 Image Classification.

Overall Accuracy = (2680/3242) 82.6650%

Kappa Coefficient = 0.7782

	Ground Truth (Percent)						
Class	Forest	Grassland	Bareland	Bushland	Woodland	Crop/Cultivat	Total
Forest	44.41	0.00	0.00	1.92	0.63	0.0000	5.55
Grassland	0.00	79.16	7.91	4.18	0.00	5.81	13.26
Bareland	0.00	5.96	80.72	0.52	0.00	0.00	16.04
Bushland	32.95	5.21	0.49	90.50	7.95	0.00	37.48
Woodland	22.64	0.00	0.00	2.79	91.00	0.00	16.84
Crop/Cultivat	0.00	9.68	10.87	0.09	0.42	94.19	10.83
Total 100.00	100.00	100.00	100.00	100.00	100.00	100.0	100.00

Class	Commission (Percent)	Omission (Percent)	Commission (Pixels)	Omission (Pixels)
Forest	13.89	55.59	25/180	194/349
Grassland	25.81	20.84	111/430	84/403
Bareland	5.77	19.28	30/520	117/607
Bushland	14.57	9.50	177/1215	109/1147
Woodland	20.33	9.00	111/546	43/478
Crop/Cultivated Land	30.77	5.81	108/351	15/258

Class	Prod. Acc. (Percent)	User Acc. (Percent)	Prod. Acc. (Pixels)	User Acc. (Pixels)
Forest	44.41	86.11	155/349	155/180
Grassland	79.16	74.19	319/403	319/430
Bareland	80.72	94.23	490/607	490/520
Bushland	90.50	85.43	1038/1147	1038/1215
Woodland	91.00	79.67	435/478	534/546
Crop/Cultivat	94.19	69.23	243/258	243/351

Table II-B: Confusion Matrix of the 2003 Bushland Fraction Image.

Overall Accuracy = (2220/3071) 72.2892%
Kappa Coefficient = 0.6409

	Ground Truth (Pixels)					
Class	0-20%	20-40%	40-60%	60-80%	80-100%	Total
0-20%	590	0	3	0	0	593
20-40%	168	424	118	1	1	712
40_60%	77	230	537	66	10	920
60_80%	1	59	20	599	42	712
80_100%	0	0	0	28	70	98
Total	858	713	678	694	128	3071

	Ground Truth (Percent)					
Class	0-20%	20-40%	40-60%	60-80%	80-100%	Total
0-20%	68.76	0.00	0.44	0.00	0.00	19.31
20-40%	19.58	59.47	17.40	0.14	0.78	3.18
40-60%	8.97	32.26	79.20	9.51	7.81	29.96
60-80%	0.12	8.27	2.95	86.31	32.81	23.48
80-100%	0.00	0.00	0.00	4.03	54.69	3.19
Total	100.00	100.00	100.00	100.00	100.00	100.00

Class	Commission (Percent)	Omission (Percent)	Commission (Pixels)	Omission (Pixels)
0-20%	0.51	31.24	3/593	268/858
20-40%	40.45	40.53	288/712	289/713
40-60%	41.63	20.80	383/920	141/678
60-80%	16.92	13.69	122/721	95/694
80-100%	28.57	45.31	28/98	58/128

Class	Prod. Acc. (Percent)	User Acc. (Percent)	Prod. Acc. (Pixels)	User Acc. (Pixels)
0-20%	68.76	99.49	590/858	590/593
20-40%	59.47	59.55	424/713	424/712
40-60%	79.20	58.37	537/678	537/920
60-80%	86.31	83.08	599/694	599/721
80-100%	54.69	71.43	70/128	70/98

Table II-C: Confusion Matrix of Bo-bush and Bushland Test Samples for the 2003 Supervised **Classification**.

Overall Accuracy = (94/104) 90.3846%
Kappa Coefficient = 0.8077

	Ground Truth (Pixels)		
Class	No-bush class	bushland	Total
No-bush	48	6	54
Bushland	4	46	50
Total	52	52	104

	Ground Truth (Percent)		
Class	No-bush class	Bushland	Total
No-bush	92.31	11.54	51.92
Bushland	7.69	88.46	48.08
Total	100.00	100.00	100.00

Class	Commission (Percent)	Omission (Percent)	Commission (Pixels)	Omission (Pixels)
No-bush	11.11	7.69	6/54	4/52
Bushland	8.00	11.54	4/50	6/52

Class	Prod. Acc. (Percent)	User Acc. (Percent)	Prod. Acc. (Pixels)	User Acc. (Pixels)
No-bush	92.31	88.89	48/52	48/54
Bushland	88.46	92.00	46/52	46/50

Table II-D: Confusion Matrix of No-bush and Bushland Test Samples for the 2003 Bush Fraction Image.

Overall Accuracy = (88/104) 84.6154%
Kappa Coefficient = 0.6923

	Ground Truth (Pixels)		
Class	No-bush	bushland	Total
No-bush	37	1	38
Bushland	15	51	66
Total	52	52	104

	Ground Truth (Percent)		
Class	No-bush	bushland	Total
No-bush	71.15	1.92	36.54
Bushland	28.85	98.08	63.46
Total	100.00	100.00	100.00

Class	Commission (Percent)	Omission (Percent)	Commission (Pixels)	Omission (Pixels)
No-bush	2.63	28.85	1/38	15/52
Bushland	22.73	1.92	15/66	1/52

Class	Prod. Acc. (Percent)	User Acc. (Percent)	Prod. Acc. (Pixels)	User Acc. (Pixels)
No-bush	71.15	97.37	37/52	37/38
Bushland	98.08	77.27	51/52	51/66

Appendix III: False Color cCmposite Images of the Study Area.

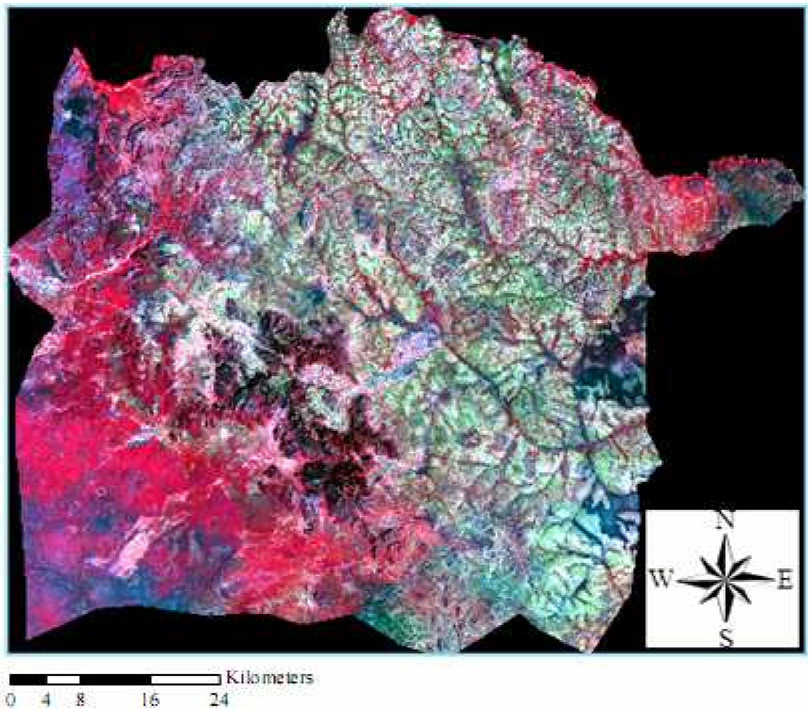

Fig. III-A: False Color Composite of Landsat ETM Taken on January 2003(R=4 G=3 B=2).

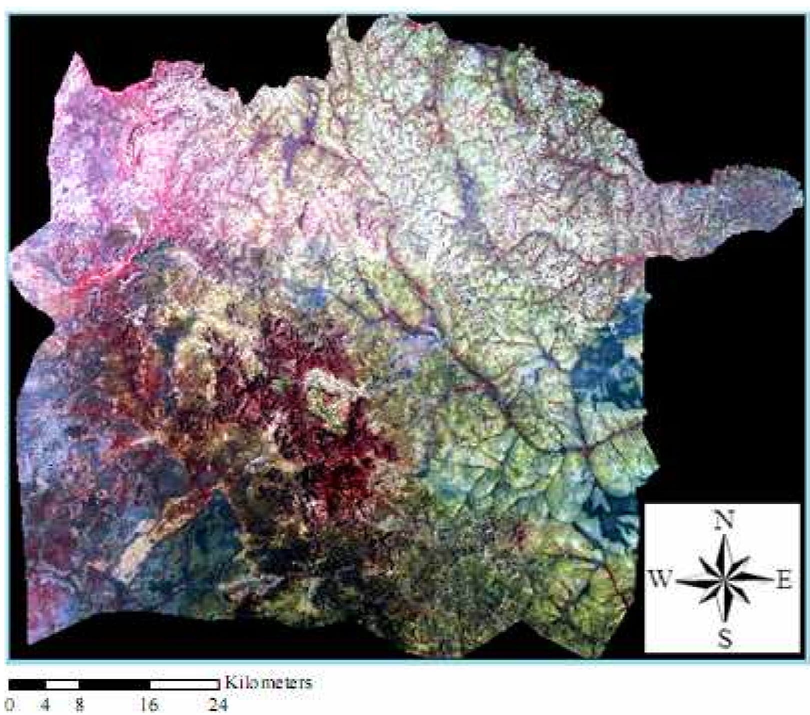

Fig. III-B: False Color Composite of Landsat TM Taken on January 1986 (R=4 G=3 B=2)

Appendix IV: MNF Transformed Images of the Study Area.

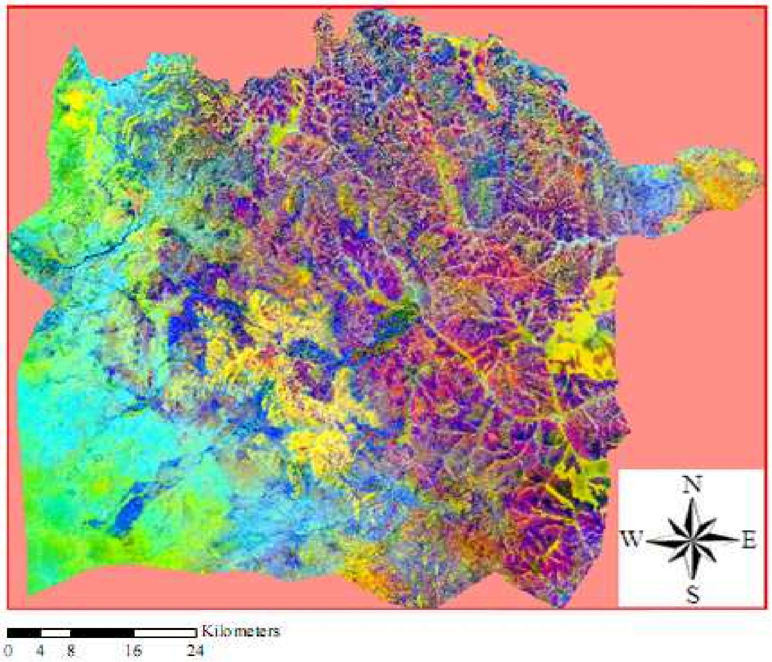

Fig. IV-A: 2003 Forward MNF Transformed Image.

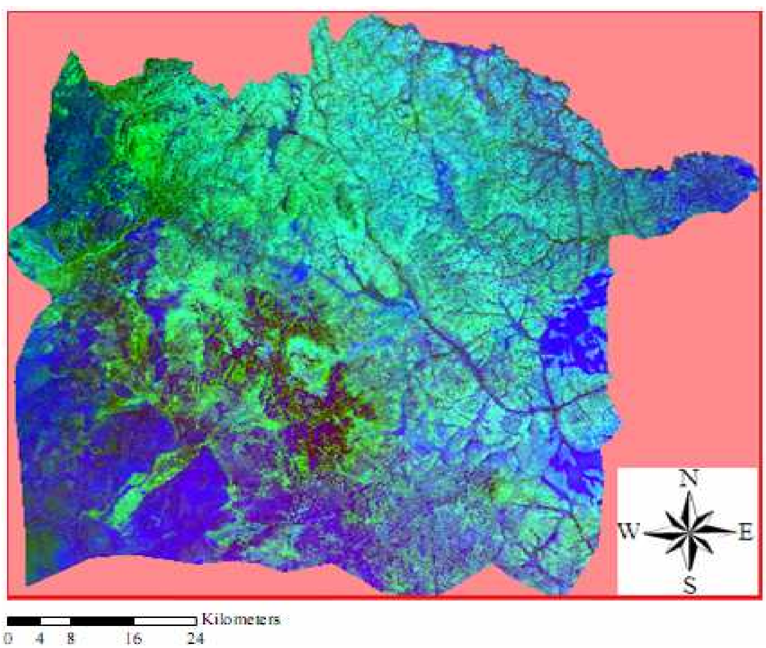

Fig. IV-B: 1986 Forward MNF Transformed Image.

Appendix V: Photos Taken from the Study Area

A. drepanolobium Stand at Deed Tuyura Ranch

C. africana at Ade Gelchet PA

A. reficiens at Haro Weyu PA

During Field Data Collection

During Field Data Collection with Experts

Declaration

I undersigned, declare that this thesis is my original work and it has not been presented for a degree in any other university, and that all sources of material used for the thesis have been duly acknowledged.

Name	Date	Signature

Addis Ababa