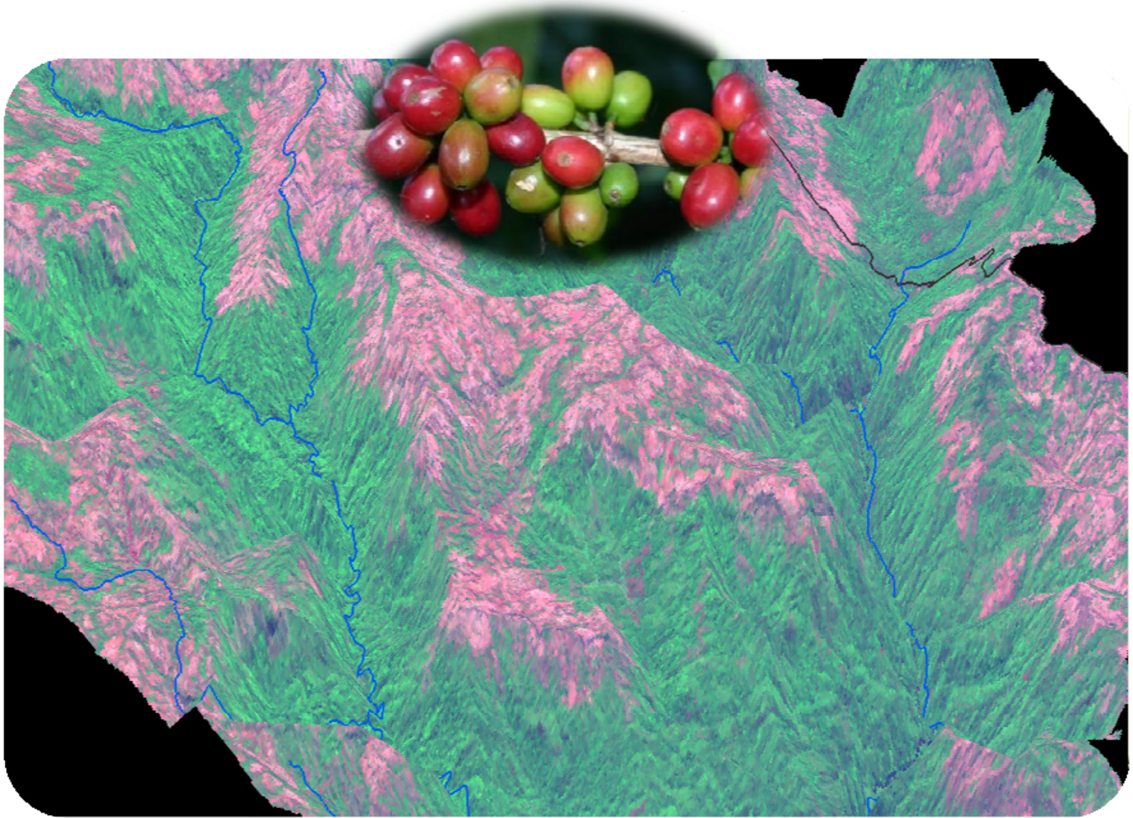
ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
FACULITY OF NATURAL SCIENCE
DEPARTMENT OF EARTH SCIENCES

REMOTE SENSING AND GIS ASSISTED PARTICIPATORY BIOSPHERE RESERVE ZONING FOR WILD COFFEE CONSERVATION: CASE OF YAYU FOREST



BY

FITE GETANEH ILFATA

AAU

December, 2008

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A Thesis Submitted to the School of Graduate Studies of Addis Ababa University, in Partial Fulfilment of the Requirements for the Degree of Master of Science in Remote Sensing and Geographic Information System

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(*Remote Sensing and GIS Stream)*

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Acronyms and Abriviations

ASTER = Advanced Spaceborne Thermal Emission and Reflection Radiometer

DEM = Digital Elevation Model

ECFF = Ethiopian Coffee Forest Forum

EIGS = Ethiopian institute of Geological Survey

EMA = Ethiopian Mapping Authority

EROS = Earth Resources Observation and Science

ETM = Enhanced Thematic Mapper

FAO = Food and Agriculture Organization of the United Nations

FCC = False Colour Composite

GDFCCP = Geba-Dogi Forest Coffee Conservation Project

GLCF = Global land Cover Fcility

GPA = Grassland Protection Area

GPS = Global Positioning System

ICO= International Coffee Organization

MAB = Man And Biosphere

MCE = Multi-Criteria Evaluation

MEA = Mellenium Ecosystem Assessment

MSS = Multi Spectral Scanner

NASA = National Aeronautics and Space Administration

NDVI = Normalized Difference Vegetation Index

NIR = Near-Infrared

ROI = Region of Interest

SRTM = Shuttle Radar Topography Mission

TCC = True Colour Composite

TM = Thematic Mapper

UNESCO = United Nations Educational, Scientific and Cultural Organization

WGS = World Geodetic System

Abstract

The original habitat of coffee is the shaded understory of montane rainforests in southwestern and southeastern Ethiopia. The wild Coffea arabica populations in these regions display a complex geographical distribution pattern of genetic diversity with most regions possessing their own genotypes. This confirms that the Ethiopian coffee is important source of coffee genetic resources for the world coffee industry, however, the forests housing much of the coffee gene pools are being lost at an alarming rate. This necessitates in-situ conservation in the forest ecosystem housing coffee genetic resources. Yayu forest, apart from its high abundance of wild coffee trees, is also known for its high plant species diversity. This study aimed at identifying and mapping the core areas for in situ wild *Coffea arabica* and forest biodiversity conservation, along with the buffer and transition zones required to establish a biosphere reserve at Yayu. The study made use of Landsat 1973, 1986 and 2001 Remote Sensing Satellite Image analysis to determine the forest change extent and pattern, and Multi Criteria Evaluation in a GIS environment and community participation to come up with the final biosphere reserve map. Dense forest, disturbed forest, farmlands and settlement, and grasslands have been identified as the major land use/land cover types in the study area. According to the change detection analysis, though there has been overall forest reduction by 7.2% over the entire period, there has been an increasing trend since 1986 owing to forest regeneration resulting from displacement of settlers from near the forest to village centers, following the then vilagization policy, and semi-forest coffee expansion. The forest cover change pattern displayed distinct spatial pattern with complete clearance on the higher altitudes and forest disturbance in the lower to mid altitudes. The complete forest clearance is attributed to farmland and settlement expansion as a function of population growth and the forest disturbance attributed to coffee expansion. Forest disturbance risk, coffee abundance and species diversity distribution pattern have been mapped as a function of the influencing environmental variables. The core zone has then been determined to represent areas of higher wild *Coffea arabica* abundance, higher plant species diversity, less prone to human disturbance, and areas that have never been under private management. However, as the participatory approach in this study didn't make individual based discussions, the output should never be considered as an absolute conflict free map; but rather a considerably socially resolved map that paves the way to a further detailed scrutiny, for a better conflict free map of the biosphere reserve.

Key Words: in-situ conservation, wild *Coffea arabica*, multi-criteria evaluation, community participation, core zone

1. Introduction

1.1. General Background

Biosphere reserves are ‘areas of terrestrial and coastal/marine ecosystems or a combination thereof, which are internationally recognized within the framework of UNESCO's Program on Man and the Biosphere (MAB) (UNESCO$_a$, 1995). They are designed to deal with one of the most important questions the World faces today: How can we reconcile conservation of biodiversity and biological resources with their sustainable use? The concept was initiated by a Task Force of UNESCO's Man and the Biosphere (MAB) Programme in 1974. The biosphere reserve network was launched in 1976 and, as of now, has grown to include 531 reserves in 105 countries (UNESCO, 2008). The network is a key component in MAB's objective for achieving a sustainable balance between the sometimes conflicting goals of conserving biological diversity, promoting economic development and maintaining associated cultural values. Biosphere reserves are sites where this objective is tested, refined, demonstrated and implemented (UNESCO, 1995).

The Afromontane rainforests of southwest and southeast Ethiopia, where Yayu is a part, is the main habitat of the wild *Coffea arabica* (Tadesse *et al.*, 2002; Tadesse, 2003; Feyera, 2006; Schimitt, 2006; Kasahun, 2006; Taye, 2006). Apart from this, it is also known for its high plant species diversity. More than 220 plant species (Tadesse 2003) were recorded in Yayu forest including the dominant understory species *Cofea arabica*.

Though Yayu forest has previously been delineated as one of the National forest priority areas, cultivation and settlement has in time been advancing well in to the boundary as a function of the multifaceted anthropogenic factors. Currently, only some part of the forest is being protected under the control of the Geba-Dogi Forest Coffee Conservation Project (GDFCCP). Given the inherent importance of the forest for coffee production and coffee being the major source of income for the people of the area, experience from the project indicates the difficulty of protecting the intended forest against anthropogenic threats (Personal communication with GDFCCP coordinator). This clearly indicates that some other systematic mechanisms, that help to reconcile conservation of the forest with *Coffea arabica* gene pool with its sustainable use, shall be sought.

1.2. Problem Statement and Justification

Modification of ecosystems by human beings, mainly for agriculture, grazing and settlements, is considered to be the major threat to the conservation of biodiversity (Tadesse, 2003; Feyera, 2006). As a result, forest biodiversity is disappearing rapidly in the forest landscapes of Ethiopia (Tadesse, 2003;Feyera, 2006). Despite this disaster, strategic management option, that harmonize conservation and use, has not been adequately practiced in the country. Even though Ethiopia is one of the top 20 richest countries in the world in terms of biodiversity, most of the ecosystems or habitats important for biodiversity conservation are not included in the country's system of protected areas (Tadesse, 2003).

The original habitat of coffee is the shaded understory of montane rainforests in southwestern and southeastern Ethiopia (Tadesse *et al*., 2002; Tadesse, 2003; Feyera, 2006; Schimitt, 2006; Kasahun, 2006; Taye, 2006) between 1,000 and 2,000 masl (Schimitt, 2006). The wild *Coffea arabica* populations in these regions display a complex geographical distribution pattern of genetic diversity with most regions possessing their own genotypes (Kasahun, 2006). As a result, the Ethiopian coffee is important source of coffee genetic resources for the world coffee industry, however, the forests housing much of the coffee gene pools are being lost at an alarming rate (Tadesse et al., 2002). Hence, in situ conservation in the forest ecosystem housing its genetic resources is the best and most reliable option (Tadesse, 2003; Feyera, 2006; Kasahun, 2006). In situ conservation offers the possibility of conserving a greater diversity of species and genepools at the same time (Engelmann et al., 2007).

Yayu is one of the localities known for their high abundance of coffee trees and hence important for conservation and sustainable use of the plant in-situ (Tadesse, 2003). In addition, the forest is known for its high plant species diversity (220 plant species; Tadesse, 2003). However, the forest in general and the constituted wild *Coffea arabica* gene pool in particular is under serious anthropogenic threats owing to modification of the forest to enhance coffee production (Personal communication with GDFCCP coordinator). The traditional coffee management system focuses on the reduction of the density of trees and shrubs in order to improve the productivity of the wild coffee plants (Feyera, 2006). In addition, farmers are introducing improved coffee varieties to maximise yield which is not desirable in the face of conserving the genetic resources of the wild populations of the species.

Given the importance of the Ethiopian wild coffee gene pool for the world coffee industry and the associated risk, there is an urgent need to device an efficient mechanism aimed at in situ conservation of the forest ecosystem housing its genetic resource. Hence, it is important to establish a system of protected areas or reserves in areas like the Yayu forest having high wild populations of the species. Towards this aim, the strategy of biosphere reserves, which are established to promote and demonstrate a balanced relationship between humans and the biosphere, is found to be the best option for in situ conservation and use of coffee gene pool and other elements of the forest biodiversity. To this end, it is important to classify the forest ecosystem into different management zones, each zone with its own management objectives, as per the classification scheme provided by the UNESCO Man And Biosphere program (MAB).

1.3. Objectives

1.3.1. General Objective

- To classify the forest area in to different management zones (core, buffer and transition) as per the classification scheme provided by the UNESCO Man And Biosphere (MAB) program, for in situ conservation and use of the wild coffee population and/or other elements of the forest biodiversity.

1.3.2. Specific Objectives

- To produce the land use/land cover map of the study area
- To study the spacio-temporal dynamics of the forest cover in the study area and analyse its implication for conservation
- To Produce forest disturbance risk map
- To produce coffee abundance and plant species diversity distribution maps
- To identify suitable conservation areas of the forest
- To discriminate and classify the study area, with local community participation, in to core, buffer and transition zones and develop a complementary map for the preparation of a proposal to nominate the forest as a biosphere reserve

2. Literature Review

2.1. General Overview of Biosphere Reserves

Biosphere reserves are designed to deal with one of the most important questions the World faces today: How can we reconcile conservation of biodiversity and biological resources with their sustainable use? An effective biosphere reserve involves natural and social scientists; conservation and development groups; management authorities and local communities - all working together on this complex issue.

The concept of biosphere reserves was initiated by a Task Force of UNESCO's Man and the Biosphere (MAB) Programme in 1974. The biosphere reserve network was launched in 1976 and, as of March 1995, had grown to include 324 reserves in 82 countries. The network is a key component in MAB's objective for achieving a sustainable balance between the sometimes conflicting goals of conserving biological diversity, promoting economic development and maintaining associated cultural values. Biosphere reserves are sites where this objective is tested, refined, demonstrated and implemented (UNESCO$_b$, 1995)

Within UNESCO's Man and the Biosphere (MAB) programme, biosphere reserves are established to promote and demonstrate a balanced relationship between humans and the biosphere. Biosphere reserves are designated by the International Co-ordinating Council of the MAB Programme, at the request of the State concerned. Biosphere reserves, each of which remains under the sole sovereignty of the State where it is situated and thereby submitted to State legislation only, form a World Network in which participation by the States is voluntary(UNESCO$_a$.1995).

2.2. Definition of a Biosphere Reserve

Biosphere reserves are 'areas of terrestrial and coastal/marine ecosystems or a combination thereof, which are internationally recognized within the framework of UNESCO's Program on Man and the Biosphere (MAB)' (UNESCO$_a$.1995).

2.3. Functions of a Biosphere Reserve

In combining three different functions, biosphere reserves should strive to be sites of excellence to explore and demonstrate approaches to conservation and sustainable development on a regional scale. The three functions are:

I. **conservation** - contribute to the conservation of landscapes, ecosystems, species and genetic variation;

II. **development** - foster economic and human development which is socio-culturally and ecologically sustainable;

III. **Logistic support** - support for demonstration projects, environmental education and training, research and monitoring related to local, regional, national and global issues of conservation and sustainable development (UNESCO_b, 1995).

2.4. Issues of *Coffea arabica* and the Need for *in situ* Gene Conservation

Wild *Coffea arabica* occurs as undergrowth in the Afromontane rainforests of southwest and southeast Ethiopia (Tadesse *et al*., 2002; Tadesse, 2003; Feyera, 2006; Schimitt, 2006; Kasahun, 2006; Taye, 2006). Ethiopia is the center of origin and diversity of *Coffea arabica*. In spite of their importance, the conservation of Afromontane rainforests with their genetic resources of wild *Coffea arabica* has been neglected in the past although these forests are under continuous threat (Feyera, 2006).

Several research works (Cilas *et al*., 1998; Anthony *et al*., 2001; Bertrand *et al*., 2001; Tadesse *et al*., 2002; Tadesse, 2003; Aga, 2003; Chaparro, 2004; Feyera, 2006; Schimitt, 2006; Kasahun, 2006; Taye, 2006; Rojan, 2006; Dereje, 2007) have been carried out on the South-western Ethiopian montane rain forest which harbours the native wild *Coffea arabica*. Most of these works have indicated the danger of anthropogenic threats to this native species implying the need for its *in situ* conservation. In addition, some of the studies (Antony et al., 2001; Aga, 2003; Chaparro, 2004;Kasahun, 2006.) have explored the genetic diversity of wild *Coffea arabica* indicating its importance in breeding works for yield, disease resistance and optimum caffeine contents and other ingredients. Among the reserachers, Tadesse (2003) has conducted a detailed study in the current study area, Yayu forest, including floristic analysis of the forest, impact of human use on the structure and species composition and the need for in situ conservation in the forest ecosystem housing the wild C*offea Arabica* species, which makes the basis for the initiation of the current study. Findings from this and some other similar works most relevant to the current study are summarised as follows.

The study carried out by Tadesse (2003) on Yayu forest provided the first detailed analysis of the vegetation of a rain forest area with wild populations of *Coffea arabica* and the impacts of human use on the ecosystem. According to this study, Yayu forest has a very high plant species diversity and abundance of the coffee trees compared to other similar forest areas in the country. About 220 species of vascular plants were recorded from the forest. The study has also identified three community groups within the forest, with *Coffea arabica*, *Argomuellera macrophylla* and *Dracaena fragrans* as indicators species, respectively. The three indicator species are the most dominant species in the small trees and shrubs stratum. The C. arabica group represents vegetation at higher altitudes and on gentle slopes. The *A. macrophylla* group occurs on steep slopes at low altitudes along the Geba river which dissects the forest, and the *D. fragrans* group on steep slopes at higher altitudes. *Coffea arabica* is one of the most abundant and frequent species in the forest. However, its abundance decreases with an increase in slope. Floristically, Yayu forest is a transitional rain forest between the Afromontane rain forest of higher altitudes and the Guineo-Congolian forest of the lowlands. Threat to the wild populations of *Coffea arabica* and to the montane rain forests due to deforestation warrants the need to take in situ conservation measures and to establish gene reserves.

This study has also identified some important environmental variables associated with wild coffee occurrence. These are: *Altitude, slope and distance from river*.

Table 2.1: Summary of Environmental variables among the three community groups identified in Yayu forest. The number in the column of each variable show mean; ± Standard deviation (Tadesse, 2003)

Group	**Altitude**	**Slope**	**Distance from river**
1(Coffea Arabica)	1450.0; ±61.6	26.8 ; ±11.2	1100.9; ±444.0
2(Argomuellera macrophylla)	1388.3; ±68.0	43.0; ±27.5	513.3 b; ±418.7
3(Dracaena fragrancs)	1439.9; ±58.4	40.1; ±20.4	837.7; ±367.3

Feyera (2006) has also carried out study on the Biodiversity and ecology of Afromontane rainforests with wild *Coffea arabica* L. populations in Ethiopia, including Yayu. In this study, he has indicated that the conversion of a forest coffee system into a semi-forest coffee system affects the floristic composition and diversity of the forest. In the same study, a comparison of semi-forest coffee and forest coffee systems in two rainforests, i.e., Harenna and Berhane-Kontir, revealed a reduction of up to 50% in the number of species of lianas, small trees and shrubs in the semi-forest coffee system. Furthermore, the families dominating in the semi-forest coffee system are different to those dominating in the forest system. Continuous management of the wild coffee in the semi-forest coffee system suppresses woody plant regeneration, reduces tree density and eventually leads to the disappearance of the forest species and finally the forest, while temporarily benefiting the coffee plants. The maintenance of wild coffee populations in the Afromontane rainforests of Ethiopia is highly dependent on the extent to which the rainforest fragments are maintained, and conservation of these rainforests is therefore urgently required.

Kasahun (2006) on his part has carried out study on the genetic diversity of wild *Coffea arabica* populations in Ethiopia, including Yayu forest, as a contribution to conservation and use planning. In this study, the results indicated the presence of a complex geographical distribution pattern of genetic diversity with most regions possessing their own genotypes. And this is the first study to provide evidence that wild populations of *C. arabica* are genetically different from semi-domesticated plants (farmer's varieties).

2.5. The Need for Biodiversity Conservation

Biodiversity is a vital but poorly appreciated resource for all of humankind that underpins the achievement of the Millennium Development Goals. Biodiversity represents the foundation of ecosystems that, through the services they provide, affect human well-being. These include provisioning services such as food, water, timber, and fibre; regulating services such as the regulation of climate, floods, disease, wastes, and water quality; cultural services such as recreation, aesthetic enjoyment, and spiritual fulfilment; and supporting services such as soil formation, photosynthesis, and nutrient cycling. The relationship between biodiversity and supporting ecosystem services depends on composition, relative abundance, functional diversity, and, to a lesser extent, taxonomic diversity. If multiple dimensions of biodiversity are driven to very low levels, both the level and stability of services may decrease (Rojahn, 2006).

In 2000 the United Nations Secretary-General Kofi Annan called for The Millennium Ecosystem Assessment (MEA). The objective of the MEA was to assess the consequences of ecosystem change for human well-being and the scientific basis for actions needed to enhance the conservation and sustainable use of those systems and their contribution to human well-being. The MEA has involved the work of more than 1,360 experts worldwide. They come to the conclusion that, unless, the rate of loss of biodiversity and the resulting degradation of ecosystem services are significantly reduced, efforts to combat poverty, reduce hunger, and provide clean water and a healthy environment will be undermined (MEA, 2005)

2.6. Forest Cover Change Studies

In 1990 there were some 1150 million ha of tropical rain forest with the area of the humid tropics deforested annually estimated at 5.8 million ha (approximately twice the size of Belgium). A further 2.3million ha of humid forest is apparently degraded annually through fragmentation, logging and/or fires. In the sub-humid and dry tropics, annual deforestation of tropical moist deciduous and tropical dry forests comes to 2.2 and 0.7million ha, respectively. Southeast Asia is the region where forests are under the highest pressure with an annual change rate of 0.8 to 0.9%. The annual area deforested in Latin America is large, but the relative rate (0.4 to 0.5%) is lower, owing to the vast area covered by the remaining Amazonian forests. The humid forests of Africa are being converted at a similar rate to those of Latin America (0.4 to 0.5% per year) (Mayaux et al., 2005)

In Ethiopia, several research works (including Dereje, 2007; Bedru, 2006) have been conducted on forest cover change. Among them, Dereje (2007) has conducted his study in the Southwest forest, which is of particular relevance to the current study. In most cases, where crop production is more important, most of the studies have discovered crop land and settlement expansion at the expense of forest cover which is driven by the high pressure of human and livestock population.

As mensioned above, Dereje (2007) has conducted research on forest cover change and socioeconomic drivers in Southwest Ethiopia. In this study, the result of satellite image analysis revealed that the high forest cover of the study area dwindled from 71 per cent to 48 per cent during the whole study period, 1973 to 2005. Since 2001 the high forest of the study area is receiving high pressure from intensive coffee management than expansion of agricultural land due to conducive marketing environment for coffee and lack of regulatory mechanism on forest coffee management. Furthermore, the traditional farming system, forest fallow system, is disappearing from the regions land use system as more land became under permanent ploughing and garden coffee planting. Government sponsored coffee plantations, allocation of forest land for large-scale private plantations, local community’s crop field expansion and smallholder forest and semi-forest coffee intensive management are identified as the proximate cause of the forest cover change. Lack of clear land use plan, change in farming system due to population growth, lack of operational regulation in managing forest coffee and poor institutional support for proper land administration at local level were identified as drivers of the forest cover change.

2.7. Application of Remote Sensing and GIS in Forest Related Studies

International and domestic forestry applications where remote sensing can be utilized include sustainable development, biodiversity, land title and tenure (cadastre), monitoring deforestation, reforestation monitoring and managing, commercial logging operations, shoreline and watershed protection, biophysical monitoring (wildlife habitat assessment), and other environmental concerns.

General forest cover information is valuable to developing countries with limited previous knowledge of their forestry resources. Remote sensing brings together a multitude of tools to better analyze the scope and scale of deforestation problem. Multitemporal data provides for change detection analyses. Images of earlier years are compared to recent scenes, to tangibly measure the differences in the sizes and extents of the clearcuts or loss of forest. Data from a variety of sources are used to provide complementary information. Radar, merged with optical data, can be used to efficiently monitor the status of existing clearcuts or emergence of new ones, and even assess regeneration condition. In countries where cutting is controlled and regulated, remote sensing serves as a monitoring tool to ensure companies are following cut guidelines and specifications.

2.8. Conservation Areas Zoning

In remote sensing, vegetation indices are widely used to measure vegetation vigor since healthy vegetation has a high spectral response in near-infrared bands of remote sensing images. Vegetation indices generally involve the direct or modified forms of the ratio between the infrared band and the red band. Among vegetation indices, Normalized Differing Vegetation Index (NDVI) is regarded as one of the most useful indices to measure vegetation vigor.

He. et al.,(2005) used remote Sensing to zone grassland conservation areas. In this study, in order to detect those grasslands with good growth condition, they calculated a vegetation coverage index based on NDVI. The index is expressed as:

$$f=(NDVI - NDVI_{\min})/(NDVI_{\max} - NDVI_{\min}) \qquad (1)$$

where f is the vegetation coverage index, and NDVImin, NDVImax are the minimum and maximum of NDVI in the study area. Accordingly, using the Landsat ETM+ image, NDVI of each pixel was calculated using band 4 and band 3. The minimum and maximum NDVI of the study area were then found. Based on Eq. (1), the vegetation coverage map of the study area was produced. ‘‘Seed points’’ were then extracted from the vegetation coverage map using a recursive thresholding procedure. Thresholds were applied to the vegetation coverage map repeatedly and the pixels that had a vegetation coverage index greater than the threshold value were selected as potential ‘‘seeds’’. Starting from 0.95 and decreasing in steps of 0.05, each thresholding result was then compared to the land use map of 2000 until obvious potentials ‘‘seeds’’ begin to appear in ‘‘medium coverage grassland’’ and ‘‘low coverage grassland’’. This comparison ensured that the extracted ‘‘seed points’’ were located in the ‘‘high coverage grassland’’ area. Finally, these pixels that have a vegetation coverage index of more than 0.85 were selected as ‘‘seed points’’. These seed points occupy about 15% of the overall high coverage grassland. GPAs should be zoned in those areas with high grass growth suitability and low levels of human disturbances..

Tibebu (2007) used remote sensing and spatial multi criteria evaluation to map sensitivity of wetlands to human disturbance which he used in conservation area zoning. To evaluate the level of disturbance around the lake, he considered four major conditions; Settlement, Land use, Road, and Slope. In his study, all these factors were rasterized and reclassified and organised in a GIS environment to evaluate the level of disturbance in the area. Finally MCE using Arc GIS 9.0 were applied to develop disturbance level map which he ultimately used to develop conservation zones of wetlands. In the study, considering different conditions, he classified the study area as “major priority if the disturbance is high” and minor priority area if the disturbance is very less.

2.9. Multi Criteria Evaluation

In decision theory, Multi-Criteria Evaluation is the process of applying a decision rule to a set of alternatives. A decision rule is a procedure by which criteria are combined to arrive at a particular evaluation, and by which evaluations are compared and acted upon. A decision is a choice between alternatives (such as alternative actions, land allocations, etc.). The basis for a decision is known as a criterion. Criteria may be of two types: factors and constraints. Factors are generally continuous in nature (such as the slope gradient or road proximity factors); they indicate the relative suitability of certain areas. Constraints, on the other hand, are always

Boolean in character (such as the reserved lands constraint in the example above). They serve to exclude certain areas from consideration. Factors and constraints can be combined in the MCE module using one of three methods (Boolean intersection, Weighted Linear Combination and Ordered Weighted Average); each method is characterized by different levels of control over tradeoffs between factors and the level of risk assumed in the combination procedure. Trade off is the degree to which one factor can compensate for another; how they compensate is governed by a set of factor weights sometimes called tradeoff weights. Factor weights are given for each factor such that all factor weights, for a set of factors, sum to one; they indicate the relative importance of each factor to the objective under consideration. A factor with a high factor/tradeoff weight may compensate for low suitability in other factors that have lower factor/tradeoff weights. In a Multi-Criteria Evaluation, an attempt is made to combine a set of criteria to achieve a single composite basis for a decision according to a specific objective. For example, a decision may need to be made about what areas are the most suitable for industrial development. Criteria might include proximity to roads, slope gradient, exclusion of reserved lands, and so on. Through a Multi-Criteria Evaluation, these criteria images representing suitability may be combined to form a single suitability map from which the final choice will be made (Eastman, 2001).

3. Materials and Methods

3.1. Study Area Description

3.1.1. Location

Yayu forest is located in Illubabor Zone of Oromia State, at about 550 km west of Addis Ababa on the major way from Addis to Metu. This study will cover the area between $8^{o}15’$-$8^{o}38’$ N and $35^{o}33’$-$36^{o}11’$E with particular emphasis on the forest landscape along Geba, Dogi and Sese rivers. The study area is shared among six districts of Illu-Aba-Bora zone namely: Yayu, Hurumu, Dorani, Nopa, Alge and Chora and covers a total of nearly 171 thousand hectares.

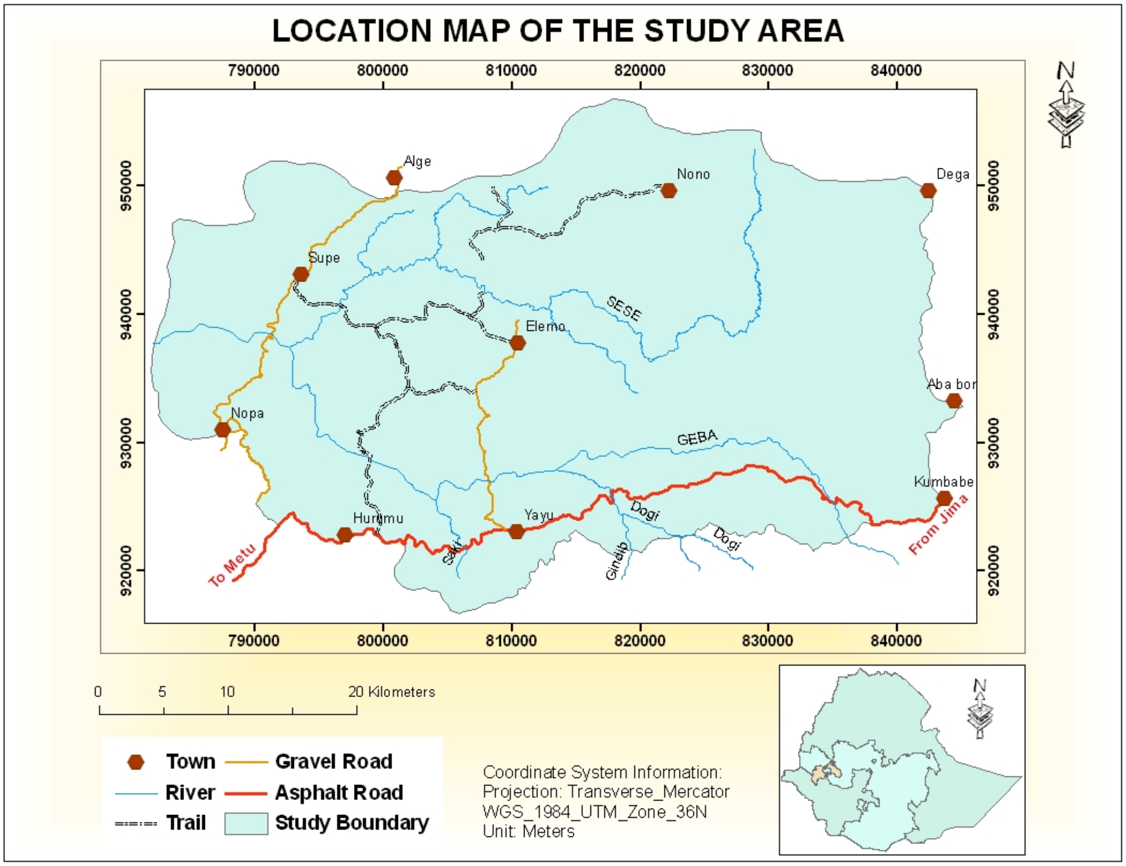


Figure 3.1: Location map of the study area

3.1.2. Geology and Sols

According to the 1996 Geological Map of Ethiopia, the area is characterised by Precambrian Metamorphic rocks consisting of biotite and hornblende gneisses, granulate migmatite with minor metasedimentary gneisses along the river valleys and by flood basalts overlying the crystalline basements on the plateaus in between the river valleys. Soils of the area are lithic or eutric leptosols along the river valleys and humic nitosols on the plateaus. At the western end, some parts of the study area are covered with haplic nitosols and eutric cambisols (FAO, 1997).

3.1.1. Topography and Drainage Systems

The forest area is characterized by a rolling topography, and is highly dissected by small streams and three major rivers, Geba, Dogi and Sese. The study area boundary represents a watershed boundary at the East, West and Northern parts while at the south, the area receives drainage from a huge area through Geba and Dogi rivers. The landform frequently changes from flat surfaces on the top of plateaus to very steep slopes and valley bottoms within short distances. The altitude ranges from 1100 at valley bottom to 2337m.a.s.l at the North-Eastern higher elevation).

3.1.2. Climate

According to the data obtained from Ethiopian Meteorological Agency, which was recorded at Nopa Station, climatically the areas is hot and humid with mean minimum and mean maximum temperature of 13.5 and 27.3^{o}C respectively and mean annual rainfall of 1859mm with the minimum and maximum being 1243 and 3445mm respectively. The hottest months are February, March and April while the coldest ones are August September and October. The rainfall pattern is uni-modal, with low rainfall in January and February, gradually increasing to the peak period between May and October, and then decreasing in November and December. The highest rainfall is received in the period between June and August.

3.1.3. Land use/Land Cover

Five major land-use types are observed in the Yayu district; forest (55.8%), agriculture (35.7%), grazing land (4.4%), wetland (2.3%), and settlement and others (2.7%). Yayu district has the highest percentage forest cover compared to other districts in Ethiopia, which by far above the percent forest cover for the SW part of Ethiopia(18%) and that of the country as a whole(2.7%). Most forest areas are demarcated as National Forest Priority areas. However, the local community heavily depends on the forest mainly for coffee, spices and honey production. The main food crops are maize, sorghum and teff. Coffee is the major cash crop growing in the area, followed by chat (Tadesse 2003).

3.1.4. Biodiversity

Yayu forest is one of the most diverse forests in Ethiopia with respect to plant species diversity. With about 220 plant species, Yayu forest excels other similar rain forests like the Harrena forest, in SE Ethiopia (128 species), and the Bonga forest in SW Ethiopia (154 species). The number of plant species in Yayu forest is also higher than most of the dry Afromontane forests of Ethiopia; for example, Chilimo forest (90 species); Jibat forest (54 species); Dakata Valley forest (202 species). Wild coffee has been identified as one of the most dominant under storey species in Yayu forest (Tadesse 2003).

3.1.5. Socio-economic Information

At zone level, population density is 80.3 persons per km ^{2} (1994) with annual growth rate of 3.2%. The major occupation in the area is agriculture, which employs over 90% of the labor force. The agricultural practice in the region is mainly smallholder subsistence farming. For more than 60% of the population, coffee production, processing and marketing are the major sources of employment (Tadesse 2003).

3.2. Data and Materials

3.2.1. Materials

S/N	Types	Description	Source
1	Instruments	GPS(GARMIN), Camera	ECFF
2	Software	ArcGIS 9.1, ENVI 4.3, ERDAS 8.6, IDRISI Andes 3.2	
3	Maps	Hard Copy Kebele Maps	District Offices
		Digital soil map	FAO, 1997
		Digital Geological map(1:2000000)	EIGS, 1999
		Topographic map(1:50,000 scale)	EMA

Table 3.1: Summary of materials used in the study

3.2.2. Data

3.2.2.1. Satellite Images

Land sat MSS

The oldest available data for the study area is Landsat MSS archive data at the EROS Data Center. The Landsat series began in 1972 with Landsat-1, carrying on board the Multispectral Scanning System (MSS) instrument. This instrument collected measurements in the visible and near-infrared bands. An image (path/row 183/54) acquired by this sensor in January 1973 is obtained from the Global Land Cover Facility (GLCF) online imagery portal and used as the oldest data in this study. This image has a spatial resolution of 58 meters.

TM

TM data have an improved spatial resolution of 28.5 meters and includes two middle-infrared and one thermal channel. These high-resolution scanners have seven spectral bands and always cover a 185-by-185km area. For the study area, a single scene, path/row 170/54, taken in March 1986 by TM sensor on board Landsat 5 is used as mid study-period image. This is also obtained from the Global Land Cover Facility (GLCF) online imagery portal.

ETM+

Landsat-7, which carries onboard the Enhanced Thematic Mapper Plus (ETM+) instrument, was launched on April 15, 1999 as part of the global research program of NASA’s Earth Science Enterprise. The sensor has six spectral bands in the visible, near-infrared, and shortwave infrared regions of the electromagnetic spectrum (at 28.5m spatial resolution), one thermal infrared band (60m and 120m spatial resolution products), and one panchromatic band (at 15m spatial resolution). Image (path/row 170/54) acquired by this sensor in February 2001 has been obtained from the online archive of the GLCF to assume the recent data in the absence of a more recent cloud free ASTER image.

Table 3.2: Summary of satellite images used in the study

Image Types	Path and Row	Date of Aquisition	Spatial Resolution(meter)
Landsat-MSS	183_54	18/01/1973	58 X 58
Landsat-TM	170_54	08/03/1986	28.50 X 28.50
Landsat-ETM+	170_54	05/02/2001	28.50 X 28.50
SRTM(Elevation)			90

3.3. Data collection

3.3.1. Satellite Images and Spatial Data

The major information required for the study has been extracted from satellite images. Land use/ land cover types at various times have been extracted from Landsat-MSS, TM, ETM+, images. Slope and physiography has been obtained from Shuttle Radar Topography Mission (SRTM) data. River and various road category networks have been generated from 1: 50 000 scale topographic map through manual digitizing. Towns' layer has been obtained from thio-GIS.

3.3.2. Field Survey

Apart from the remote sensing data, field visits have been the second major data collection mechanisms. The field visit has been made in two sessions:

3.3.2.1. Preliminary Field Visit

Through the Preliminary field visit, it was made possible to have an overall overview of the study area, identify the various land use/ Land cover types, identify stakeholders in the locality and collect GPS readings of the various features and land use/land cover types for the subsequent supervised classification.

3.3.2.2. Second Field Survey

The Second field visit was made to verify the various land use/ land cover types identified through satellite image manipulation and to consult the local community including agricultural officers in order to (1) identify the factors behind the forest cover change, (2) introduce the concept and usefulness of in-situ wild coffee conservation (3) identify and refine priority areas for forest coffee conservation and (4) identify criteria for conservation areas zoning. In addition, GPS readings of important corners for core zone boundary delineation have been collected through the guidance of the local community.

3.3.2.3. Community Participation

The main objective behind the participatory zoning is to ensure the sustainability of the conservation effort to be made. As discussing with each of the farmers in the five districts of the forest area is impractical and beyond the scope of this thesis research, another practical approach had to be sought. Accordingly, parts of the supposed conservation area that are prone to high social conflict have been identified and prioritized with district bureau agriculture and Geba-Dogi Forest Coffee Conservation Project (GDFCCP)officials. Right at these spots, group discussions have been made with the representatives of the concerned local community. These representatives Included elders, the youth, kebele administrators and other interested people. During the discussion, farmers were allowed to brainstorm the uses of conservation. After reaching consensus on the importance of conservation, they were allowed to discuss on the criteria to be used for conservation area zoning and also to identify and indicate areas that are under their (farmers') management and therefore need to be excluded from the conservation boundary or areas that were ignored but should be included in conservation. This was done through group discussions, participatory mapping and transact walks, where GPS readings were obtained at strategic corners important for the boundary delineation.

3.3.3. Secondary Data

Secondary data collection has been made from various sources. Background information of the study area has been obtained from previous research works in the study area. Hard copy maps of kebele boundaries and digital copies of the geology and soil maps have been used to describe the study area.

3.4. Data Analysis

3.4.1. Spatial Data Pre-processing

As described above, the remote sensing and spatial data used in this study are Landsat satellite images (of the years 1973, 1986 and 2001), topographic maps, GPS readings and SRTM DEM data. The 1:50,000 topographic maps of the study area were scanned, georeferenced and projected to UTM coordinate system (WGS-84). The satellite images and the DEM data were originally ortho-rectified and therefore did not require geo-referencing. Road and river networks have been digitised from the georeferenced topographic maps.

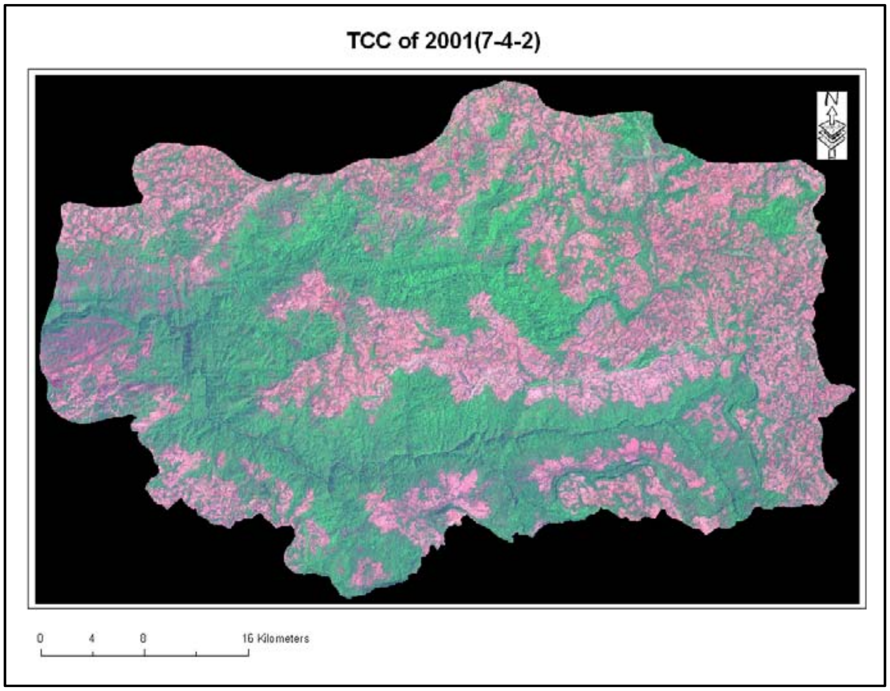
3.4.2. Band Selection

Typically, bands 3, 4, and 5 of Landsat TM and ETM+ are used in land cover and wetland classification however, many studies include band 7 as well (Cardozo, 2003). Landsat TM and ETM+ bands 3 and 4 are useful in the discrimination and classification of vegetation types; bands 5 and 7 are sensitive to the content of moisture in vegetation; and bands 4, 5, and 7 are all useful for the delineation of water bodies (Lillesand and Kiefer 2004). Accordingly, bands 1, 2, 3, 4, 5 and 7 of the TM and ETM+ images and bands 1, 2, 3 and 4 of the MSS image were layer stacked for interactive band combination, and subset to region of interest using ENVI 4.3 software.

3.4.3. Visual Image Interpretation and Unsupervised Classification

To aid the visual interpretability of the satellite images, both TCC and FCC were produced and then subjected to some image enhancement techniques including haze reduction and histogram equalized stretch. In such a way, the number of land cover types has been determined to run unsupervised classification which aided the preliminary field visit. The TCC and FCC composites of the 2001 ETM+ images subset to the study area boundary are provided in figure 3.2 a and b respectively for evidence.

(a)



(b)

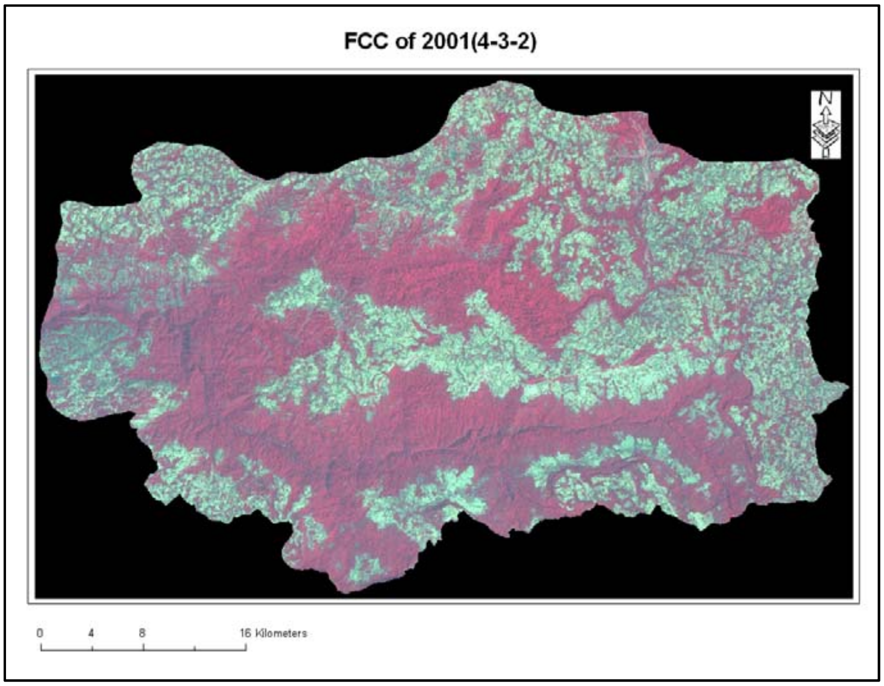


Figure 3.2: Samples of the FCC and TCC composite images used in the study

3.4.4. Sample Training Areas and Supervised Classification

During the preliminary field visit, representative points thought to represent the various land cover classes were marked using GARMIN GPS. These points were used to sample representative signatures for the various land cover types identified during the preliminary field visit. Accordingly, supervised land use land cover classification has been carried out using ENVI 4.3 software from the satellite images of the various years.

3.4.5. Post Classification Processing

One of the disadvantages of automatic digital image classification is that it yields ‘salt and pepper’ pattern on an image after classification (Lillesand, et al, 2004). To solve this problem 3 by 3 window majority filters is employed to eliminate the unwanted patterns over the classified images. The different signatures used for the same type of land cover, due to variation in reflectance resulted from variation in aspect were recognised and the classes were merged using ENVI 4.3.

3.4.6. Computation of Classification Accuracy

The classified image has to be checked on ground to assess for classification accuracy. Knowledge of the area and sample land use field GPS readings were used to create ROIs on representative sites from each land use type to suite the requirement of ENVI 4.3for accuracy assessment. Accordingly, classification accuracy has been calculated using ENVI 4.3 for each of the classified land use types and overall accuracy has also been produced by dividing the number of correctly classified pixels to the total number of pixels.

3.4.7. Forest Change Detection

After supervised land use/land cover classification is made for each year, land cover change matrix is produced using ENVI 4.3 to know the forest cover changes in different periods as well as to which land cover the forest is changed. The result is then presented in tabular form. Digital elevation model (DEM) is also used to classify the study area into different altitude classes to identify which altitude ranges are highly affected by deforestation and hence deserve special attention in the conservation area zoning.

3.4.8. GIS Analysis

Spatial Multi-criteria Evaluation (MCE) has been the major tool used in the study to generate both the intermediate layers and the final output. All the raster and vector layers required in the study were developed and organised in to a GIS environment using ESRI's ArcGIS 9.1software. In all the MCE operations, weights have been given to the various factors used in the evaluation process using the pair wise comparison module provided by the IDRISI Andes 3.2 software. These values were then used to run weighted overlay analysis in the spatial analyst tool of ArcGIS 9.1 Sotware to produce the evaluation layers.

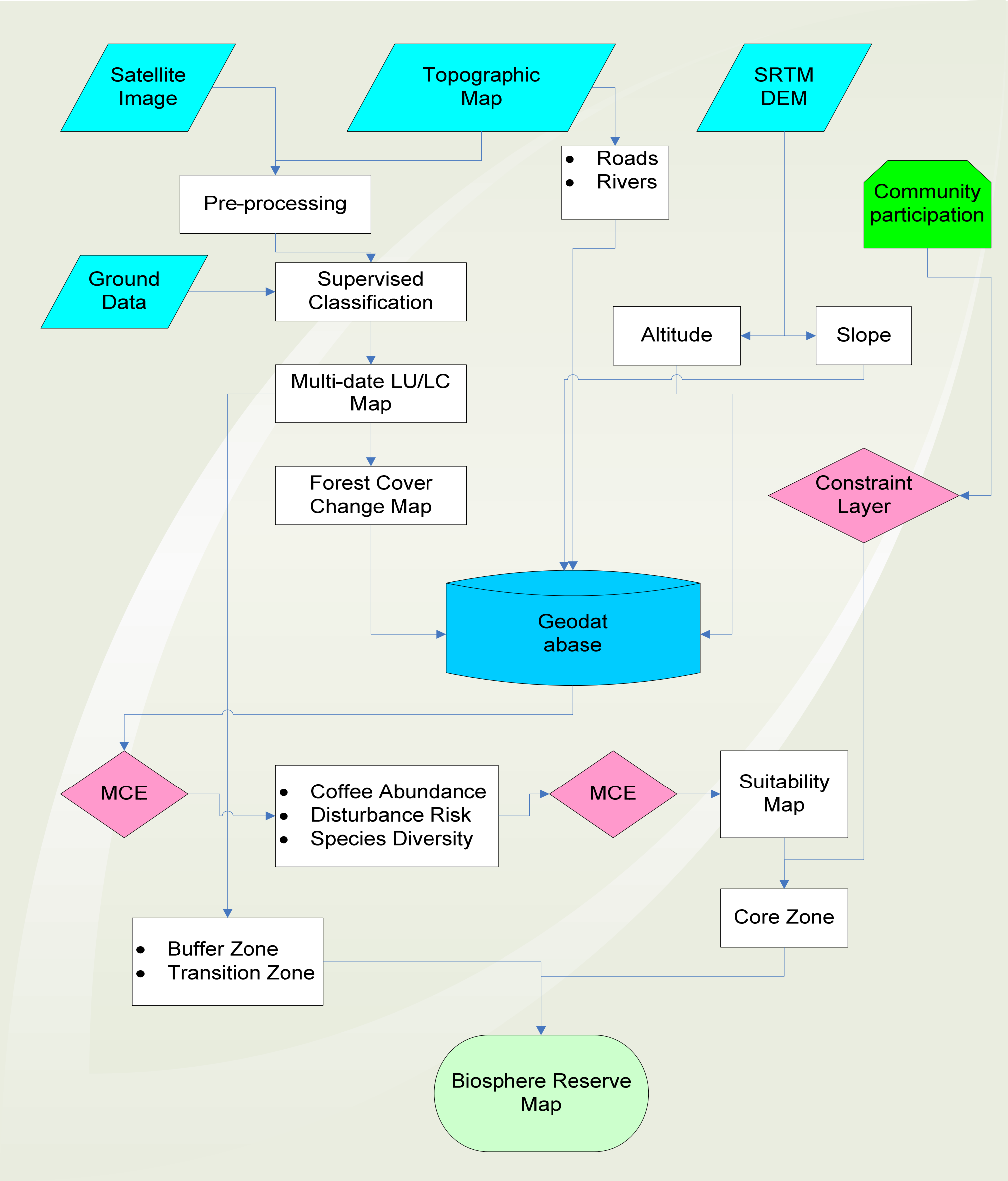


Figure 3.3: Methodology flowchart

4. Results and Discussions

4.1. Land Use Land Cover

4.1.1. Land Use/Land Cover Map from the 2001 Image

Land use Land cover map is the foremost information required to attain the preset objective of conservation area zoning. Land use land cover map of the study area has been generated through supervised classification from the 2001 Landsat ETM + image by the use of sample training areas determined during the preliminary field visit. The classified image was then subjected to the necessary post classification operations to come up with the final land use land cover map of the study area. One of the disadvantages of automatic digital image classification is that it yields ‘salt and pepper’ pattern on an image after classification (Lillesand, et al, 2004). To solve this problem 3 by 3 window majority filters is employed to eliminate the unwanted patterns over the classified images. The different signatures for the same type of land cover, due to variation in reflectance resulted from variation in aspect, were classified separately and then merged using the post classification operations provided by ENVI 4.3.

Accordingly, four major land use/land cover types have been identified and classified in the study area. These are: *Dense Forest*, *Disturbed Forest*, *Farmland and Settlement* and *Grassland*. The forest in the study area has been divided in to two (*Dense Forest* and *Disturbed Forest*) based on variation in tone and NDVI values, and field verification. The intension is to separately identify the natural dense undisturbed forest that should go in to the conservation zone in the final biosphere reserve map. Here, these major land use land cover types and their classification accuracy are separately discussed as follows.

4.1.1.1. Dense Forest

This land cover type is the most important class that is intended for conservation. It occurs on the relatively sloppy lands along the major rivers in the study area. Several past research works have demonstrated that the forest is composed of high species diversity including the foremost target *Coffee arabica*. Previous researchers (Feyera, 2006; Kasahun, 2006) have named the coffee production system in this forest category as *forest coffee* as opposed to *semi-forest coffee* production system in the managed/disturbed forest. Tadesse (2003) has identified about 220 plant species in this forest category. Among these, he identified three community groups where *Coffee arabica* is the best indicator species of community group1.

The five most abundant and common trees in the canopy layer are *Diospyros abyssinica, Albizia grandibracteata*, *Blighia unijugata*, *Trichilia dregeana and Celtis africana*, while most dominant trees in the lower stratum are *Dracaena fragrans, Coffea arabica, Argomuellera macrophylla*, *Canthium giordanii and Clausena anisata.* Among the climbers, the most dominant ones are *Landolphia buchananii, Paullinia pinnata, Hippocratea africana, Tiliachora troupinii and Combretum paniculatum,* while the dominant shrubs include *Maytenus gracilipes, Justicia schimperiana, Rhus ruspoli, Justicia betonica and Phyllanthus ovalifolius*(Tadesse 2003).

From satellite image, this cover type appears to have a bright red signature as compared to the other cover types from the FCC (4, 3, 2) composites (Figure 3.5b). It also displayed higher NDVI values (Figure 4.4) owing to its high infrared reflectance. These two indicators have then been used to discriminate this land cover category from the 2001 satellite image.

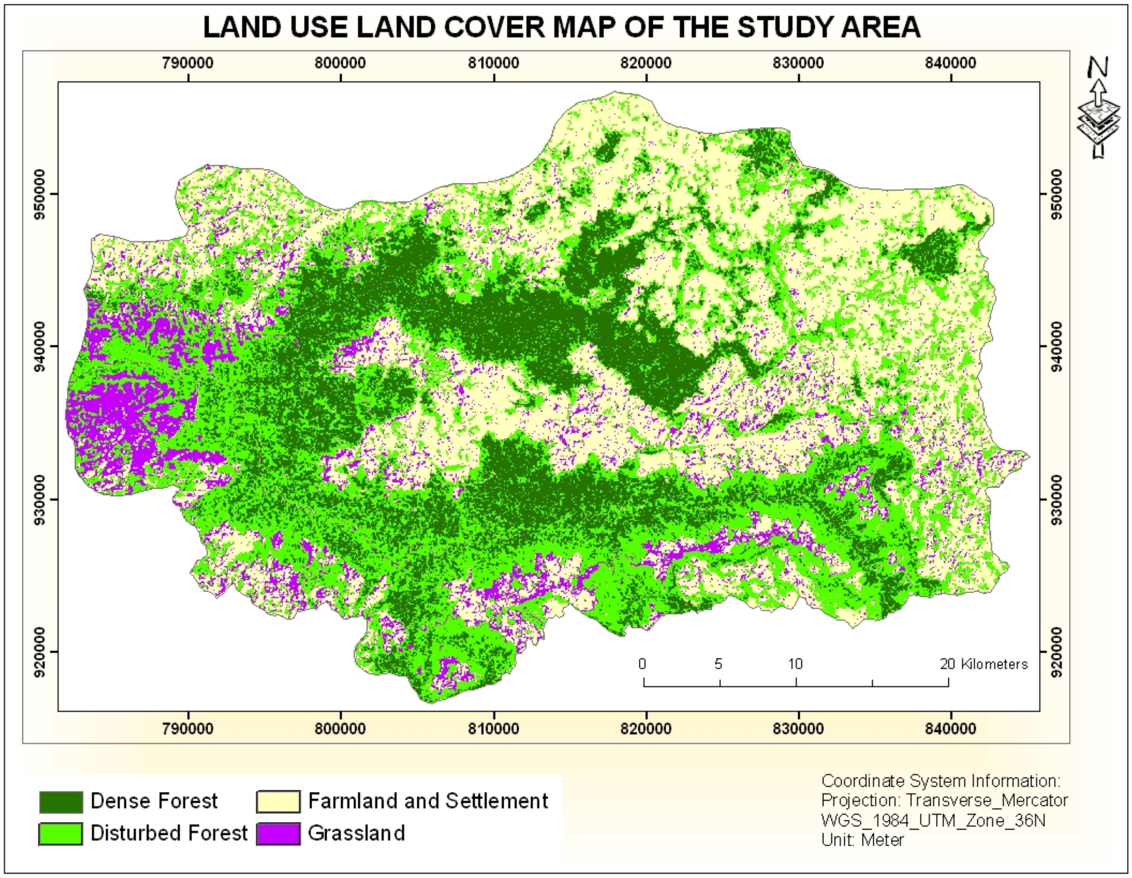


Figure 4.1: Land use land cover map of the study area

4.1.1.2. Disturbed Forest

Major part of this cover type occurs at the outer periphery of the forest next to the dense forest though some part of it also occurs in the middle of the dense forest. Majority of this cover type (the part encompassing the dense forest) has previously been part of the dense forest and has gradually been evolved to the current state due to human influence mainly for coffee production (semi-forest coffee), and other uses. In order to maximize their coffee yield, farmers were managing the forest in such a way that favours the coffee plants. Most importantly, they selectively remove the lower associated layer species that are thought to compete with the coffee plants and selectively leave some of the canopy layer trees thought to provide the required shade for coffee. Due to such immense human impact, this cover type has attained a considerably lower density and species diversity as compared to the dense forest category. When requested to prioritize tree species good for coffee plants, farmers have listed: *Acacia abissinica, Albizia gummifera, Albizia grandibracteata, Millettia ferruginea, Cordia africana, and Anageria altissima* over the unwanted and therefore endangered species like: *Celtis africana, Sapium elinticum, Ehretia cymosa, Olea capensis subs. hochstetteri, Maesa lanceolata and Ficus vasta* and other associated bushes and climbers at coffee layer. On the other hand, part of this cover type that occurs in the middle of the dense forest has attained such a lesser density (and hence this cover type) due to some inherent environmental factors than human influence, like steep slopes near the major rivers.

From the satellite image, this cover type appears to have a relatively dark red signature as compared to the previous cover type (*dense forest*) on the FCC (4, 3, 2) composite of the satellite image. It is also identified by its relatively lower infrared reflectance and hence lower NDVI value as compared to the previous cover type (dense forest).

4.1.1.3. Farmlands and Settlement

This land use type appears to have a light green or cyan signature from the FCC composite satellite image. Such signature possibly resulted because the image was taken in dry season when there is less vegetation cover and hence the exposure of dry soil. It extends all over the plateaus in between the river valleys having a higher altitude and gentler slope and hence convenient for cultivation. The settlement areas are categorized along with this class as it is difficult to separately discriminate settlements from the Landsat satellite images. The major crops cultivated in the area include Maize, sorghum and teff on some higher altitudes. Chat fields are also common next to crop lands. As livestock production is highly hampered by disease, the land area allotted for grazing is very small and not significant. In some places, small patches of lands are allocated for grazing while in some places fallowed farmlands are used for grazing. Both ways, these patches of grazing lands and settlements display similar signature and therefore categorized along with the surrounding dominant cultivated lands.

4.1.1.4. Grassland

This cover type is concentrated in the extreme western low elevation areas next to the forest along Geba River while some of it occurs in the transition area in between the highland plateau cultivated lands and the lower elevation forest lands. In some places, rock outcrops and bare soil have also been categorised with this cover type. This class is dominated by grass with openly scattered smaller trees and shrubs. It develops when the larger trees in the forest are removed by human for domestic uses and other purposes thereby leaving the shrubs and smaller trees which favour the dominance of grasses and bushes.

4.1.1.5. Classification Accuracy

As one of the most important post classification operations, classification accuracy has been assessed using ENVI 4.3 software against the ground truth data collected during field survey. Accordingly, cultivation and settlement has been classified with higher accuracy (97.87%) followed by dense forest, grassland and disturbed forest with 95.32, 93.63 and 78.49% accuracies respectively. The overall accuracy of the classification has been calculated to be 88.8% with Kappa Coefficient of 0.85.

4.1.2. Land Use/Land Cover Change

Land use/ land cover change detection is a powerful technique in analysing the temporal dynamics of the various land use/ land cover types. The major objective in this particular study is identifying and delineating the most suitable forest areas for in-situ wild *Coffea arabica* gene reserve. Therefore, analysing the changes associated with the particular cover of interest at various times and the associated causing factors would help determine part of the forest most convenient to manage on a sustainable basis and identify the part that deserves special attention in the management process. Besides, determining the seriousness of the change process would strengthen the premise behind the need for conservation. For this purpose, satellite images of three different years have been considered to explore scenarios at various time intervals of particular interest. Accordingly, land use/ land cover classification has been carried out from the 1973, 1986 and 2001 Landsat satellite images acquired by MSS, TM and ETM+ sensors respectively.

The statistics derived from the image differencing of the various time intervals is summarised in Table 4.1 and Table 4.2. The tables explain both the magnitude of change and to which land use/land cover type one has changed. As different scenarios may prevail at different times, segmenting the whole range of time under consideration in to parts would help determine which time range has been more important in terms of change. This would in turn help determine which drivers of change have been more important at different times. Here, two time intervals have been considered. The first one is from 1973 to 1986 and the second one from 1986 to 2001. Then the whole range of time is considered.

4.1.2.1. Change in Between 1973 and 1986

The major cover changes observed during this period had been the significant reduction in the overall area of both forest categories, dense and disturbed forest (by 3722 and 12222ha respectively), and grasslands (by 11,429ha), and a considerable increase in the overall areas of cultivated land and settlements (by 26,963ha). As indicated in Table 4.1, the reduced forest and grassland had been changed to farm land and Settlements. In this study, grassland is defined as part of the study area which is most dominantly covered by grasses but also includes openly scattered bushes shrubs and small trees and some rock outcrops and bare soils. This cover type develops when the larger trees in the forest are removed by human for domestic uses and other purposes thereby leaving the shrubs and smaller trees which favour the dominance of grasses and bushes. Though the overall change on grasslands had been negative, there had also been forest conversion to grasslands (Table 4.1) in this period. Therefore, the removal of forest land to expand cultivation and cutting of trees for different purposed had been the most important scenario worthy of considering in this particular period.

In this period, expansion of farmlands and intense deforestation are directly linked to population growth within that period. Rise in human population in this period had in turn been the result of the then resettlement program on the higher altitudes of the study area as mentioned by elders during the discussions made with the local community. During that time, the new settlers had to get land for cultivation and settlement through forest clearance. On the other hand, the forest had been the only source of wood for construction and other domestic uses like fuel.

Table 4.1: Land use land cove change matrix between 1973 and 1986(area in hectares)

Land Use/Land Cover		Initial State				
		Dense Forest	Disturbed Forest	Farmlands and Settlement	Grassland	Class Total
Final State	Dense Forest	**15216**	21483	261	1182	**38205**
	Disturbed Forest	13265	**24950**	2508	6804	**47632**
	Farmlands and Settlement	9405	9048	**23619**	16519	**58812**
	Grassland	3905	4182	5211	**10155**	**23511**
	Class Total	**41927**	**59854**	**31849**	**34940**	
	Class Changes	26711	34904	8231	24785	
	Image Difference	-3722	-12222	26963	-11429	

Note: The numbers in the class total ***row*** *indicate initial state where as the class total* ***column*** *indicates the final state of a given land use/land cover type. The diagonals indicate areas remained unchanged.*

4.1.2.2. Change in Between 1986 and 2001

This period reversed the trend of the previous period. Here, contrary to the previous period, the area covered by forest increased while the area covered by all other cover types reduced. The major change observed in this period had been an increase in the overall area of disturbed forest from 47,632 ha in 1986 to 57,976 ha (by 10317ha) in 2001 and a decrease in the areas of the grassland and to some extent, cultivated lands (Table 4.2). One may think that this is unacceptable while thinking of the other scenarios in the other parts of Ethiopia. In most parts of the highlands of Ethiopia, forest lands are continuously cleared to expand crop cultivation. In this particular period, overall forest cover has increased at Yayu owing to two major factors; villagization and coffee expansion.

Table 4.2: Land use land cove change matrix between 1986 and 2001 (area in hectares)

		Initial Stage				
		Dense Forest	Disturbed Forest	Farmlands and Settlement	Grassland	Class Total
Final Stage	Dense Forest	**24055**	10858	523	975	**36445**
	Disturbed Forest	12069	**26778**	9548	9494	**57976**
	Farmlands and Settlement	1720	8520	**40690**	7107	**58175**
	Grassland	337	1476	7896	**5856**	**15587**
	Class Total	**38205**	**47632**	**58812**	**23511**	
	Class Changes	14152	20881	18068	17613	
	Image Difference	-1761	10317	-583	-7882	

Note: The numbers in the class total ***row*** *indicate initial state where as the class total* ***column*** *indicates the final state of a given land use/land cover type. The diagonals indicate areas remained unchanged.*

As per the discussions made with the people of the area, the villagization policy initiated at the beginning of this period contributed to the increase in forest area coverage mainly at the earlier times. Following this policy, farmers were moved from near the forest to the higher altitudes and made to settle in village centres. As a result, farmers started ploughing near their settlement instead of their original places which initiated the regeneration and hence expansion of forest. This is further justified by the traces of previous settlement observed right in the forest during the transact walks made with farmers (Figure 4.2).

Figure 4.2: Evidences of previous settlement in the forest

A remarkable increase in the world coffee price (Figure 4.3) at different times had its own imprints in the study area in terms of forest cover. This has specially been of much influence after the implementation of economic liberalization policy in Ethiopia since 1991, which exposed (Kodama, 2007) coffee farmers to both the merits and demerits of global price fluctuation and competition. While considering the trend, there had been times of remarkable higher prices (Figure 4.3) at the end of the first period and in the middle of the second period which directly influenced coffee farmers to plant coffee both in the dense forest and the surrounding areas, with shade trees where required, which contributed to an increase in the area of the disturbed forest cover in the second study period. Most people including the urban dwellers have started expanding coffee lands where the foremost target has been modifying the natural forest endowed with wild population of coffee in such a way that favours the growth and development of coffee trees, hence the reduction (by 1761hactares) in the coverage of dense forest (Table 4.2). However, developing the already degraded forest land, and hence evolved to grassland, in to coffee land by planting or allowing the development of some shade trees, had been the major move. Hence, the area covered by grassland reduced by 7882hactares (Table 4.2). In comparison of coffee price with other food crops like maize, some croplands were also victims of coffee expansion. Dereje (2007) also reported increase in price of coffee (since 1995) encouraged farmers to plant coffee both in the forest and in their garden in a similar study conducted in southwest Ethiopia.

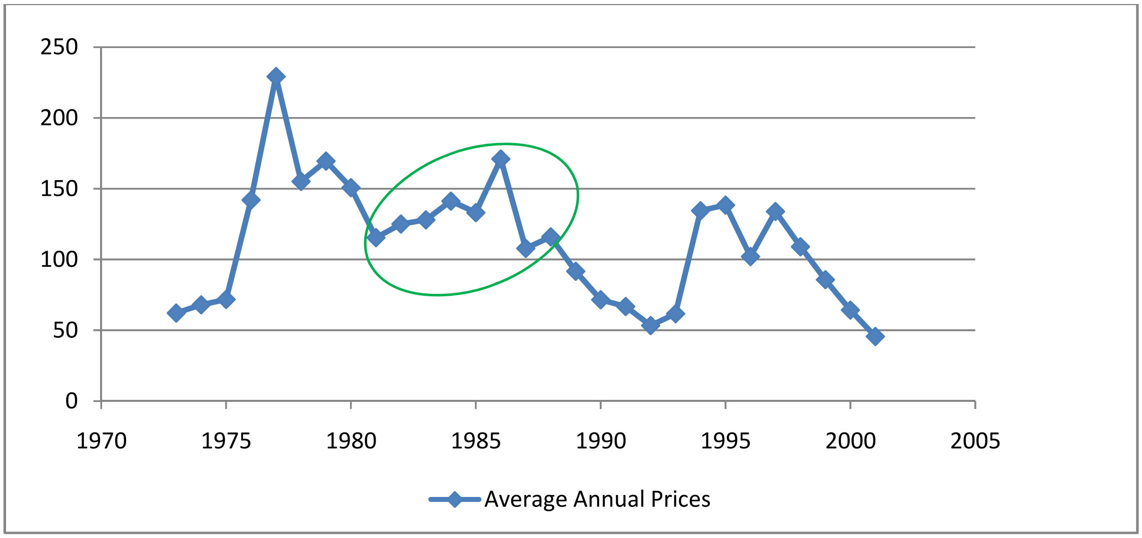


Figure 4.3: World composite average annual coffee price trend (US cents per lb). Plots in the circle are remarkable high prices at the end of the first period and in the middle of the second period. Source: ICO composite coffee indicator price statistical data.

4.1.2.3. Change in Between 1973 and 2001

While considering the whole range of time under consideration, the reduction in the area covered by forest had been remarkable despite the forest expansion observed in the second time period. Image differencing of the two extreme times, 1973 and 2001 indicated that forest cover reduced from 101,781to 94,421 ha (by 7.2%). This portion had in part gone to cultivation owing to crop land expansion as a function of population growth caused by the then resettlement program and in part gone to grassland owing to deforestation during the first time period.

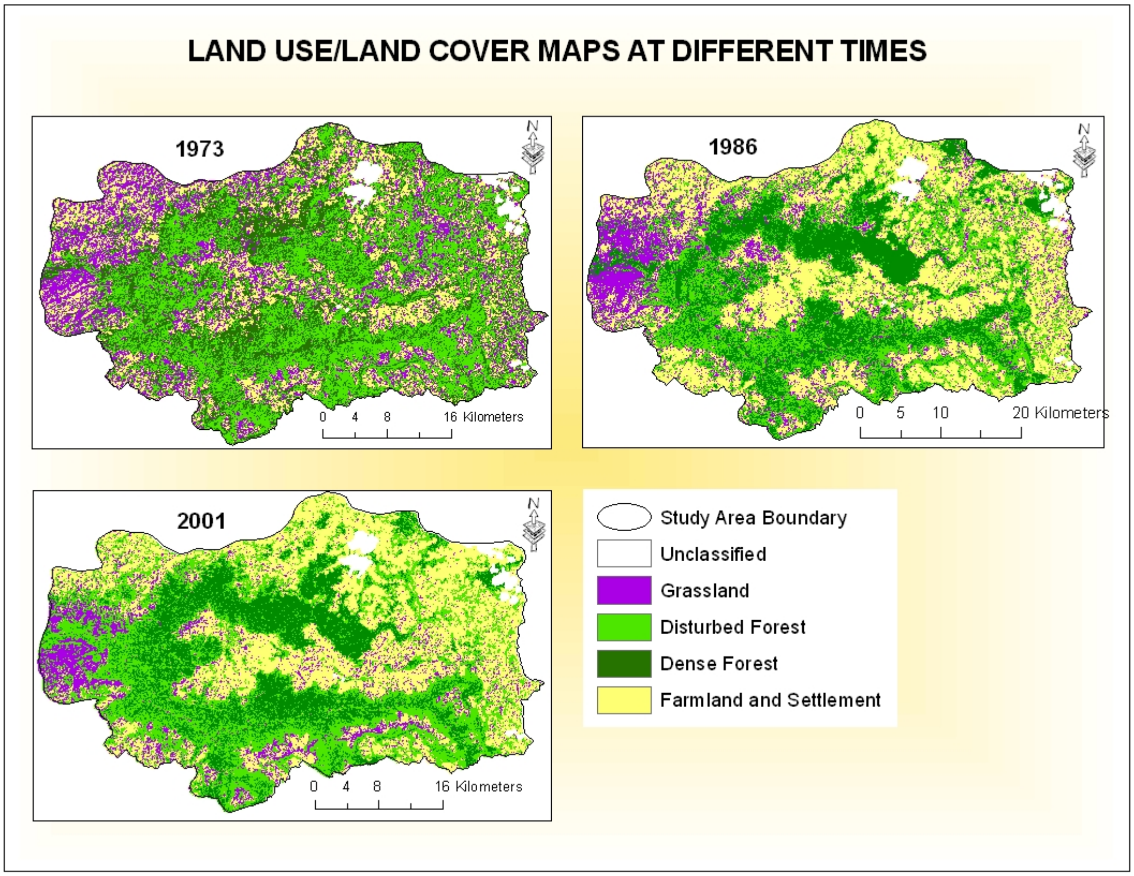


Figure 4.4: Land use/land cover maps at different times. The 1986 image has a cloud cover on the masked areas indicated as unclassified. The same cloud mask has been applied to the other two images to assume equal total area for comparison.

Table 4.3: Land use land cove change matrix between 1973 and 2001 (Area in hectares)

		Initial Stage				
		Dense Forest	Disturbed Forest	Farmlands and Settlement	Grassland	Class Total
Final Stage	Dense Forest	**14947**	19550	529	1343	**36445**
	Disturbed Forest	15269	**26772**	4953	10994	**57976**
	Farmlands and Settlement	10179	10991	**21913**	14930	**58175**
	Grassland	1426	2403	4316	**7517**	**15587**
	Class Total	**41927**	**59854**	**31850**	**34940**	
	Class Changes	26980	33083	9937	27423	
	Image Difference	-5547	-1836	26236	-19270	

Note: The numbers in the class total ***row*** *indicate initial state where as the class total* ***column*** *indicates the final state of a given land use/land cover type. The diagonals indicate areas remained unchanged.*

Table 4.4: Summary of the land use/ land covers extents at the three different years. The percentage is calculated as a proportion of the total study area

	1973		1986		2001	
	ha	%	ha	%	ha	%
Dense Forest	41927	24.87	38205	22.66	36445	21.62
Disturbed Forest	59854	35.51	47632	28.26	57976	34.39
Farmlands and Settlement	31850	18.89	58812	34.89	58175	34.51
Grassland	34940	20.73	23511	13.95	15587	9.25
Total	168,571		168,571		168,571	

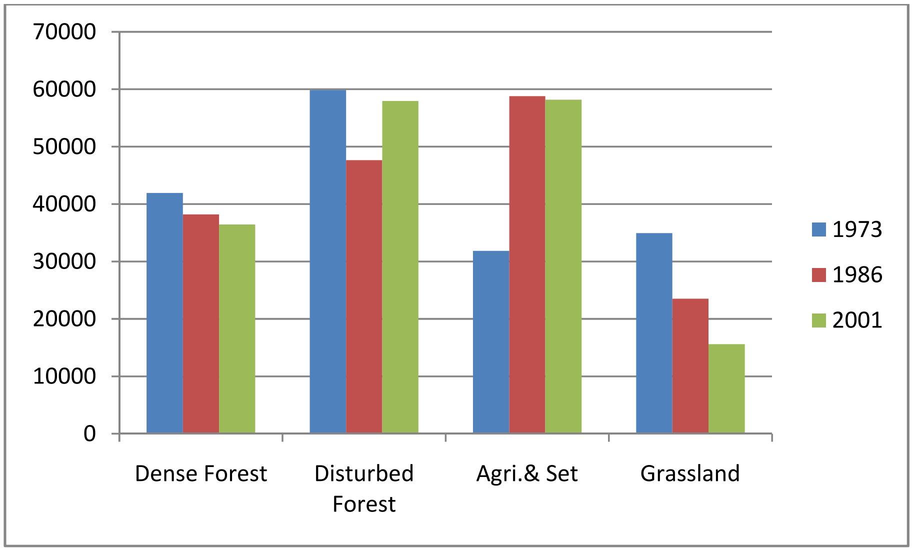


Figure 4.5: Summery of land use/Land cover extents (in hectares) at different years

4.1.2.4. Spatial Pattern of the Forest Cover Change; its implication for conservation areas zoning

Having done the cover change through different periods, it would be futile to fail to link the result with the ultimate objective; reserve zoning. The result of the cover change analysis can be linked to the reserve zoning exercise in two ways. One is the fact that it makes possible to visualize and analyze the spatial pattern of change, which would help to identify the various factors assumed to cause forest loss and determine their relative importance for the successive disturbance risk analysis and management strategy formulation. Second is that it highlights the seriousness of the forest cover change dynamics which strengthens the need for protected forest reserve establishment.

In view of the first notion, for instance, the huge forest loss in the north eastern and central parts (Figure 4.6) of the study area is not random. These parts are on the relatively higher altitude which is convenient for settlement and crop cultivation. At these sites, as the altitude is above 1800masl, crop cultivation is more important than coffee production, and hence, results in more complete forest clearance. On the other hand, forest increment was observed in the medium altitude ranges (1500-1800masl). As discussed in the preceding section, one of the reasons for forest cover increment was coffee land expansion induced by relatively encouraging prices. Given that coffee well performs in medium altitude range, dense forest in such altitudes is the foremost target for the people to expand semi-forest coffee production. In view of that, while considering the current remnant forest, the majority is confined in the altitude below 1800masl. Therefore, it should be noted that in the context of the current remnant forest intended for conservation, medium altitude ranges of the forest area are highly susceptible to human disturbance mainly for coffee production. This information is therefore going to be used in the upcoming disturbance risk analysis, which will intern be used as one of the factors determining suitability of the forest for conservation.

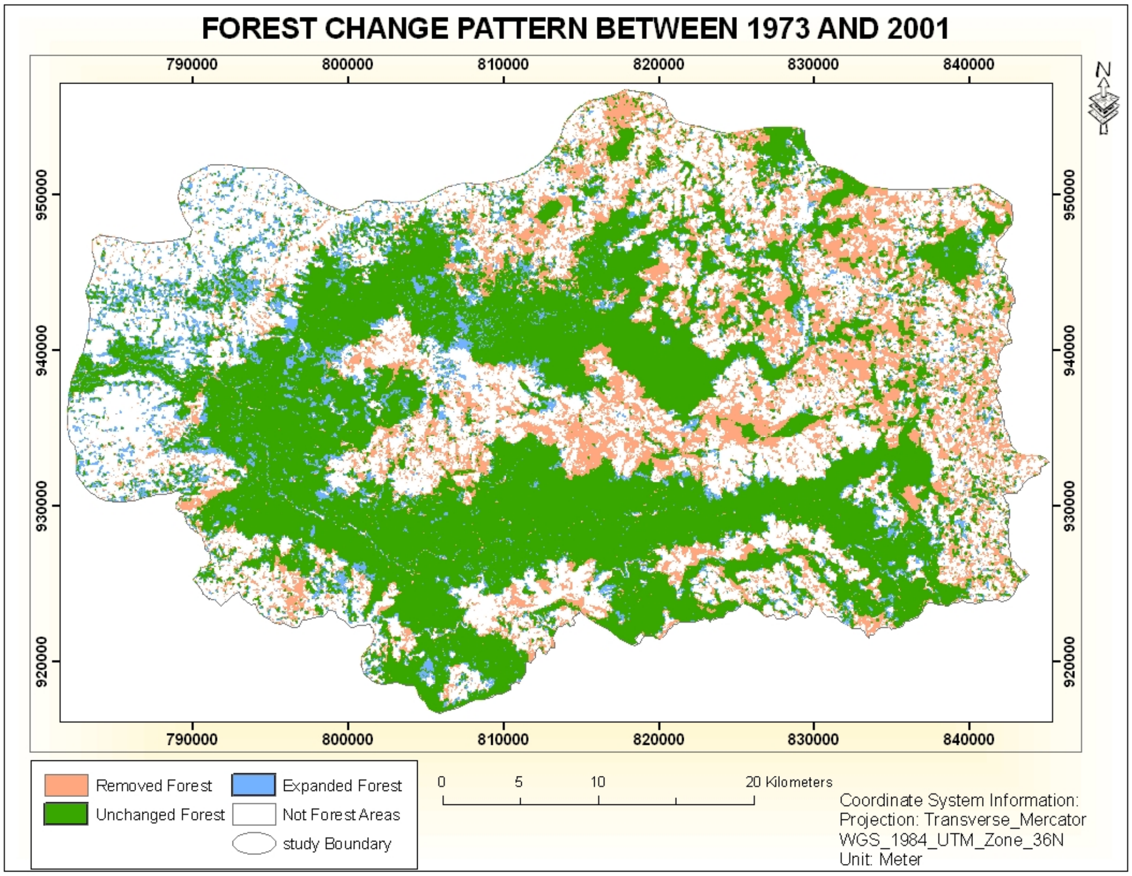


Figure 4.6: Spatial pattern of forest cover change in between 1973 and 2001

4.2. Extraction of Potential Forest Areas for the Subsequent Analysis

In order to determine core areas of the forest to be subjected to strict conservation, suitability analysis has been made taking several factors in to consideration. This includes the forest disturbance risk, coffee abundance and species diversity distribution. Each of these factors have intern been developed through multi-criteria evaluation taking several factors in to account. This analysis would be meaningful only within the area covered with forest and therefore requires the extraction of polygons representing the forest areas. On the other hand, reducing the data extent would speed up the subsequent processes. Accordingly, polygons representing the forest areas have been extracted. This was done by converting the 2001 classified forest areas raster data in to vector. The various data layers to be used in the subsequent analysis will therefore be extracted using these polygons. Therefore, the disturbance risk, coffee abundance and species diversity mapping and the suitability analysis to be discussed in the coming sections are confined only within the areas covered with forest.

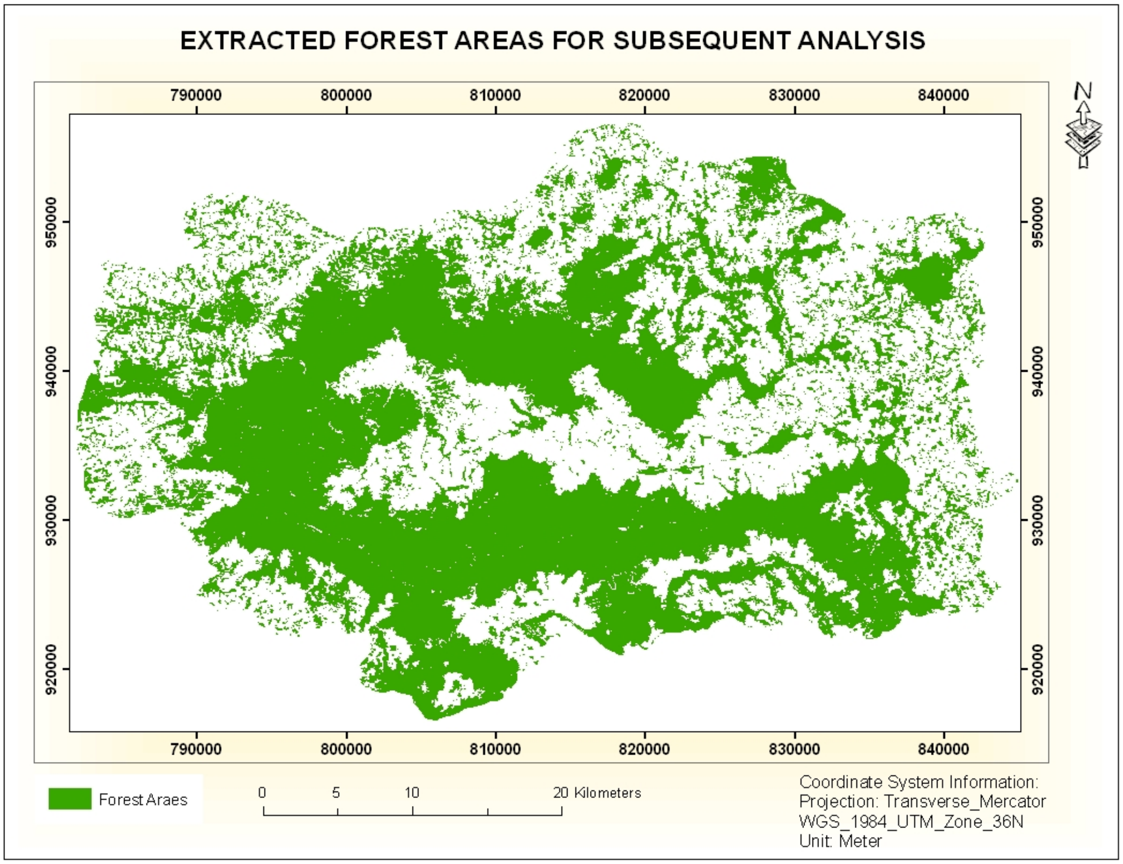


Figure 4.7: Extracted forest areas for subsequent analysis

4.3. Human Disturbance Risk Mapping

In order to classify the forest area in to various management zones, it is vital to determine which part of the forest is at risk of human disturbance. This would help to decide which part of the forest should belong to either of the three biosphere reserve zones; core, buffer and transition. To arrive at this disturbance risk map, various factors that are likely to cause forest disturbance should be examined. Tibebu (2007) used remote sensing and spatial multi criteria evaluation to map sensitivity of wetlands to human disturbance which he used in conservation area zoning. To evaluate the level of disturbance around lakes, he considered four major conditions; Settlement, Land use, Road, and Slope. In another study (Dereje, 2007) conducted in the south-western Ethiopian forest, it has been indicated that high deforestation is related with road network and major settlement centers (towns), through the analysis of spatial forest change pattern. In the current study, through close examination of the spatial forest change pattern in the study area (Figure 4.6), seven factors have been identified to be evaluated. These are: altitude, settlement (towns), proximity to the major rivers, slope, and proximity to various road categories (asphalt, gravel road, trails). These factors are separately discussed below.

4.3.1. Factors Influencing Forest Disturbance

4.3.1.1. Altitude

Altitude is one of the major environmental variables that determine the convenience of a certain area for various uses including human settlement. Agricultural practices are highly governed by altitude. In the current study area, clear deforestation has shown a strong correlation with altitude. As shown in Figure 4.6, intense deforestation has been observed in the North-Eastern higher altitudes and central plateau parts of the study area which are much convenient for crop production. This is mainly attributed to the settlement and agricultural land expansion associated with the previous resettlement programs. However, within the context of the current remnant forest under consideration, destruction of the forest ecosystem for coffee production is more important than the previous forest clearance for the sake of crop cultivation at higher altitudes. Hence, medium altitudes much convenient for coffee production are more prone to disturbance than the higher altitudes within the current context. Therefore higher disturbance value has been assigned to the medium altitudes followed by the higher ones.

4.3.1.2. Settlement (towns)

Human action for development and survival has long been the main threat to the stability of natural ecosystems where lose of biodiversity is the major expense incurred. Around the major settlement centers like towns, crop lands have been expanding at the expense of natural forest. This view is further justified by overlaying the major settlement areas (towns) on the spatial forest change pattern indicated in Figure 4.6. For this reason, proximity to towns has been considered as the second major factor in the disturbance analysis.

4.3.1.3. Proximity to Roads

Proximity to roads has been another factor considered in the disturbance risk analysis. Apart from the impact they have during their construction, roads provide access for human to distract the natural forest. However, their influence on disturbance depends on how intensively they are being used by human. In the study area, three different road types have been identified; Asphalt road, Gravel road, and trails. As they are more intensively used, asphalt roads contribute larger influence followed by gravel road and trails to forest disturbance by human.

4.3.1.4. Proximity to River

Areas near the major rivers are steep and rugged and hence less workable and therefore less preferred by people. On the other hand, farmers have pointed out that areas in the near vicinity of the major rivers in the study area are more prone to both human and livestock diseases and therefore less convenient for settlement. They also mentioned that there had been times when people were displaced due to this reason. Therefore areas near the major rivers are less prone to human disturbance.

4.3.1.5. Slope

Gentler slopes are preferred to steep ones by human for various agricultural uses. This is because steep slopes are prone to erosion, less workable and have shallower soil depth as compared to the gentler slopes. Based on this fact, steeper slopes are given lower values in terms of their influence on forest disturbance by human.

Table 4.5: Factors of forest disturbance along with their range, scale values, ranks and weights used in mapping

No	Factors	Range	Scale Value	Rank	Weight
	Altitude(masl)	1100-1500	1	Low	0.2698
		1500-1800	4	Very high	
		1800-2100	3	High	
		>2100	2	Medium	
	Slope (%)	0-8	4	Very high	0.1322
		8-16	3	High	
		16-30	2	Medium	
		>30	1	Low	
	Distance from river(km)	0-0.5	1	Low	0.1841
		0.5-1	2	Medium	
		1-3	3	High	
		>3	4	Very high	
	Proximity to towns	0-0.5	4	Very high	0.2549
		0.5-1.5	3	High	
		1.5-3	2	Medium	
		>3	1	Low	
	Proximity to Asphalt	0-0.35	4	Very high	0.0810
		0.35-0.7	3	High	
		0.7-1	2	Medium	
		>1	1	Low	
	Proximity to dry Weather road	0-0.25	4	Very high	0.0541
		0.25-0.5	3	High	
		0.5-0.8	2	Medium	
		>0.8	1	Low	
	Proximity to trails	0-0.1	4	Very high	0.0238
		0.1-0.3	3	High	
		0.3-0.5	2	Medium	
		>0.5	1	Low	

4.3.2. Dataset Preparation and Overlay Analysis

In order to run the overlay analysis required to arrive at the forest disturbance map, the various causing factors identified should be converted to raster formats and reclassified in to meaningful scale values. Accordingly, the layers have been prepared in raster format and reclassified in to various risk categories (Figure 4.8) as per the detail provided in Table 4.5.

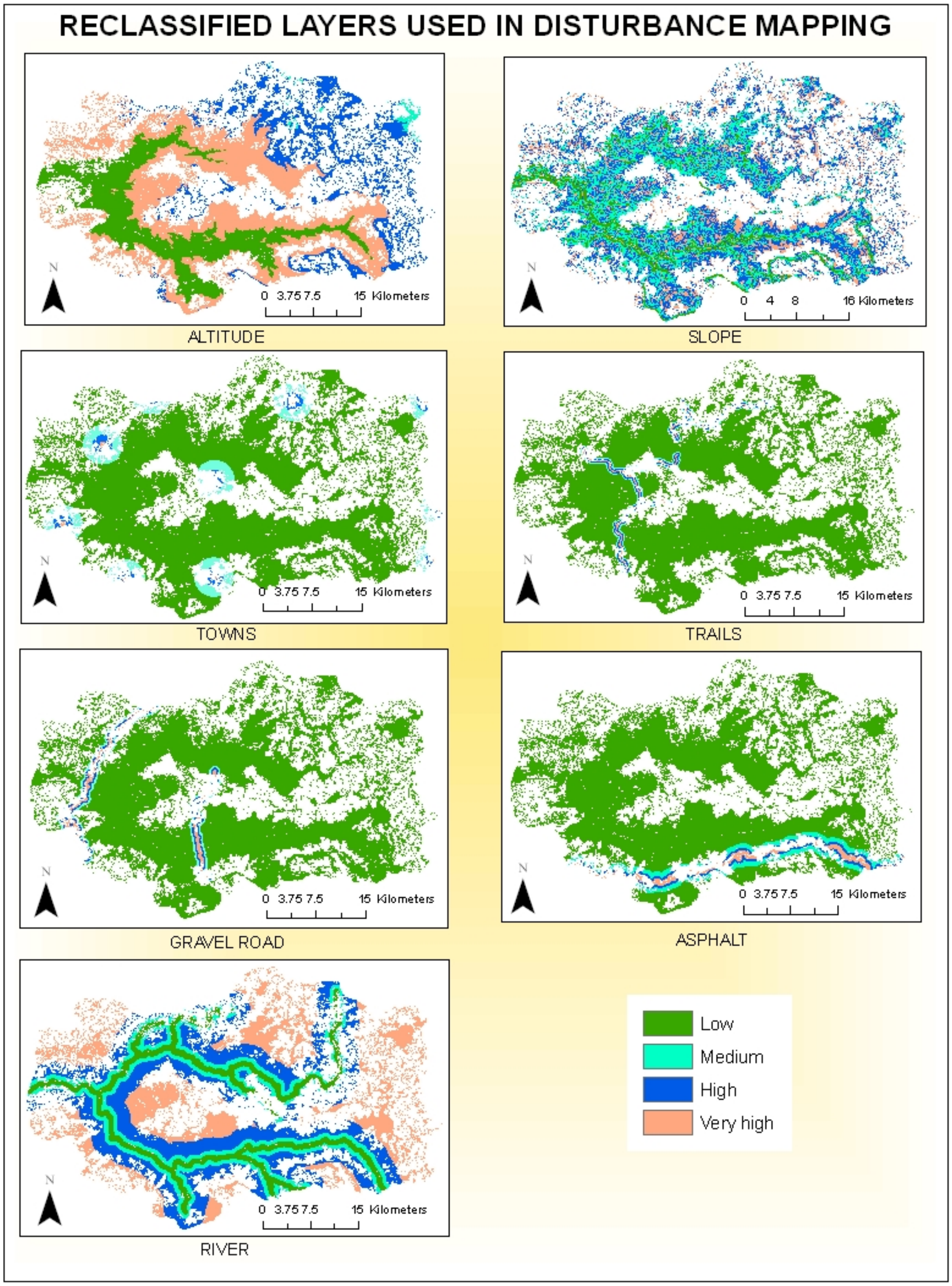


Figure 4.8: Raster layers used in forest disturbance risk analysis.

In order to produce the human disturbance risk map of the forest area, the above raster layers along with their weighted values have been developed in to equation(1) and then fed in to the spatial analyst raster calculator of the ESRI- ArcGIS 9.1 software.

*Disturbance Risk = Altitude*0.2698 +Slope*0.1322+Distance from river*0.1841+Towns*0.2549+Proximity to asphalt Road*0.0810+Proximity to dry weather road*0.0541+Proximity to trails*0.0238…………………(1)*

According to the above equation, *human disturbance Risk* map (Figure 4.9) has been obtained.

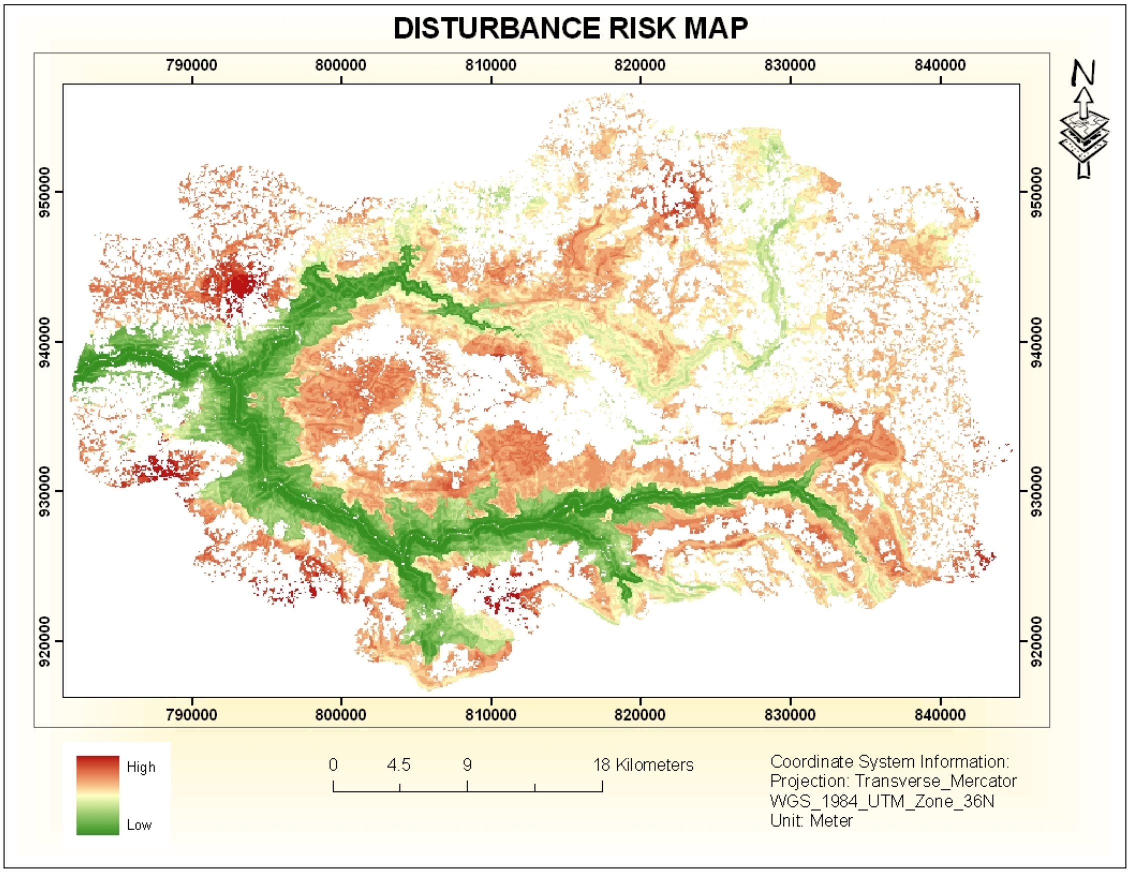


Figure 4.9: Sensitivity to human disturbance map

Figure 4.9 illustrates the proneness of the forest to human disturbance. The green areas indicate parts of the forest that are less prone to human disturbance while the red areas indicate parts that are most prone and therefore at high risk of human disturbance. It therefore follows that parts of the forest at low risk of human disturbance would imply higher suitability for conservation. This information is therefore going to be used as one of the most important factors to determine suitable areas of the forest for conservation.

4.4. Coffee Abundance and Species Diversity Distribution Mapping

Conservation Biology is an emerging discipline dedicated to the preservation of endangered species and habitats. To develop effective protection strategies, experts need to understand the relationship between species and ecosystem. Most importantly, they need to decide which areas are the most important to protect. Consequently, mapping the areas with high plant biodiversity has a priority for decision-makers. Effective management plans and actions can only be achieved with this valuable spatial information (Dogan H. M. and Dogan M., 2006).

Mapping the potential distribution of plant species is now within reach of many botanists, thanks to desktop modelling software and Geographical Information Systems (GIS)(Carpenter *et al* ., 1993; Skov, 2000 as cited in J.H. Vargas et al., 2004). The main requirements for mapping potential species distributions are environmental data at an appropriate scale and accurately geo-referenced collection data (Vargas et al., 2004).

In the study conducted in north-east Spain, Francesco de Bello (2006) stated that different components of biodiversity may vary independently of each other along environmental gradients giving insights into the mechanisms that regulate species coexistence. He concluded that environmental factors, such as climate and disturbance, account for a large proportion of the variance of different components of biodiversity. Altitude is an important terrain variable, since it affects atmospheric pressure, moisture and temperature, which intern influence the growth and development of plants, and the pattern in vegetation distribution (Tadesse, 2003 after Hedberg, 1964). Gonzalez and Mata (2005) have also stated that elevation is the variable which best explains variations in species richness and diversity, and that local variables such as the degree of slope and soil organic matter and cations play a secondary role. For most taxa there is a decline in the number of species with increasing elevation (Brown, 1988; Begon et al., 1996 as cited in Gunnar Austrheim, 2002). Though these findings at various geographical locations may not exactly apply to the current location, they can indicate the possibility of modelling and mapping spatial distribution of plant species and biodiversity as a function of environmental variables.

4.4.1. Coffee Abundance Distribution Mapping

As the theme of this research work is the in-situ conservation of wild coffee gene pool, determining coffee spatial distribution pattern in the forest would be essential in the attempt to identify suitable areas for conservation. In order to produce coffee distribution pattern map, determining the association between coffee occurrence and some indicative environmental variables would be mandatory. However, this wouldn't be an easy task as it needs a detail floristic analysis with respect to environmental gradients taking the whole forest area in to consideration. Fortunately, a detail study has been conducted by Tadesse (2003), in part of the forest under consideration, where he identified some important environmental variables found to influence coffee occurrence. According to this study, in Yayu forest, the plant species distribution, and hence the patterns in forest vegetation are mainly influenced by the gradients in terrain variables such as altitude, slope and distance from the river banks. Among these, slope has a strong negative correlation with coffee abundance. In here, the environmental variables ranges (Table 2.1) forwarded by Tadesse (2003) were used to map the distribution of coffee plants within the forest under consideration. He identified three community groups within the forest. Among these, *Coffea arabica* is found in the community group 1. The environmental variables ranges given for this community group is then used to map coffee distribution within the forest.

Table 4.6: Factors of coffee abundance distribution along with their range, scale values, ranks and weights used in mapping

No	Factors	Range	Scale Value	Rank	Weight
1	Altitude(masl)	1100-1388.4	3	Medium	0.4054
		1388.4-1511.6	5	Very high	
		1511.6-1800	4	high	
		1800-2000	2	low	
		>2000	1	Very low	
2	Slope(%)	0-8	3	Medium	0.4806
		8-15.6	4	high	
		15.6-38	5	Very high	
		38-50	2	Low	
		>50	1	Very low	
3	Distance from river(m)	0-300	1	Very low	0.1140
		300-656.9	3	Medium	
		656.9-1544.9	5	Very high	
		1544.9-3000	4	High	
		>3000	2	Low	

Based on the environmental variables given for the *Coffea arabica* community group, three raster layers representing these variables have been produced and reclassified in accordance with the values given there in Table 2.1. These variables along with their range, scale values, ranks and weights are summarized in Table 4.7. The weights have been assigned to the respective variables through the aid of the pair wise comparison function provided in the IDRISI Andes 15.0 software.

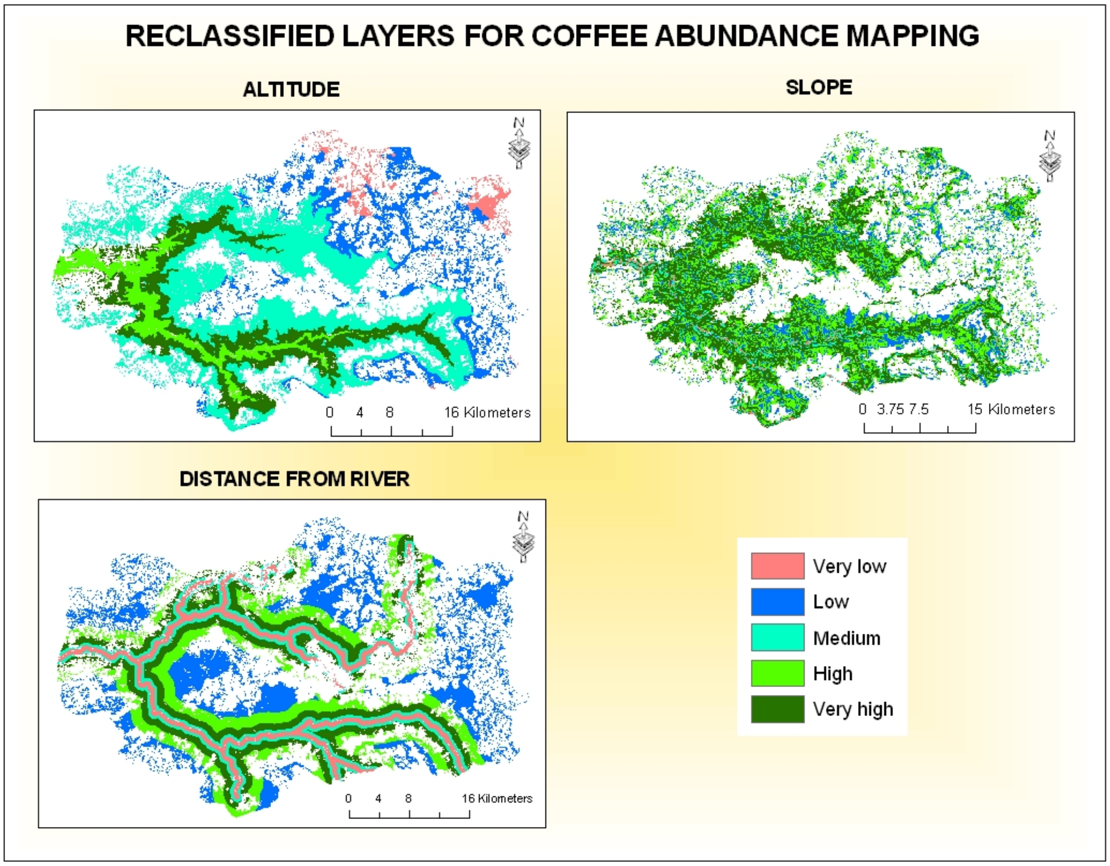


Figure 4.10: Raster layers of environmental variables used for coffee abundance distribution mapping

As discussed above, the raster layers (Figure 4.10) of environmental variables (altitude, slope and distance from river) used for coffee abundance distribution mapping have been prepared being constrained within the aforementioned extracted forest areas. These layers have then been used to run weighted overlay analysis as per the weights given there in Table 4.7 through equation (2).

$$Coffee\ abundance = Altitude*0.4054+Sope*0.4806+Distance\ from\ river*0.1140\ldots(2)$$

Accordingly, coffee abundance map (Figure 4.11) has been obtained as an output.

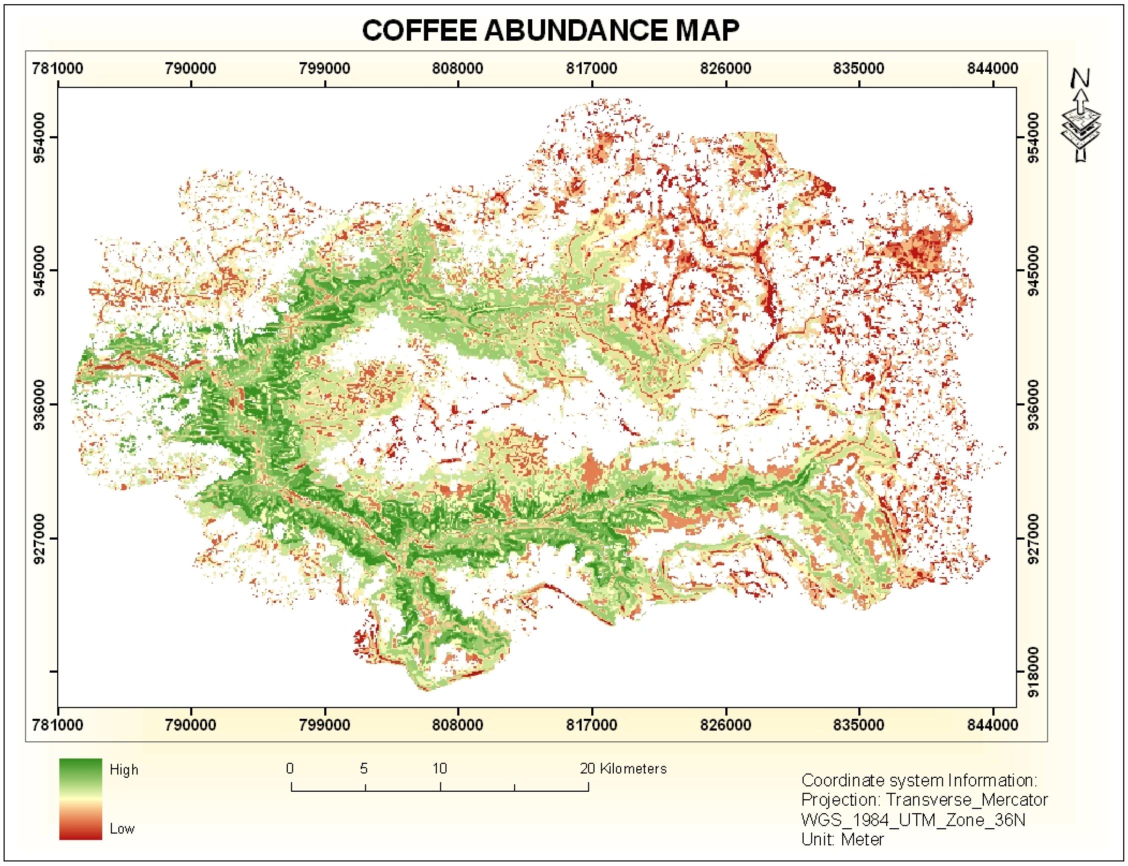


Figure 4.11: Coffee abundance distribution map in Yayu forest

As seen on Figure 4.11, coffee abundance is lower close to the major rivers and at the upper right higher altitude. Areas close to the river are known for their steep slope, high soil moisture and lower altitude. Distances from river and soil moisture content are known to be inversely related and hence play an important role in zonation of vegetation along riversides (Tadesse, 2003). As was also verified during the field visit, coffee is less abundant near the major river. The upper right part of the forest is mainly influenced by higher altitude than the other variables in terms of coffee abundance. As per the discussion made with the local community, these areas are more important for crop production rather than coffee and hence the intensity of forest disturbance for coffee management is less.

4.4.2. Forest Species Diversity Mapping

As stated in the background, Yayu forest is known for its high species diversity (>220 species) (Tadesse, 2003). In the same study, Tadesse (2003) reported higher diversity at lower elevation along the Geba river, and lower diversity at higher elevation along the ridges. Based on these findings, this study used distance from river and elevation gradients to produce the species diversity map for the whole forest under consideration. The raster layers used in the overlay analysis to produce the final diversity map are indicated in Figure 4.12.

Table 4.7 Factors of species diversity distribution along with their range, scale values, ranks and weights used in mapping

No	Factors	Range	Scale Value	Rank	Weight
1	Altitude(masl)	1100-1300	5	Very high	0.6370
		1300- 1500	4	high	
		1500-1800	3	Medium	
		1800-2000	2	low	
		2000- 2333	1	Very low	
2	Distance from river(m)	0-500	5	Very high	0.363
		500-1500	4	high	
		1500-3000	3	Medium	
		3000-5000	2	low	
		>5000	1	Very low	

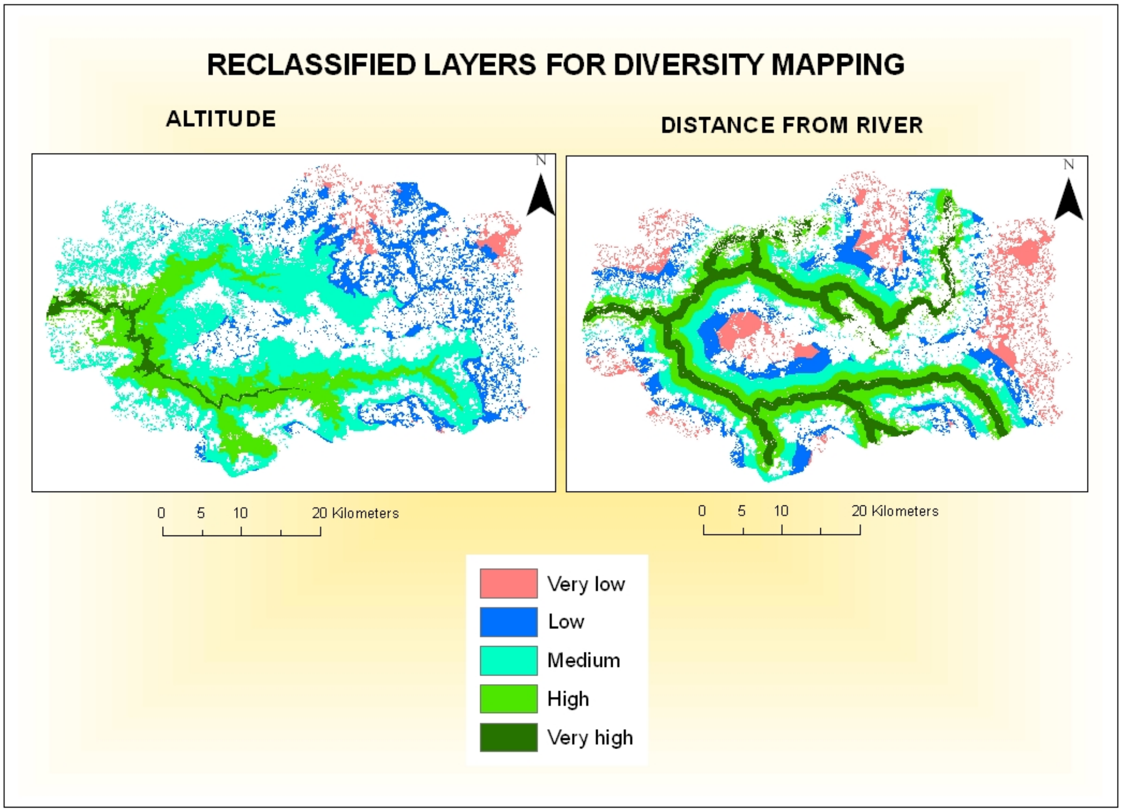


Figure 4.12: Raster layers of environmental variables used in species diversity mapping

The above layers (Figure 4.12) along with their estimated weights from pair wise comparison have then been used to run weighted overlay analysis through the equation:

*Species Diversity = Altitude*0.6370+ Distance from river*0.363*

Accordingly, species diversity distribution map has been obtained as an output (Figure 4.13)

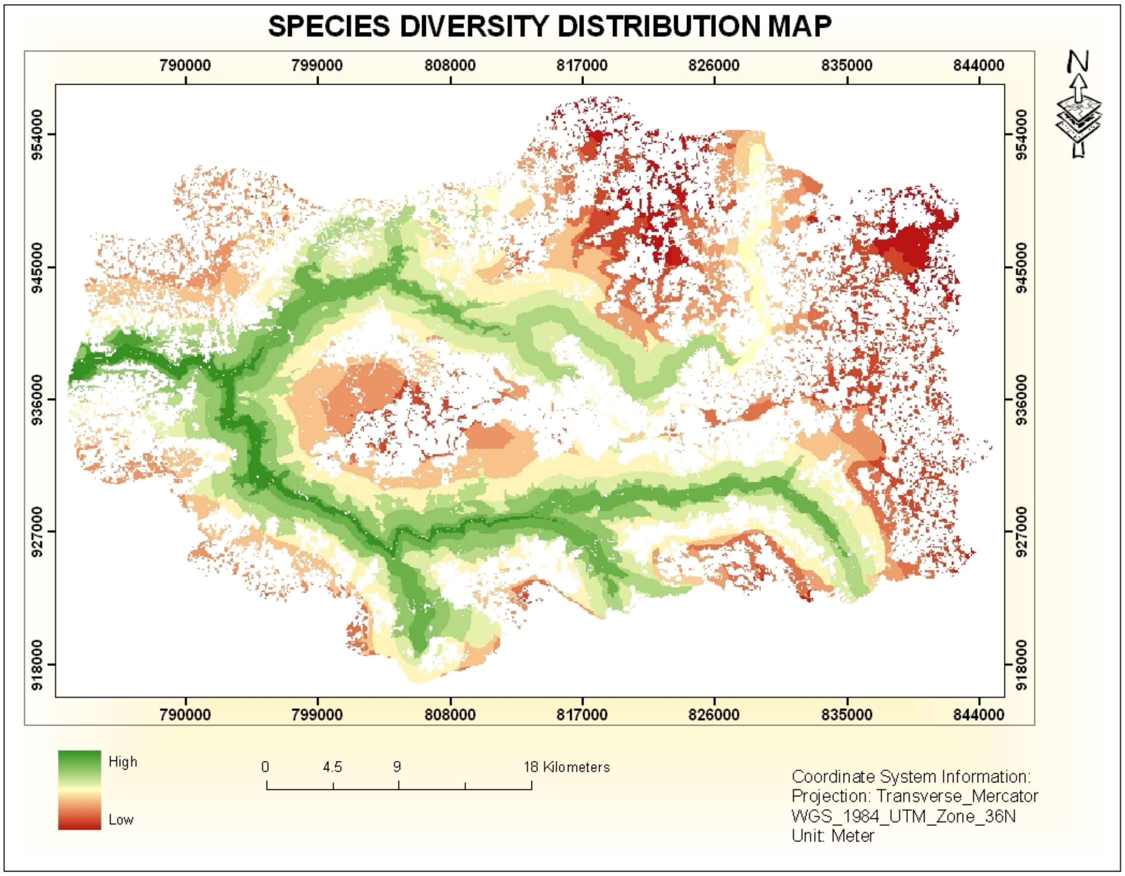


Figure 4.13: Species diversity distribution map

Figure 4.13 demonstrates higher species diversity at lower elevations along the major rivers mainly Geba and its tributaries Dogi and Saki. According to the analysis, the upper right parts of the forest showed lower diversity values which is mainly attributed to its higher elevation. Overall, this would have important implication in the suitability analysis to be made later in this paper for conservation areas selection.

4.5. Biosphere Reserve Zoning

A Biosphere Reserve should have an appropriate size to serve the three functions: a *conservation function*, to preserve genetic resources, species, ecosystems and landscapes; a *development function*, to foster sustainable economic and human development, and a *logistic support function*, to support demonstration projects, environmental education and training, and research and monitoring related to local, national and global issues of conservation and sustainable development as set out in Article 3 of the Statutory Framework of the World Network of Biosphere Reserves. It should include these functions, through appropriate zonation, recognizing: (a) a legally constituted core area or areas devoted to long-term protection, according to the conservation objectives of the biosphere reserve, and of sufficient size to meet these objectives; (b) a buffer zone or zones clearly identified and surrounding or contiguous to the core area or areas, where only activities compatible with the conservation objectives can take place; (c) an outer transition area where sustainable resource management practices are promoted and developed. In this particular exercise, several factors have been considered to determine the three boundaries; transition, buffer and core. Most importantly, determination of the boundary of the core zone has been given due consideration as it should include the target of interest, wild coffee gene pool, and is to be devoted to long-term protection where no human intervention is allowed. The processes and factors considered to determine each of these zones are discussed in detail in the following sections.

4.5.1. Outer Boundary of the Biosphere Reserve and the Transition Zone

The transition zone represents areas of the biosphere reserve where sustainable resource management is to be promoted. It may contain a variety of agricultural activities, settlements and other uses and in which local communities, management agencies, scientists, non-governmental organizations, cultural groups, economic interests and other stakeholders work together to manage and sustainably develop the area's resources (UNESCO. 1995_b). Determination of the outer boundary should therefore take this in to account. Accordingly, some systematic approach has been followed in order to determine the outer border of the transition zone, and hence of the Biosphere Reserve inclusive of the target forest.

As stated in the location area description part, most of the boundary has been delineated following a watershed divide line. This creates a convenient platform for the subsequent promotion of sustainable resource management which is the major goal to be achieved in the transition zone. This includes the northern, eastern and western parts of the boundary while at the southern part, the catchment extends along Geba and Dogi rivers so far to assume an unmanageable size and therefore some other way had to be sought. Accordingly, the southern border has been demarcated fallowing either of roads or some linear features like escarpments or external forest boundaries (Figure 4.22).

4.5.2. Buffer Zone

The outer boundary of the buffer zone has intentionally been determined to follow the boundary of the target forest that continuously extends along the major rivers, Geba, Dogi and Saki, either managed or natural. This has been produced by converting the land use land cover raster data produced from the 2001 Landsat ETM+ Satellite image in to polygons and then merging those polygons that represent the potential forest area. Most dominantly, this zone includes managed coffee forests by the local people. While at the north eastern part, as the area lies on a relatively higher altitude, crop production is more important than coffee, and hence, there is less or no managed forest for coffee and therefore dense forest is usually neighboured by cultivated lands. In these areas, minimum of 400m buffer, composed of dense undisturbed natural forest, has been allowed to shield the core zone (Figure 4.22).

4.5.3. Core Zone; zone of strict conservation

The most challenging task in the whole exercise, which needed careful assessment and critical decision, has been delineating the inner core boundary which is intended to be subjected to strict long-term protection. In general, this area should have *high wild coffee population*, *high species diversity*, *less human disturbance risk* and *should not encompass areas owned by individual farmers*. The first three factors have already been assessed and prepared as a continuous raster format in the preceding sections. These layers have been used to produce a suitable areas map in a continuous raster format, through multi criteria evaluation. The output is then subjected to evaluation against a constraint factor that excludes forest lands currently managed by coffee producers. The details of the suitability mapping, farmers' interest and constraint layer development and final output are discussed in the following sections.

4.5.3.1. Suitability Mapping

Instead of subjective decisions, it has been tried to follow some systematic ways to determine areas that should belong to the core zone. One of the ways used has been suitability analysis. This suitability has been developed in terms of the previously listed factors; coffee abundance, species diversity and disturbance risk, which have intern been developed through multi-criteria evaluation taking several factors in to account (refer to sections 4.2 and 4.3). Accordingly, these factors, developed in raster formats, have been subjected to multi-criteria evaluation in ArcGIS 9.1. The weights associated with each factor have been determined through pair wise comparison function embedded in the IDRISI Andes software.

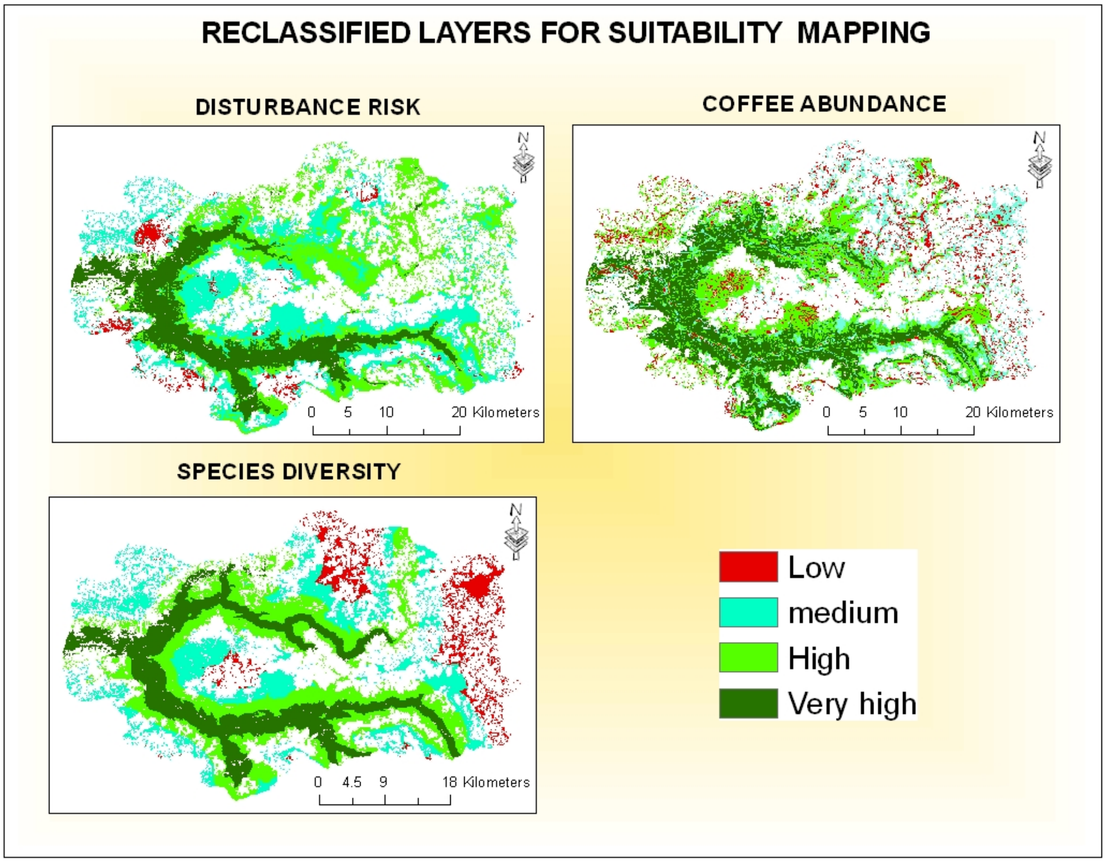


Figure 4.14: Layers used in suitable conservation areas analysis

Table 4.8: Factors used in suitability analysis along with the associated weight values

Factors	Weights
Coffee abundance	0.6175
Species diversity	0.2969
Disturbance risk	0.0856

The above layers (Figure 4.14), along with their estimated weights from pair wise comparison, have then been used to run weighted overlay analysis through the equation:

Suitability= Coffee abundance*0. 6175+ Diversity*0. 2969 + Sensitivity to disturbance*0. 0856

Accordingly, the following suitability map has been obtained as an output.

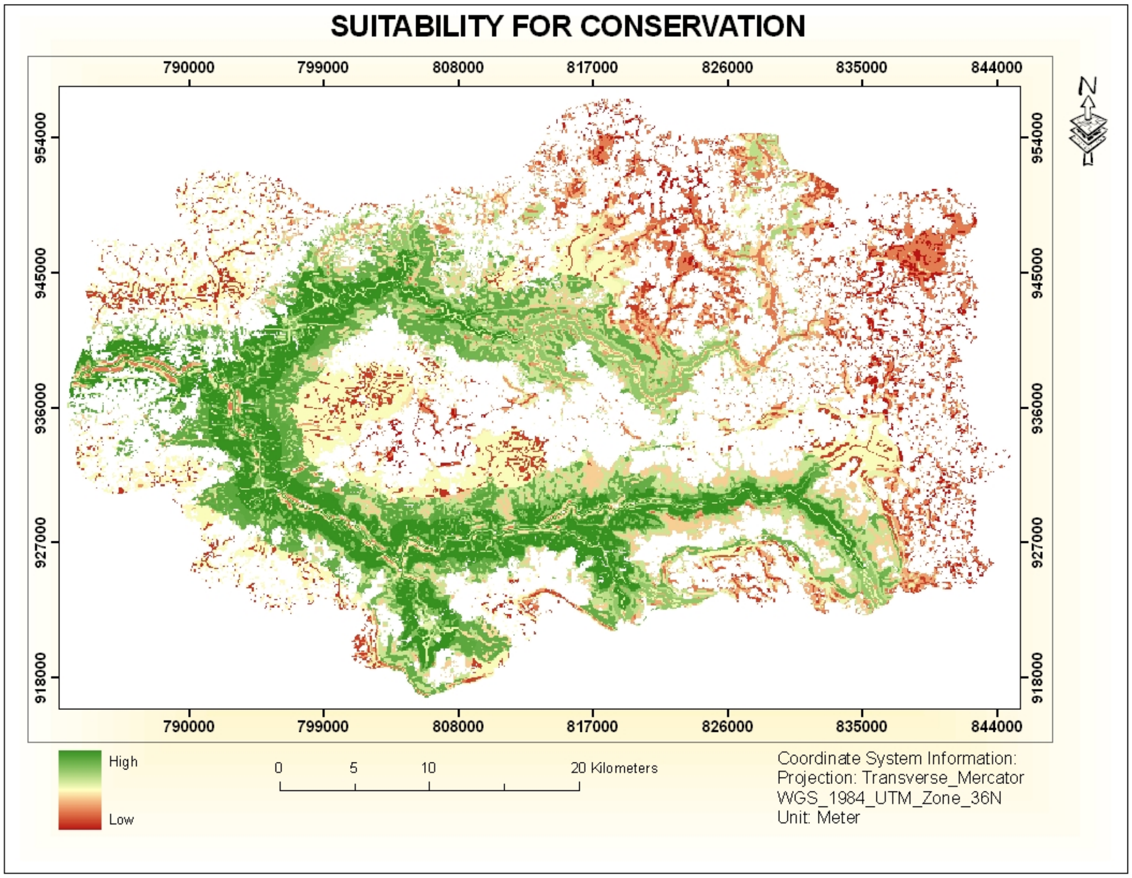


Figure 4.15: Suitability map for conservation

Figure 4.15 demonstrates parts of the forest that are more suitable for conservation in terms of the pre-discussed ecological factors; coffee abundance, species diversity and human disturbance risk. It therefore follows that the green areas are the most suitable parts for conservation while the red areas are less suitable parts. However, this doesn’t mean that all the green areas can be devoted to protection; instead, it means that parts at high suitability values are ecologically suitable and can be subjected to further scrutiny against the community’s interest. This is because any conservation effort should be in harmony with the surrounding community’s interest in order to insure its sustainability. The community participation and the resulting output will therefore be discussed shortly.

4.5.3.2. Community Participation and Constraint Layer Development

As the title of this research indicates, participation of the local community has been given due attention in determining which areas should belong to areas of strict conservation; the core zone. The major objective behind the participatory approach is to minimise human conflict with the conservation effort and ensure its sustainability. As discussing with each of the farmers in the five districts of the forest area is impractical and beyond the scope of this thesis research, another practical approach had to be sought. Accordingly, parts of the potential conservation areas, that are prone to high social conflict, have been identified and prioritized with district agriculture and forest coffee conservation officials so that such areas may systematically be subjected to discussions with the local community.


(a) (b) (c) (d)

Figure 4.16 Field photos; (a) Discussion with farmers around homestead (b) participatory mapping around homestead, (c and d) Discussion in the forest during transact walks

Accordingly, contribution of the farming community has been obtained in two ways. First, farmers were given opportunity to discuss and comment on the criteria to be used to delineate the boundaries of strict conservation areas, through group discussions. Second, they were given opportunity to identify and indicate, areas prone to high social conflict and therefore should be excluded, and areas having other social values and therefore should be protected, through discussions, transact walks and in some places, through participatory mapping.

As per the participatory campaigns, the most important criteria that farmers pointed out is that the core zone should not include areas that had once been under their management and currently delineated, or areas that are currently under their management for coffee production. Considering this criterion has been one of the biggest challenges as it requires a farm to farm ground survey which is beyond the scope of this study. As a result, some other manageable way had to be sought. Accordingly, one option has been evaluating if the areas under farmers management for coffee production can be differentiable from satellite image.

As discussed in section 4.1 of this paper, forest areas under coffee production occur at the outer periphery of the forest next to the dense forest. It has previously been part of the dense natural forest and has, since certain times, been evolved to the current state due to human influence for coffee production. In order to maximize their coffee yield, farmers were managing the forest in such a way that favours the coffee plants. Most importantly, they selectively remove the lower associated layers species that are thought to compete with the coffee plants and selectively leave some of the canopy layer trees thought to provide the required shade for coffee. Due to such immense human impact, this cover type has attained a considerably lower density and species diversity as compared to the natural dense forest category. Fortunately, the preferred trees are usually flat topped with narrow light green leaves that in most cases display a dark red signature on the FCC colour composite of the satellite image. In addition, due to the lesser density as compared to the undisturbed dense forest, this cover type displays a relatively lower NDVI values. These have been used as an opportunity to discriminate this cover type and exclude from the core zone as per the communities interest. However, as limitation, this system couldn’t differentiate part of the forest having lower density due to some other natural factors than human influence for coffee production. In such areas, ground verification using GPS has been made to resolve the problem. The output of this activity is presented in figure 4.17.

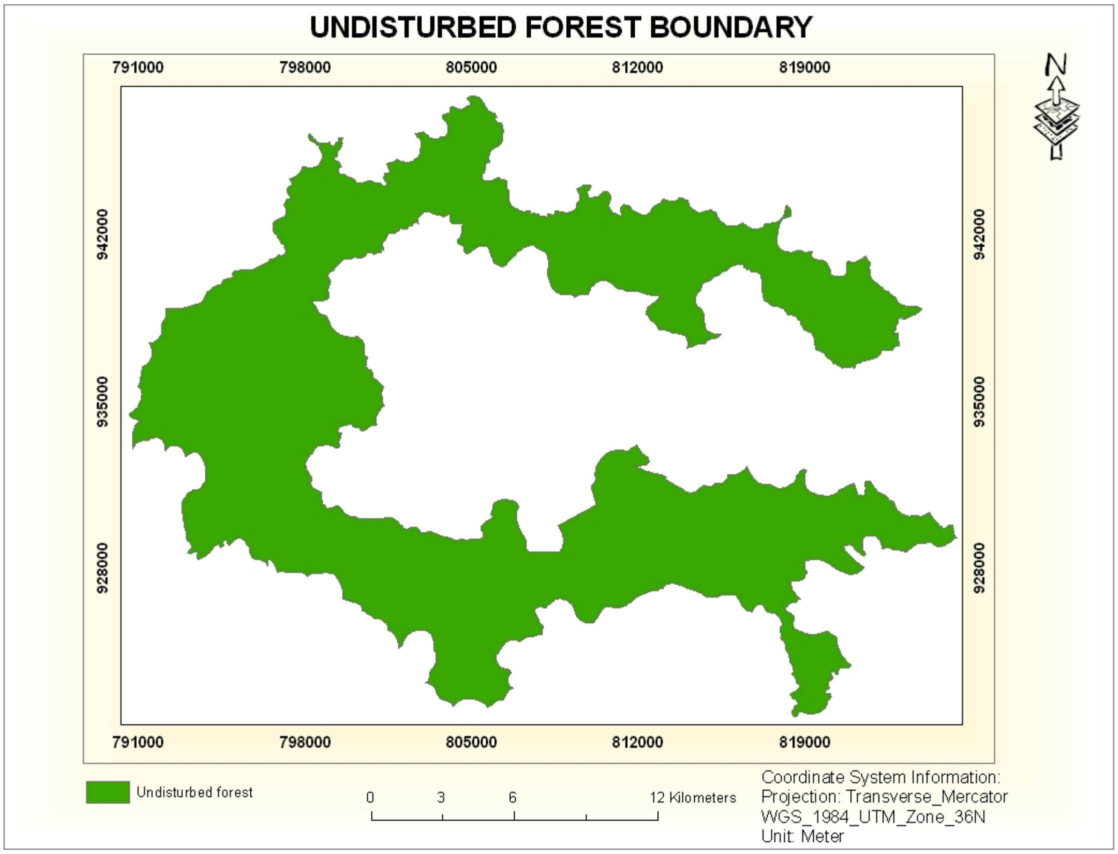


Figure 4.17: Unmanaged natural forest boundary developed with community participation

Figure 4.17 represents boundaries of unmanaged natural forest areas along Geba, Sese and Dogi rivers. The boundary has first been obtained from the 2001 land use/land cover map and then further refined with ground verification and community participation. Through ground verification, it was made possible to refine boundary of the natural forest in areas where the reflectance is identical with the managed forest. And through community participation, it was made possible to exclude major parts of the forest confronted with intense claim and conflict from farmers. The output has been a narrow and elongated forest along the rivers, which is encroached by various agricultural activities from every direction. However, having such an elongated core area encroached from all direction would create difficulty for management and therefore, segmenting the whole length in to parts would be more convenient. Towards this aim, various road categories intensively used within this forest and therefore should not occur in the core areas have been used as dividing lines. This was done by developing a 350 meters buffer on both sides of the roads and excluding the resulting buffer area from the potential core areas. This as a result divided the whole forested area in to six compartments. This is acceptable as having multiple core areas within a single biosphere reserve is possible as per the UNESCO's guideline.

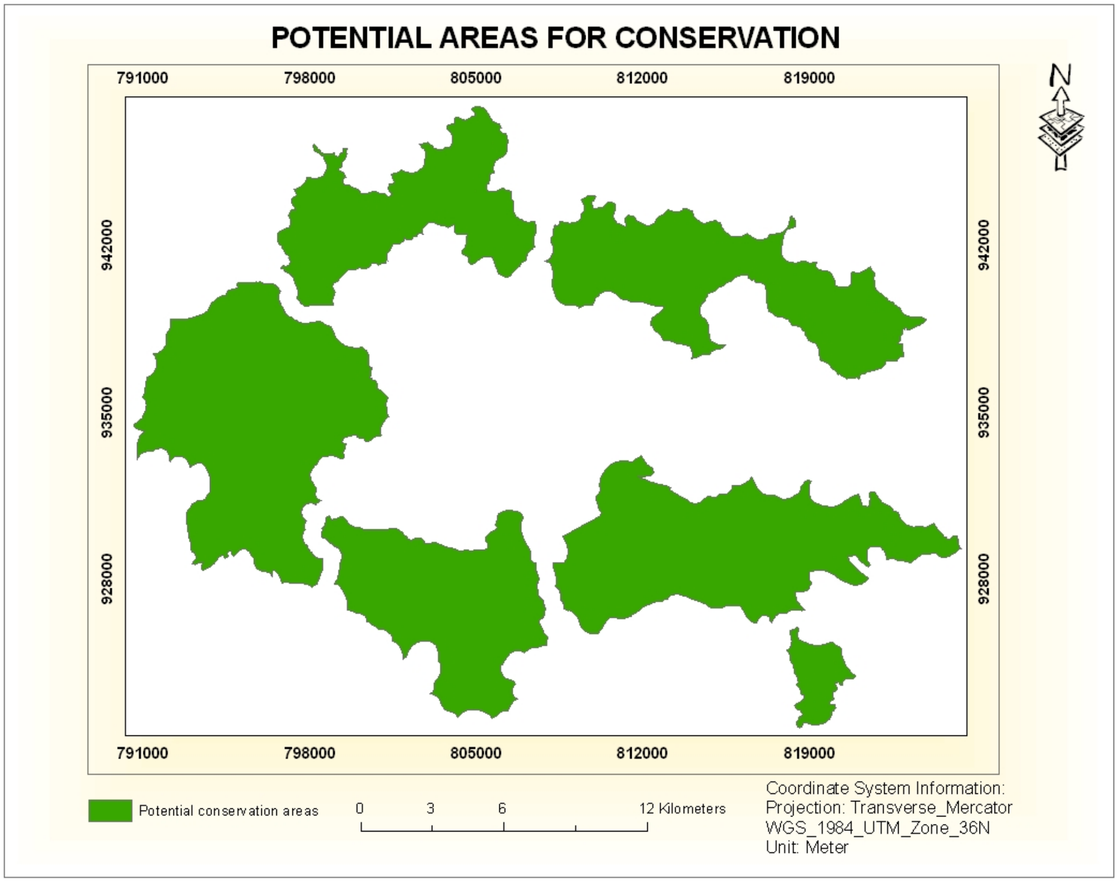


Figure 4.18: Potential core forest areas for conservation

Figure 4.18 presents possible core areas of the forest for conservation from past management intensity point of view, as it is believed to have been not managed by farmers for coffee or any other use. However, this has to be further evaluated against the preceding suitability analysis in order to determine whether all possible core areas are also suitable from ecological point of view. For this, the previous suitability data has been extracted with the polygons of the possible core forest areas after being reclassified in to four suitability categories (Figure 4.19). Accordingly, though the four suitability categories are found in the possible core areas, majority of the areas are in the highly suitable and suitable categories. As a verdict from this, excluding the few areas that fall in the not suitable and less suitable categories would have no strategic significance for management and therefore left to occur in the conservation areas. However, the sixth possible core area polygon at the south-eastern end is located in an isolated location with relatively smaller size. Besides, it is isolated from the rest of the core areas by an asphalt road. This possibly creates a management difficulty due to both its smaller size and isolation from the rest of the core areas by an intensively used asphalt road. Accordingly, despite its higher suitability and cultural significance, this possible core area has been excluded from the core zone and added to the buffer zone. As a result, the remaining five possible core areas have been selected to be core conservation areas of the biosphere reserve that are going to be subjected to strict protection.

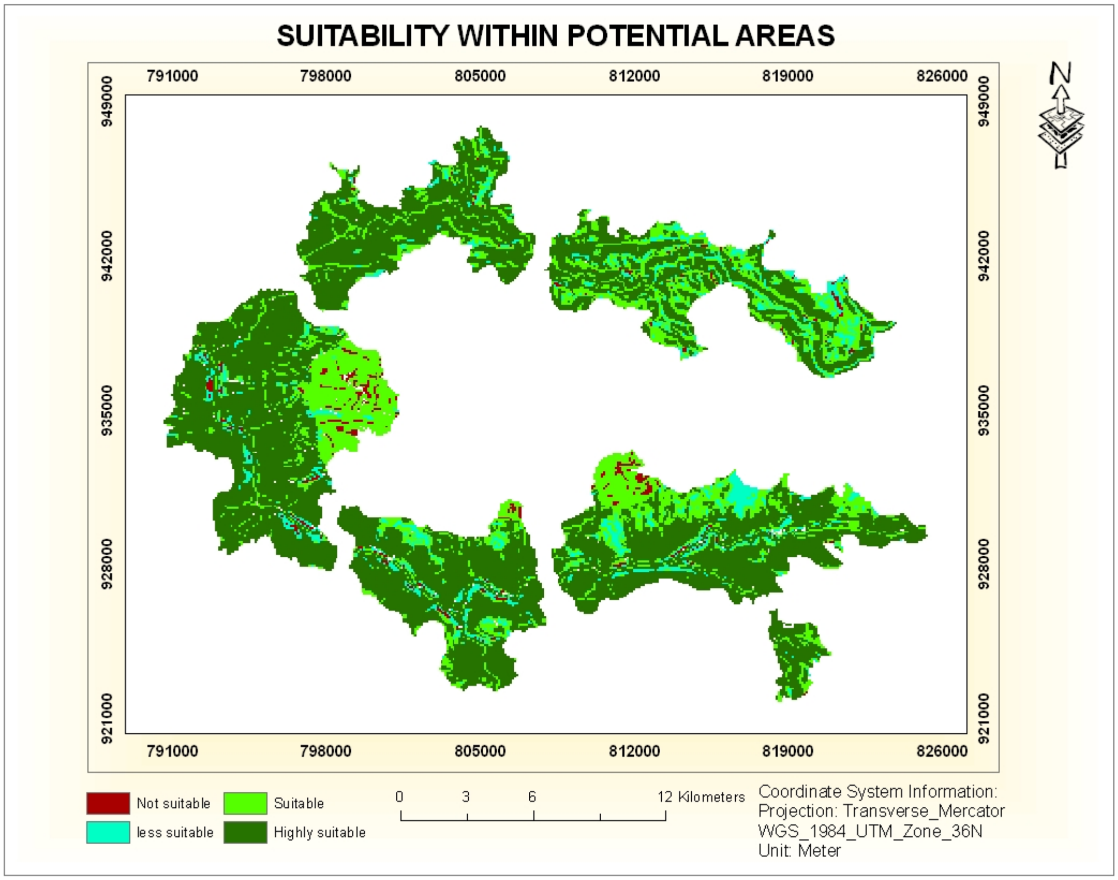


Figure 4.19: Suitability within possible core areas of the forest

4.5.4. Consideration of the Cultural and Aesthetic Values of the Yayu Forest

Farmers have also identified one cultural site (in the excluded possible core area) that they value which is called "*Teso Aba Alange*" in Oromo language meaning "*the throne of the judge*". This site is a place where the constitutions of the previous "Geda System" were being made under the leadership of the so called "Aba-Geda" in Oromo culture. As per the discussions with the people of the area, the rules, regulations and lows formulated at this site had been in effect in the whole area currently under the Ilubabore administrative Zone.

At this site, currently there is an old "Oda" tree fell due to its age (Fiugure 4.20a) and an abandoned surface (kind of stage) covered with stones (Fiugure 4.20b). The shade under the tree had previously been used as a meeting place for the people's gatherings under the "Geda System" while the stony surface had been used as a worship place but currently abandoned and trees grew on it.

Figure 4.20 (a) fell Oda tree due to its age (its shade previously used as a meeting place during the gathering of the Geda System) (b) a man standing on a stone covered surface previously used as a worship place

This therefore indicates that the Yayu forest, apart from its importance for the conservation of the wild coffee population and other biodiversity elements, also has cultural values that should be maintained or conserved. This is therefore in agreement with the premise that biosphere reserves also strive to maintain features of cultural importance. Apart from its cultural value, this area has high wild coffee abundance and is yet kept under natural condition.

Furthermore, Yayu forest can also be explored for its aesthetic values as it harbours set of rivers, waterfalls and wild life. Besides, the visual appearance of the complex ecosystem in the forest would create invigorative impression to one when visited. This highlights the importance of the forest for tourism. However, further investigation shall be made to produce appropriate documentation with this regard, especially on the wild animals it harbours, in order to exploit the forest for tourism purpose.

Figure 4.21 Some features of aesthetic value within Yayu forest: (a) Colobus Monkey, (b) Strangler, (c) Forest landscape with clouds in the gorges, (d) Geba river, (e) waterfall

4.5.5. The Proposed Biosphere Reserve

Figure 4.22 presents the proposed biosphere reserve map intended to be established at Yayu. The middle dark green areas represent the core zones that collectively make up a total area of 27733 hectares. As was made clear in the preceding parts, these zones represent undisturbed dense natural forest areas of high coffee abundance, high species diversity, less prone to human disturbance. The divides in between these zones were intentionally allowed to occur following different kinds of intensively used roads thought to influence disturbance by human. Theses divides on one hand help to avoid the crossing of roads in core zones and on the other hand help to pay due attention in the areas having relatively higher risk of human disturbance. The light green areas shielding the core zones are the buffer zones of the reserve which mainly are managed coffee forests by human, except in the upper right end of the north-eastern compartment, and are considerably disturbed as compared to the interior core zones. This zone covers a total area of nearly 22 thousand hectares. The outer boundaries of these buffer zones are also boundaries of an extensive continuous forest area along the major river Geba and its tributaries Sese, Dogi and Saki. The extensive area represented by a cyan colour is the transition zone of the biosphere reserve and covers nearly 122 thousand hectares. This zone mainly consists of agricultural lands, settlements including towns, grasslands and other scattered forest patches not that important for conservation. Though the smaller undisturbed forest at the south-eastern end (Figure 4.19) isolated from the rest of the undisturbed forest by asphalt road is of cultural importance and also has dense population of the wild coffee, it has been excluded from the core areas due to its isolated nature and small size which would create difficulty for management.

Table 4.9: Summary of the areas occupied by each biosphere reserve zone

Zone	Area(ha)
Core	27,733
Buffer	21,552
Transition	122,003
Total	171,288

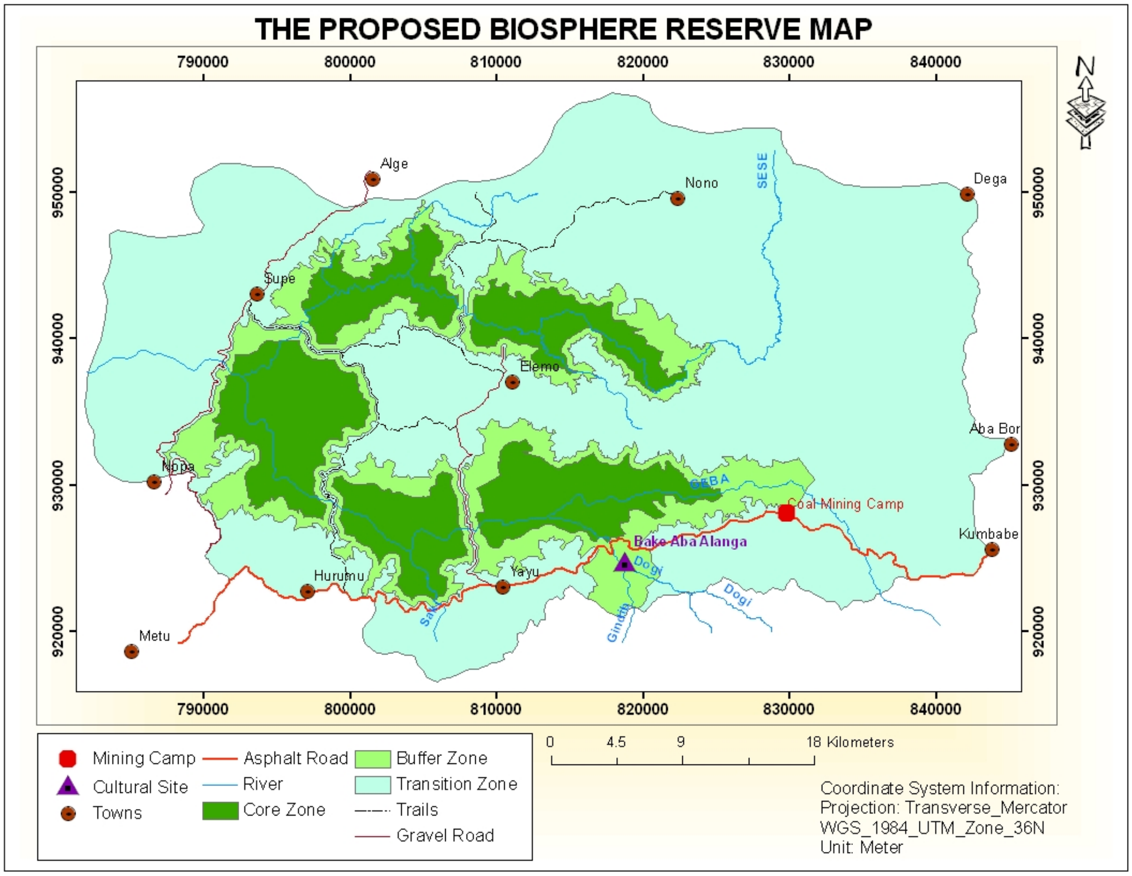


Figure 4.22: Proposed biosphere reserve zones' map

4.5.6. Limitations of the Proposed Map

Overall, though several important factors have been considered in the determination of the three zones of the biosphere reserve, finer refinements will still be required while demarcating the boundaries of these zones on the ground. The participatory approach in this study didn't make individual farm to farm based survey and discussions during core zone boundary delineation and concentrated on prioritised areas of high social conflict. In addition, the land use land cover map used in the zoning exercise has been developed from the 2001 Landsat satellite image (in the absence of a cloud free recent ASTER image) which may not exactly represent the present situation.

4.5.7. The Present Scenario in the Area

Currently, there are some active destructive processes within the study area. This includes semi-forest coffee expansion in to the core zone, power line alignment which requires forest clearance and mining activity which is almost at its inception (Personal communication with GDFCC project coordinator). This possibly poses potential threat to the target forest in the core zone. With respect to this, the relatively wider buffer zone near the coal mining site has been allowed to shield the core zone for two main reasons. One is that people have disturbed the forest at this area for coffee, even up to the river at some spots, leaving very few undisturbed areas. Second is that, though not yet started, the coal mining plant at the south-eastern tip of the forest would have an immense impact associated with both the mining activities and population pressure to be induced by the immigrant workers. Nevertheless, this still alarms a cautionary tone which needs an immediate precautionary response from the concerned body ahead of time.

5. Conclusions and Recommendations

In general, according to this study, the area is composed of four major land use/land cover types; Dense forest, disturbed forest, farmlands and settlement, and grasslands. In between 1973 and 1986, there had been a considerable forest loss due to farm land expansion and deforestation as influenced by population pressure from the then resettlement program. In between 1986 and 2001, there had been a slight increase in overall forest cover owing to to (1) forest regeneration resulting from displacement of settlers from near the forest to village centers following the then vilagization policy, and (2) coffee expansion. The spatial forest cover change pattern indicated that the major complete forest clearance occurred on the relatively higher altitudes (> 1800masl) of the study area which are more convenient for both human settlement and crop cultivation. On the other hand, both the disturbance of the natural forest for the sake of coffee production and increment of the forest cover as a result of coffee land expansion mainly occurred in the medium to low altitudes(<1800masl) of the study area. This implies that forest resource management strategies at higher altitudes where crop production is more important should differ from that of the mid to lower altitudes where coffee production is more important.

Influence of coffee expansion on the overall forest condition is somewhat controversial; on one hand, it plays a positive role in maintaining large areas covered by forest however, on the other hand, through the modification of the natural forest for coffee production enhancement, it endangered the associated plant species and hence biodiversity, implying that a balance mechanism shall be sought. This strengthens the premise that a biosphere reserve should be established at Yayu in order to optimize the use and conservation of the irreplaceable wild *Coffea arabica* gene pool along with the other associated biodiversity elements of the forest.

To this end, it has been tried to determine suitable core zone areas of the forest, and the associated buffer and transition zones required to establish a biosphere reserve, taking several factors in to consideration. The outer boundary of the biosphere reserve, and hence of the transition zone, has been demarcated following, to a large extent, watershed boundaries. This creates a convenient platform for the subsequent promotion of sustainable natural resource management, which is the major goal to be achieved in the transition zone. The buffer zone, except a few areas in the north-eastern part, has been demarcated to compose part of the disturbed forest which is intensively managed for coffee production and hence represent the semi-forest coffee production system. This helps to formulate pertinent management packages to semi-forest coffee production in the buffer zone. The core zone has been delineated mainly from the dense forest to represent areas of higher wild *Coffea Arabica* abundance, higher plant species diversity, less prone to human disturbance, and areas that have never been under private management, which employed community participation during decision making. However, as the participatory approach in this study didn’t make individual based discussions, the output should never be considered as an absolute conflict free map; but rather a considerably socially resolved map that paves the way to a further detailed scrutiny for a better conflict free map of the biosphere reserve.

For the successful establishment of a biosphere reserve at Yayu, this paper outlines the following points as essential:

- The participatory approach in this study didn’t make individual farm to farm based survey and discussions. In addition, the land use land cover map used in the zoning exercise has been developed from the 2001 Landsat satellite image (in the absence of a cloud free recent ASTER image) which may not exactly represent the present situation. Therefore, further boundary refinement, especially the core zone, is yet mandatory during on-ground boundary demarcation in accordance with the prevailing situation.
- In some cases, there are farmers who claim for a little patch of land at the middle of the dense forest (core zone) which wouldn’t be worth considering for delineation. In such cases, negotiations should be made with such individuals during on-ground boundary demarcation in order to avoid unnecessary compromise of a potential size of natural forest for the sake of excluding such patches of forest lands.
- As the major activity in the transition zone is production of crops including maize, sorghum and teff, production enhancement packages pertinent to these crops should be formulated and promoted to maximize income of the settlers which may reduce the pressure on the dense forest for coffee production.
- As the buffer zone mainly represents semi-forest coffee production system, forest management options within the context of semi-forest coffee production should be formulated and promoted among the occupants of the buffer zone.
- Expecting that the process of establishing a biosphere reserve at Yayu would take time, certain enforcement should be made as of now in order to control the currently

active destructive processes such as semi-forest coffee expansion in to the core zone, power line alignment and coal mining activities.

- In order to maximize the cultural and, tourism value of the forest, further investigation should be made on these aspects and proper documentation should be compiled for the already explored cultural site called “Teso Aba Alange”, which is a trace of the traditional Oromo Democratic Constitution; the “Geda System”.

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Appendices

Appendix 1: ICO world composite indicator coffee price (US cents per lb). Annual and monthly averages (1965 to 2008)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
1965			38.2	38.41	37.05	39.27	40.67	42.2	41.65	42.15	41.73	42.32	40.37
1966	42.15	40.91	40.14	40.3	40.46	39.83	39.49	39.14	38.31	38.45	38.24	37.91	39.61
1967	37.22	37.13	36.68	37.43	38.3	38.57	37.58	36.69	36.52	36.44	37.21	36.82	37.22
1968	37.26	37.37	37.68	37.82	37.61	37.7	37.56	37.38	37.3	37.38	36.93	36.37	37.36
1969	36.33	36.54	36.05	35.17	34.96	35.35	35.42	37.01	40.28	45.33	45.83	46.22	38.71
1970	49.15	48.73	49.27	50.4	51.14	50.89	51.7	51.99	52.03	51.87	50.23	48.88	50.52
1971	49.02	46.96	45.08	44.28	44.31	43.76	43.5	43.67	43.31	43.13	43.68	45.23	44.66
1972	44.8	44.92	46.01	46.42	47.33	47.76	54.11	55.83	53.99	53.95	54.55	55.19	50.41
1973	57.04	60.75	61.77	59.78	61.63	62.78	62.85	62.33	63.07	64.05	64.82	65.09	62.16
1974	66.22	70.78	72.04	72.89	73.74	71.49	68.45	64.55	61.97	63.04	64.57	65.63	67.95
1975	64.96	63.8	60.71	59.53	60.29	63	60.01	88.49	85.8	84.59	82.73	86.84	71.73
1976	94.97	101.49	100.5	123.15	138.93	149.24	142.34	150.87	154.19	162.62	179.63	205.54	141.96
1977	217.61	245.93	305.13	314.96	277.41	243.06	209	201.36	195.78	172.48	182.13	185.7	229.21
1978	191.65	186.08	166.37	161.69	152.86	159.82	130.17	133.34	151.12	151.89	145.21	131.58	155.15
1979	130.93	127.76	132.76	140.22	148.74	190.99	199.78	189.7	198.36	196.97	192.19	185.63	169.5
1980	165.62	163.42	177.14	171.86	182.3	175.22	151.81	134.02	125.42	125.79	115.61	119.87	150.67
1981	124.93	120.18	119.93	120.57	117.15	98.59	104.13	107.24	107.45	117.67	124.6	122.64	115.42
1982	124.43	134.3	129.01	124.01	120.56	121.14	115.92	117.45	122.78	128.84	130.17	131.33	125
1983	127.24	124.35	123.14	123	125.82	123.8	124.2	124.93	127.11	135.52	136.95	139.72	127.98
1984	138.32	141.11	143.18	143.89	148.36	145.43	141.01	143.13	141.85	135.99	138.14	133.89	141.19
1985	135.46	133.3	132.36	132.02	131.87	131.04	120.68	119.96	118.78	125.93	140.91	174.84	133.1
1986	204.02	195.11	204.23	191.73	176.92	151.14	149.12	154.38	181.45	163.21	149.42	130.41	170.93
1987	118.39	115.52	100.81	104.33	111.45	101.59	96.17	98.38	104.93	111.45	115.53	115.14	107.81
1988	115.07	120.76	117.75	116.31	116.35	118.72	113.65	107.11	113.8	113.92	114.03	124.06	115.96

1989	126.69	118.04	117.36	117.55	115.89	104.52	76.67	69.05	69.23	61.1	62.07	61.9	91.67
1990	62.75	67.01	75.25	75.34	73.3	69.91	68.36	74.1	75.55	73.89	70.1	72.83	71.53
1991	69.38	70.55	72.47	71.45	67.47	65.58	64.31	63.34	66.86	62.83	64.3	63.07	66.8
1992	61.12	55.51	56.48	53.64	49.27	48.13	48.7	45.89	47.11	52.88	57.49	64	53.35
1993	58.14	57.32	54.76	51.38	54.18	54.54	60.61	67.69	71.64	67.78	70.03	71.5	61.63
1994	69.17	72.37	76.11	81.19	108.42	127.91	191.44	181.53	202.39	185.64	168.12	149.14	134.45
1995	152.08	152.24	162.73	159.59	155.96	141.66	132.71	141.7	124.76	120.02	117.99	99.57	138.42
1996	100.33	110.5	105.89	107.09	110.24	105.79	99.97	102.73	96.52	98.56	97.14	90.04	102.07
1997	100.03	121.89	137.47	142.2	180.44	155.38	135.04	132.63	132.51	121.09	118.16	130.02	133.91
1998	130.61	130.78	119.93	119.66	114.23	103.84	97.32	101.25	95.82	95.01	98.26	100.73	108.95
1999	97.62	92.36	89.4	85.71	89.51	86.4	78.2	77.22	71.94	76.36	88.22	95.62	85.71
2000	82.14	76.15	73.49	69.53	69.23	64.56	64.08	57.58	57.3	56.39	52.17	48.27	64.24
2001	49.19	49.38	48.51	47.31	49.38	46.53	43.07	42.76	41.17	42.21	44.24	43.35	45.59
2002	43.46	44.3	49.49	50.2	47.3	45.56	44.7	42.79	47.96	50.79	54.68	51.69	47.74
2003	54.04	54.07	49.61	51.87	53.19	48.9	50.89	52.22	54.1	51.72	49.8	52.44	51.9
2004	58.68	59.87	60.8	58.8	59.91	64.28	58.46	56.98	61.47	61.1	67.74	77.72	62.15
2005	79.35	89.4	101.44	98.2	99.78	96.29	88.48	85.31	78.79	82.55	85.93	86.85	89.36
2006	101.2	97.39	92.76	94.2	90	86.04	88.57	95.78	95.98	95.53	103.48	108.01	95.75
2007	105.81	104.18	100.09	99.3	100.09	107.03	106.2	107.98	113.2	115.71	114.43	118.16	107.68

Source: International Coffee Organization (ICO)

Appendix 2: Meteorological data recorded at Nopa station

Appendix 2.1: Monthly rainfall data in mm

YEAR	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1979	20.8	0	45.6	128.2	358.1	363.7	302.2	211.9	145	152.3	3.2	0
1980	7.5	24.8	82.2	167.4	244.7	244.6	160.5	239.2	153.9	68.1	73.3	0
1981	5.1	11.5	134.1	46.3	169.7	190.5	364.9	576.2	613.1	113.2	87.8	10
1982	181.1	136.7	367	440.1	702.2	523.4	436.8	244.9	248.1	58.4	0	0
1983	0	5.3	94	18.7	135.7	250.2	233	238.7	175.3	78.7	23.6	1.3
1984	3.5	0	80	32.1	177.8	263.2	290.4	282.1	188.7	9.9	51.1	3.6
1986	0	20.2	134.7	46.1	305.6	706.2	879.3	317.5	748.5	237.1	50.2	0
1987	3.5	4.6	28.4	181.6	422.1	374.6	559.6	409.1	247.7	250.9	22.6	12.6
1989	0	12	127.4	63.9	185	212.3	229.1	377.5	245.1	87.3	49	117.4
1990	12.5	16.6	20	50.2	141.1	247.6	313.8	357.4	296.8	101.7	15.2	0.3
1991	21.3	4.6	75.7	189.2	351.8	228	247.7	353.7	219.7	153.8	38.5	8.8
1994	25.4	0	1.8	66	306.5	199.5	228.4	160.2	255.9	29.8	19.2	5.8
1995	0	3.9	64.2	169.4	155.4	156.6	140.5	321.3	238.8	63.4	37.8	21.2
1996	88.5	13.4	66.4	136.4	465.9	313.9	457.9	168.8	243.7	107.4	10.8	30.5
1997		9.2	44.8	175.2	157.4	285.5	220.8	342.2	131.5	342.6	114.8	25.8
2002	33.6	0	50.7	61.4	181.4	211.1	408.2	223	85	189.4	0	24.8
2003	0	53.5	38.1	32.8	27.6	233.5	281.6	288.5	209.2	29.1	38.8	10.2
2004	4.7	17	109.2	171.6	224.9	232.6	227.7	141.1	174.7	87.4	93.3	12.2

Source: Ethiopian Meteorological Agency

Appendix 2.2: Monthly maximum temperature in ^{0}c

YEAR	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1981	28.3	26.3	31.8	23.6	20.6	25.3	21.2	17.1	19.6	18.3	16.4	15.7
1982	20.1	17.9	16.4	24	25.8	20.6	18.8	17.7	18	16.8	16.6	18
1984	28.2	27.9	28	29.2	27.7	26.9	26.1	25.4	26.9	27.4	28.2	28
1986	29.4	29	28.8	28.8	29.5	27.6	26.1	26.7	27.1	26.9	27.1	26.8
1987	27	26.7	26.9	26.7	25.9	26	25.5	25.8	26.6	26.5	26.5	28
1989	29.1	30.4	30	28.8	27.4	25.8	25.1	25.1	26	27.8	28	27
1990	28.9	29.2	31.1	31.6	29.4	26.5	25.4	25	25.9	27.8	28.6	30
1991	30.4	32.6	31.6	29	27.7	26.8	24.5	25	27.1	27.9	28.5	29.4
1993	29.6	30.5	31.7	28.9	28.1	26.6	25.2	25.7	26.2	27.8	29.1	29.7
1994	30.7	32.6	33.8	31.3	27.3	26.5	25.6	25.7	26.4	28.9	28.4	30.2
1996	30.8	32.2	31.5	32.3	29.5	26.6	26.9	24.6	26.3	29.1	30.2	30.3
1997	30.2	32	32.7	30.6	27.1	26.7	24.6	22.9	26.7	28.5	27.8	29.6
1998	30.1	32.3	32	33.5	28.1	25.3	24.3	23	26.2	26.8	28.9	30
2000	30.7	33.5		28.5	26.8	25.3	24	23.5	25.2	26	27.6	29.2
2002	28.9	33.9	31.3	30.8	28.5	24.3	25.3	24.6	25	25.4	30.4	31.3
2003	32.8	32.3	32.3	32.5	33.1	24.9	23.3	22.7	25.5	28.1	29.2	30
2004	30.8	32	29.4	29.2	28.9	25.5	24.2	23.6	25.2	27.1	29.3	30.4

Source: Ethiopian Meteorological Agency

Appendix 2.3: Monthly minimum temperature in ^{0}c

YEAR	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1981	17.7	18.9	19.4	16.5	14.7	14.7	11.2	11.5	11.6	12.2	11.7	12.5
1982	13.3	11.5	12.5	18.2	18.7	14.3	13.7	14	12.1	11.8	11.5	12.5
1983	11.4	9.8	11.8	12.5	12.1	12.1	12.8	14.2	14	13.7	13.9	13.5
1984	14.4	14.7	14.7	14.7	14.6	14.3	14.4	14.4	14	13.8	14.3	14.1
1986	15.4	15.9	14.5	15.9	15.9	14	13.2	13	13	12.6	12.9	12.7
1987	12.8	13.2	13.6	13.5	13.1	13	12.9	12.9	12.8	12.8	11.9	9.8
1989	11.9	12.6	12.9	13	12	11.2	10.7	10.6	10.3	10.5	10.7	10.5
1990	10.7	11.3	11.8	12.6	12.1	10.9	10.5	10.4	10.4	10.4	11	15
1991	14.6	15.5	15.8	15.5	15.1	15.2	14.8	14.1	14.2	14	14.4	14
1993	13.9	14.6	15	15.4	15.3	14.9	14.5	14.4	14.2	14.4	14.8	14.7
1996	12.7	13.2	12.5	14.1	13.2	13.5	12.3	13.4	12.8	11.1	14.1	12.7
1997	13.8	13.9	15.7	14.4	14.2	14.1	14.3	14.8	14.9	15.6	15.4	15
1998	15.1	16.2	16.8	16.9	17.1	16.5	13.3	11.3	11.4	11.4	10.9	10.8
2002	13.3	14.4	15.1	15.3	14	12.1	13.7	13.4	12.5	13.1	14.1	13.9
2003	14.5	13.2	14.5	15.8	17	14.2	12	14	12.4	13.8	14.4	14.4
2004	14.3	13.8	14.8	14.8	14.7	11.4	11.2	11.5	10.7	11.1	11.2	10.7

Source: Ethiopian Meteorological Agency

Appendix 3: Checklists of issues for discussion with farmers and officers

I-Checklist of issues discussed with farmers regarding forest cover change

1. What are your livelihood support means
2. What are your cash income sources
3. Do you have domestic Animals?
4. Where do you take your animals usually for grazing? In the forest? Why?
5. Where do you collect firewood for your household use? In the forest? Why?
6. From where do you collect construction wood for your household use? In the forest? Why?
7. What factors do you think contribute for loss of forest from your area?
8. Is there any other group that uses forest land in your village other than people in your Village? And for what purpose?
9. Which rights do you have regarding trees in your coffee land?
10. Which responsibilities do you have regarding trees in your coffee land?
11. Why do you remove tree from coffee land?
12. Which wild tree species are good for coffee shade?
13. Which tree species are not wanted for coffee management?
14. When did restriction and protection of the forest started?
15. Was there time in the past when people were freely accessing, settling or utilizing the forest resources?
16. Is there any indication of settlement in the forest? Can we take the picture?
17. Why the settlers did left the forest?
18. For what purpose did people use the forest in the past?
19. How do you compare restrictions during the Emperor, military and now?
20. Was there the practice of shifting cultivation in the past where the forest area is made use?

II-Checklist of issues to extract information needed to fine tune the biosphere reserve zoning (For both farmers and officers)

1. Criteria used in zoning;
    - The core zone:
        - Should represent undisturbed coffee forest
        - Should not be under private use right
        - Should have significant wild coffee population
        - Should not be prone to human disturbance
        - Should be surrounded with forest buffer, either managed or not
        - What else should be added? Are there any culturally important sites? If so what shall be done with that?

    Purpose: Helps to avoid/include other important criteria if any.

2. Which parts of the core are most claimed by farmers?

Purpose: Helps to cluster and prioritize areas worthy of field checking and refining.

3. What kinds of use/benefit does the surrounding community expect/deserve to gain from the delineated forest?

   Purpose*: Helps to assess and determine the protocol to be set for the core zone and services that should be developed and promoted in order to minimize human presser on the core zone.*

4. What compensation shall be sought in place of enclosed areas of strategic importance that are claimed by farmers?

   Purpose*: To insure efficient conflict resolution.*

III-Checklist of issues for officials (regarding forest cover change)

1. Status of Forest

- How does the forest cover look like in area since the past 10 to 20 years?
- What are the main factors contributing for forest cover change and how the whole process of change takes place?
- What are the particular practices that caused loss of forest cover in the area?
- What driving forces do you think are behind the forest cover change?
- What solution do you propose to change the situation?

2. Policy Impact

- What general government policies were implemented in the past 30 years in the study area? (What practices are encouraged, what supports provided, what changes can be observed).
- How do you see those policy implementations in relation to forest cover change?
- Any direct government involvement in affroestation/deforestation and its impact?
- -How was the process and progress of coffee production system in the area and its impact on forest?

3 Farming systems

- Is there any farming system difference between the different community groups? Describe each difference systems to impact on forest?
- Any observable evolution (change) of farming system you can see in the area and what drives the change? Its impact on forest?
- How do the local community use the natural forest for their own domestic use? Any market demand that caused over utilization?
- How is the situation of small carpentry and their wood source?
- Is there shift from other economic activity to coffee management and why?
- The situation of cattle production and culture of grazing in the area?
- Any other local practice that affects forest cover?

4. Technology

- How was the development in road network, coffee processing machinery and sawmill in the area and its impact on forest?
- Extension technology components during different period?
- Any positive technological progress that contribute for forest conservation?

5. Cultural change

- Can you observe any social change in different community/ethnic group, and how these changes impose pressure on resource use?
- How the social change happened in relation to forest resource conservation/utilization?
- How do you see the impact of settler and state farm on local culture and farming system of the area?
- Your experience on impact of extension service on farming system and local traditional practice?