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# Remote Sensing & GIS for Land Cover/ Land Use Change Detection and Analysis in the Semi-Natural Ecosystems and Agriculture Landscapes of the Central Ethiopian Rift Valley

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## Declaration

I hereby solemnly declare that the work presented in this dissertation is my own work and that, to the best of my knowledge, it contains no material previously published or written by another person and has not been previously submitted to any other University or educational institute for an academic qualification or any other degree. The work I am submitting does not contravene any copyright.

Bedru Sherefa Muzein

Dresden, Germany
November 2006

**to**

**my wife and best friend**
**Maria Scurrell**

## Table of Contents

# 4. Data Organization and Methodology

# 5. Multi-Temporal and Multi-Scale Land Cover Classification and Biophysical Information Extraction by Means of Low-Cost Remote Sensing



# 6. Livestock Centred Land Use and the Natural Ecosystem

## List of Figures

## List of Tables

## Abbreviations and acronyms

| | |
|---|---|
| APAR | Absorbed Photosynthetically Active Radiation |
| ARTEMIS | The Africa Real Time Environmental Monitoring Information System |
| ASTER | Advanced Spaceborne Thermal Emission and Reflection Radiometer |
| ASLNP | Abijjata Shala Lakes National Park |
| AVHRR | Advanced Very High Resolution Radiometer |
| CASA | Carnegie-Ames-Stanford Approach |
| CBD | Convention on Biological Diversity |
| CCA | Canonical Correspondence Analysis |
| CITES | Convention on International Trade in Endangered Species |
| CMS | Convention on Migratory Species |
| COST | Cosine of Solar Zenith Angle. Correction |
| CSA | Central Statistics Agency |
| DCA | Detrended Correspondence Analysis |
| DEM | Digital Elevation Model |
| DEPHA | Data Exchange Platform for Horn of Africa |
| DN | Digital Numbers |
| DOS | Dark Object Subtraction |
| DOY | Date Of Year |
| EMA | Ethiopian Mapping Agency |
| EROS | Earth Resource Observation |
| ESDI | Earth Science Data Interface |
| ESRI | Environmental Systems Research Institute |
| ETM+ | Enhanced Thematic Mapper plus |
| EWCO | Ethiopian Wildlife Conservation Organisation |
| EWNHS | Ethiopian Wildlife and Natural History Society |
| FAO | Food and Agriculture Organisation |
| FAPAR | Fraction of Absorbed Photosynthetically Active Radiation |
| FDRE | Federal Democratic Republic of Ethiopia |
| FEWS | Famine Early Warning System |
| GCP | Ground Control Points |
| GIEWS | Global Information and Early Warning System |
| GIS | Geographic Information System |
| GLCF | Global Land Cover Facility |
| GPP | Gross Primary Production |
| GROMS | Global Register of Migratory Species |
| Ha | Hectare |
| HS | Habitat Suitability |
| IBA | Important Bird Areas |
| IDWA | Inverse Distance Weighted Average |
| ILRI | International Livestock Research Institute |
| IR | Infrared |
| ISODATA | Iterative Self Organizing Data Analysis Technique |
| IUCN | International Union for the Conservation of Nature and Natural Resources |
| KBC | Knowledge Base Classification |
| Kg | Kilogram |

| | |
|---|---|
| LAI | Leaf Area Index |
| LSR | Least Square Regression |
| LUE | Light Utilisation Efficiency |
| LULC | Land Use Land Cover |
| MFF | Modified Flat Field |
| MIR | Mid Infrared |
| MJ | Mega Joule |
| MLC | Maximum Likelihood Classifier |
| MODIS | Moderate Resolution Imaging Spectroradiometer |
| MSS | Multispectral Scanner |
| NASA | National Aeronautics and Space Administration |
| NDVI | Naturalized Differential Vegetation Index |
| NDVIc | Corrected Naturalized Differential Vegetation Index |
| NIR | Near Infrared |
| NPP | Net Primary Production |
| PAR | Photosynthetically Active Radiation |
| PCA | Principal Component Analysis |
| RSR | Reduced simple Ratio |
| RS | Remote Sensing |
| $R^2$ | Goodness of Fit |
| SAR | Synthetic Aperture Radar |
| SAVI | Soil Adjusted Vegetation Index |
| SD | Standard Deviation |
| SPOT | Satellite Pour l'Observation de la Terre |
| SR | Simple Ratio |
| SRTM | Shuttle Radar Topography Mission |
| SWIR | Short Wave Infrared |
| TCT | Tasseled Cap Transformation |
| TIN | Triangular Irregular Network |
| TLU | Tropical Livestock Unit |
| TM | Thematic Mapper |
| TRFIC | Tropical Rainforest Information Center |
| UNCCD | United Nations Convention to Combat Desertification |
| UNEP | United Nations Environmental Programme |
| UNITAR | United Nations Institute for Training and Research |
| UNOOSA | United Nations Office for Outer Space Affairs |
| UNOPS | United Nations Office for Project Services |
| UNOSAT | United Nations Satellite (image providing service) |
| USGS | United Sates Geological Service |
| VI | Vegetation Index |
| WCMC | World Conservation Monitoring Center |
| WHC | World Heritage Convention |

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## Abstract

Technical complexities and the high cost of satellite images have hindered the adoption of remote sensing technology and tools for nature conservation works in Ethiopia as in many developing countries. The terrestrial and aquatic ecosystems in Abijjata Shala Lakes National Park (ASLNP) and the Important Bird Areas (IBAs) around the park are considered to be one of the most important home ranges for birds. However, little is known about the effect of land use/land cover (LULC) dynamics, due to lack of technical know how and logistical problems. However, it has been shown in this study that sophisticated image management works are not always relevant. Instead a simple method of utilizing the thermal band has been demonstrated. A new approach of long-term dynamics analysis method has also been suggested. A successful classification of images was achieved after such simple enhancement tests. It has been discovered that, there were more active LULC change processes in the area in the first study period (1973 to 1986) than during the second study period (1986-2000). In the first period nearly half of the landscape underwent land cover change processes with more than 26% of the entire landscape experiencing forest or land degradation. In the second period the extent of the change process was limited to only 1/3 of the total area with a smaller amount of degradation processes than before. During the entire study period, agriculture was responsible for the loss of more than 4/5 of the total terrestrial productive ecosystem. More than 37.6% of the total park area has been experiencing this loss for the past 3 decades. Only 1/5 of this area has a chance to revive, the remaining has undergone a permanent degradation. Lake Abijjata lost half of its size during the past 30 years. In the Zeway-Awassa basin 750 $km^2$, 2428$km^2$ and 3575$km^2$ of terrestrial lands and water bodies are within a distance of 10km, 20km and 30km from IBAs respectively. There are ecologically important areas where two or more IBAs overlap. In areas where more than two to five IBAs overlap, up to 85$km^2$ of areas have been recently degraded. High livestock density is one of the reasons for degradation. Using a monthly MODIS data from 2000-2005 and a series of interpolation techniques, the productivity of the area as well as the standing biomass were estimated. Moreover, a new method of spatially accurate livestock density assessment was developed in this study. Only 0.3% of the park area is found to be suitable for productive livestock development but nearly all inhabitants think the area is suitable. Feed availability in ASLNP is scarce even during rainy seasons. Especially the open woodlands are subject to overgrazing. Such shortage forces the inhabitants to cut trees for charcoal making to buy animal feed and non-food consumables. While more than 95% of the inhabitants in the park expanded their agriculture lands, only 13.3% of the farmers managed to produce cereals for market. The application of low cost remote sensing and GIS methods provided ample information that enables to conclude that low productivity and household food insecurity are the main driving forces behind land cover changes that are negatively affecting the natural and semi-natural ecosystems in the central and southern Rift Valley of Ethiopia. The restoration of natural ecosystems or conservation of biodiversity can be achieved only if those driving forces are tackled sustainably.

# Chapter 1

# Introduction

## 1.1 Remote Sensing for Ecosystem Management

The continuing capacity of ecosystems to maintain biological processes in order to provide their multitude of benefits is the corner stone of life on this planet. Yet, for too long in both rich and poor countries, development priorities have focused on how much humanity can take from ecosystems, and too little attention has been paid to the impact of our actions (White et al. 2000). Recent awareness of the importance of identifying, surveying, delineating, monitoring and reporting of globally and locally important ecosystems has been reflected at high-level global environmental keynote meetings such as the Convention on Biological Diversity (CBD), the Convention on International Trade in Endangered Species (CITES), the Convention on Migratory Species (CMS), the Ramsar Convention on Wetlands of International Importance, United Nations Convention to Combat Desertification (UNCCD), The World Heritage Convention (WHC) and others (de Sherbirinin 2005). However, intensive ground surveys cannot keep pace with the rate of land use/land cover changes over large areas and developing and applying new methods is necessary (Osborne et al 2001). Information and data needs on the other hand have been growing in scope and complexity (de Sherbinin 2005). For the past couple of decades the application of remote sensing (RS) not only revolutionised the way data has been collected but also significantly improved the quality and accessibility of important spatial information for natural resources management and conservation. The rapid acceptance of the use of remote sensing for conservation and nature protection coincides with the frequent reporting of wide spread modification of natural systems and destruction of wildlife habitats during the past three to four decades. Concerns about the increase in adverse environmental conditions prompted the remote sensing experts and users to quickly catch up with the evolving technology. The parallel advance in the reliability of Geographic Information System (GIS) has allowed the processing of the large quantity of data generated through remote sensing (Lunetta et al. 1999) . It is now more or less up to the commitment and seriousness of the international and local natural resources and biodiversity management organizations to make sure their institutional systems are ready to fully seize this opportunity, in order to develop the required capability of natural resources mapping and periodical monitoring.

Undoubtedly the remote sensing and GIS technology has enabled ecologists and natural resources managers to acquire timely data and observe periodical changes. Although space borne and airborne generated data are becoming basic tools for the day-to-day activities of natural resources managers, ecologists, conservationists and others, its full potential and reliability are still unused in many of ecosystem conservation programmes. The trend and extent of wild animal species range and habitat within such ecosystems are even less known.

Mapping ecosystems with all their habitats and associated components is hardly possible (Edwards et al 1996). Habitats or ecosystem are dynamic, interrelated and change through time either due to environmental factors (Lamb et al 2001) or anthropogenic pressures (Osborne et al. 2001). In the recent past, acquiring the necessary data to generate information for this purpose had been time consuming and expensive (Hepinstall et al 1997). Consequently, our knowledge of internationally important ecosystems and habitats, which are situated in economically poor countries, is inadequate (Stattersfield 1998). Since the invention of satellite remote sensing techniques and the advent of affordable powerful computing devices, such areas are also getting the deserved international attention with detailed studies as well as mapping. This is a big step forward towards monitoring global biodiversity and towards supporting the efforts of national and regional natural ecosystems conservation.

## 1.2 Alteration of Ecosystems and its Consequences in the Ethiopian Rift Valley

An ecosystem is a biotic community together with its physical environment, considered as an integrated unit. Implied within this definition is the concept of structural and functional units unified through physical, chemical and biological processes. Ecosystems continuously change and such changes are part and parcel of evolutionary processes. For example, historical spore analyses show that natural and semi natural ecosystems in the Rift Valley are on a long trend of vegetation loss since time immemorial (Lamb 2001). The biggest task for contemporary scientists, in this regard, is to distinguish between this natural decline due to environmental changes and the recent man made alterations.

Natural ecosystems are "open" systems in the sense that energy and matter are transferred in and out, keeping the system in balance. However, adverse environmental events or excessive human intervention seriously affects this balance. Consequently undesirable and perpetuating side effects follow that trigger land degradation, desertification, habitat loss, species extinction and so on. According to Temple (1986), habitat loss due to destruction of ecosystems has been responsible for 82% of all population extinctions especially in small spatial scales. At the larger spatial scales, decrease in habitat patches below a critical threshold level may be the foremost reason for extinction (Nee and May 1992). In East Africa habitat loss is the biggest single problem affecting birds (Arinaitwe 1999).

There is not as such an intentional destruction of a functioning ecosystem by small-scale farmers in Ethiopia. However, land use decisions that are made at an individual local level accumulate to a degree in which their impacts are damaging. The additive nature of responses to individual land use behaviour therefore affects the ecological processes on a broader scale. The deliberate intervention of human beings on nature via land use is as old as the age of agriculture itself. The reputation of Ethiopia as one of the earliest crop domestication countries indicates that ecosystem modification has probably been an age-old phenomenon (Tewolde-Berhan 2006). There might not have been a significant intervention to influence the structural and functional integrity of the systems. Recorded anthropogenic interference in ecosystems through land use change in Ethiopia does not date back farther than four or five decades (Hailu 2000, FDRE 1998). Zerihun et al. (1990) tried to construct recent land cover changes through vegetation composition analysis. They described that tree-shrub clusters show a strong relationship with land use and some habitat characteristics, while clusters of herbs are indicators of intensities of anthropogenic pressure in the Rift Valley. Exacerbated land cover changes and wetland alterations in Abijjata-Shala area are even more recent phenomena whose real effect on the avian populations has not yet been adequately addressed. Quantifying the extent and rate of the gradual shift from pastoral to agropastoral land use practices and the recent expansion of the sedentary agriculture system by the local inhabitants may provided important hint pertaining the spatio-temporal LULC change process.

To feed the increasing human population, available common grazing land is continually being converted to agriculture fields. Livestock feed shortages and nutrient deficiencies become more acute in the dry season in both the highlands and lowlands. Studies have indicated that there is a deficit of about 12,300,000 tons of dry matter in Ethiopia. Cultivation of forage is not widely adopted and commercial feed production has not been developed (Alemayehu 2002). So long as parks, wildlife reserves or sanctuaries are in the reach of the local inhabitants, it is imaginable that there will be an attempt to alleviate their feed resource problem by grazing on such 'protected' lands. The ever-increasing agricultural expansion pushes livestock to semi-natural ecosystems especially during rainy seasons. This phenomenon is prevalent in the Zeway-Awassa basin in general and the Abijjata-Shala area in particular.

As far as global migrating flyways are concerned, the Abijjata-Shala Lakes National Park and its surrounding areas are regarded as one of the key 'bottleneck' locations for migration whose global importance is invaluable. However, Lake Abijjata- the main water bird feeding ground- is going through difficult times and it appears that the ecology of the whole lake system is at stake (EWNHS 1996, Fekadu et al. 2002). In the rainy season of 2006 the area of the lake was recorded to be only less than half of its actual size of January 1973. There has been no sign of revival since then. The cause of the decline has its roots in both environmental and man-made effects. The deforestation of the surrounding Acacia forests for charcoal making and agricultural expansion is at an alarming rate (Zinabu 2001). The increase in livestock density as a result of farming system shift from pastoralism to sedentary agriculture has been probably spilling into 'protected' area systems in the Rift Valley in general and the Abijjata-Shala Lakes National Park in particular. The number of cattle in the park reached a level in which the National Park is confused with a cattle ranch (Fekadu et al. 2002). However, it seems there is little attention given to the direct and indirect link of this habitat disturbance to the basic economic reality of the surroundings (FDRE 1997). Generally, disturbances induced by human economic interest pose a resource conflict that has a wide range of implications for species diversity, abundance and the ecosystem as a whole. As most migratory species are habitat generalists, they are known to quickly adapt to changes that are induced naturally (Morse 1971). However, the changes in this area have probably been caused by anthropogenic interference (Hillman 1988, Feoli et al. 2000, Jacobs et al. 2001) to which seasonally visiting species are not evolutionarily well adapted to cope with (Morse 1971). In the case of the Ethiopian Rift Valley, there is barely any specific work on the impact of long term land cover change on the entire ecosystems of the area in general and on winter habitat range of migrating birds in particular.

Ethiopia is endowed with considerable biodiversity and natural resources, as well as many endemic fauna and flora (Stattersfield et al. 1998). It has had, however, insignificant success in protecting some of this globally important natural wealth since the commencement of sectoral land management and conservation program in 1965 (Hillman 1993, Hailu 2000). This may be a direct or indirect outcome of the prolonged engagement of the country in various armed conflicts, political turmoil (Jacobs et al 2001) as well as the resulting poverty and disruption of local peoples harmony with their natural environment. The result has been that during the last four decades, the number of threatened and endangered species (at least locally) increased and adverse ecosystem and habitat modification have become part of the landscape process.

## 1.3 Aim and scope of the study

### 1.3.1 Conceptual Framework of the Study

Naturally, life forms in an ecosystem interact with the surrounding environmental components to keep the system in a sustaining dynamic equilibrium. However, this equilibrium can be disrupted when environmental components drastically change or when external sudden impacts overwhelm the system. In the central and southern Ethiopian Rift Valley, the local inhabitants' interference in the natural and semi-natural system as well as modification of their agricultural practices used to be usually directly related to the management of their livestock. Conversely, the impact of increasing livestock density in partially protected areas is either due to the inability of the land to produce the way it used to or due to disproportional increase of the number of livestock. By applying readily available periodical remote sensing data and making use of the advances in GIS technology, the spatial dynamic of these impacts may be assessed. This hypothesis formulates the general conceptual framework of this study.

Unclear, loosely defined and insufficiently enforced land management rights of national parks and forest conservation areas are some of the bottlenecks hindering proper natural resources management and conservation activities. Frequent conflict and excessive use of resources emanate from such vague ownership arrangements. To this end, this study is guided by the principal question: "when and where did the major land cover changes that significantly affect the existing natural system occur?" A close look to the empirical and statistical relation of the land cover/ land use changes in and around Abijjata-Shala Lakes National Park, Important Bird Areas and Intercontinental and Intra African migratory bird rich sites and to the livestock density and livestock feed status shall reveal the much needed information to answer the above question.

### 1.3.2 General Objective

Guided by the conceptual framework of the study as stated above, an attempt will be made to address the problem of acquiring reliable and timely spatio-temporal information for better management of natural resources be it in National Parks or their surroundings. Therefore, the general objective of the study is:

- Coming up with a strategy and methodology that facilitates generation of continuous, reliable and cost effective spatial information, which can be used for management of environmentally sensitive ecosystems and designated protected areas in the central Rift Valley of Ethiopia in general and in Abijjata-Shala lakes area in particular.

### 1.3.3 Specific objectives

In order to achieve the general objective five sub-objectives are formulated. These are:

- Testing efficient satellite image enhancement methods for land cover classification in minimum external input and low cost conditions.
- Identifying the land cover/land use change and examining the change dynamics at different spatial and temporal scales.
- Assessing the status of Livestock feed demand and supply by means of remote sensing and GIS in a fine temporal scale covering the central and southern Ethiopian Rift Valley .
- Finding out the integrity of terrestrial ecosystems through time and space in Abijjata-Shala Lakes National Park and the Important Bird Areas located in the Zeway-Awassa Basin.
- Identify the underlying and proximate causes of land cover/land use changes, which have been leading to undesirable side effects for nature and biodiversity conservation.

## 1.4 Organisation of the Dissertation

The first chapter highlights the problem statements by introducing the opportunities and constraints of using remote sensing and GIS for nature conservation in general and ecosystem monitoring in general. The main objectives and sub-objectives which facilitate the task of achieving the higher goal are also narrated in this chapter. The second chapter largely concentrates on describing the relevance of RS and GIS for natural resources monitoring with emphasis mainly given to low cost variants. The physical and socio-economical state of the study area is described in words and portrayed graphically in the third chapter. Spatial details ranging from location to the sizes of important features as well as the biological, topographical, hydrological and climatic attributes of the study area are explained in the same chapter. The fourth chapter is devoted to the description of the major methodologies followed for land cover classification and land cover change detection. Series of atmospheric correction, radiometric normalization and topographic normalisation are discussed in context of their applicability for multi temporal image comparison. Modalities of extraction of biophysical information from low cost remote sensing approaches, estimation of available livestock feed and livestock carrying capacity are thoroughly discussed in the fifth chapter. The relationship between the dynamics of land cover and carrying capacity as well as the proximity of affected areas to Abijjata-Shala lakes National Park and the IBAs situated in Zeway-Awassa are analysed and discussed in the sixth chapter. The last chapter tries to converge the major contents and concepts in the previous chapters in such a direction that the basic research question may be answered. To this effect, summaries and conclusions with indications for future research are detailed there.

# Chapter 2

# The Evolution and Revolution of Remote Sensing and GIS for Nature Conservation.

## 2.1 Historical Development of Application of Remote Sensing and GIS in Conservation.

Present day wildlife habitat studies are in a seemingly spinning framework of endless site and time specific tasks because our understanding of the cause, distribution, abundance and performance are not in the state of advanced level that permits sound generalization (van Langevelde 1999, Morrison 2001). While the measure of success differs considerably, research to overcome specific site dependency through modelling of large area changes, based on specific information from similar smaller sites, are bearing promising results (e.g. Aspinall et al. 1993, Herr et al. 1993, Rappole et al. 1994, Hepinstall et al. 1997, Debinski et al. 1999, Osborne et al. 2001, Sevaraid et al. 2001, Lauver et al. 2002). As several unpredictable natural and manmade variables as induced by LULC change play great roles in shaping ecosystem dynamics, the temporal matter is the most important factor though it is still the main hitch in many ecosystem studies (Feoli et al. 2000, Lamb 2001).

### 2.1.1 History of Remote Sensing

Remote sensing is broadly defined as the art and science of obtaining information about an object without being in direct physical contact with the object (Colwell 1983, Lillesand et al. 2004). Trying to detect objects from afar was probably one of the defence and protection strategies of our early ancestors. During the time when there were no reliable weapons to protect from aggressive animals, their early warning system was detecting danger from afar and preparing a quick escape. Histories of early wars between different kingdoms describe in one way or another the importance of collecting information about the enemy from afar. This might not have involved anything more than selecting a strategic high point where observation with the naked eye revealed the desired information. This all indicates that remote sensing is as old as human history itself.

The modern usage of the term 'Remote Sensing' has more to do with the technical ways of collecting airborne and space borne information. Earth observation from airborne platforms has a one hundred and fifty years old history although the majority of the innovation and development has taken place in the past thirty years. The first Earth observation using a balloon in the 1860s is regarded as an important benchmark in the history of remote sensing (Lillesand et al. 2004). Since then platforms have evolved to space stations, sensors have evolved from cameras to sophisticated scanning devices and the user base has grown from specialized cartographers to all rounded disciplines. It was the launch of the first civilian remote sensing satellite in the late July 1972 that paved the way for the modern remote sensing applications in many fields including natural resources management (Tucker et al. 1983, Csaplovics 1992, Campbell 1996, Lillesand et al. 2004).

The multispectral data provided by the on-board sensors led to an improved understanding of crops, forests, soils, urban growth, land degradation and many other earth features and processes. The Landsat images that were made available soon after its launch disclosed the shocking reality of Amazonian deforestation. The so-called 'fish-bone' pattern that was detected by remote sensors revealed the role of new roads in facilitating deforestation. All navigable waters in the Amazon that might have been used for illegal log transportation were also detected (Peres et al. 1995). This event not only triggered the alarm of global deforestation but also opened the door for wide acceptance of remote sensing for natural resources conservation.

The 80's saw a sharp increase in the application of remote sensing for natural resources management (Tucker 1980, Guyot 1990). The increasing availability of powerful desktop computers and the advances in object oriented GIS have allowed many sectors to explore the use of remotely sensed products. Precision agriculture, health care, disaster early warning systems and a wide variety of other fields have quickly adapted the opportunity that remote sensing has brought about. Since the early 1990s, there has been a logarithmic increase in the use of remotely sensed information for land management, coastal ecology, biodiversity research, wildlife ecology, greenhouse effect monitoring and similar tasks. Applied geospatial researches that link the natural resource disciplines with the remote sensing field started to take off (e.g. Csaplovics 1992). From 1980 to 1990 alone the use of remote sensing data for tropical deforestation monitoring grew almost seven fold (Rudel et al. 2000). The increase in these applications has also provided opportunities for feedback for the improvement of radiometric sensitivity, spatial, temporal and spectral resolutions. New generation of platforms and scanning systems like RADAR, LIDAR and SONAR systems are now emerging. While optical remote sensing provides digital images of the amount of electromagnetic energy reflected or emitted from the surface of Earth at various wavelengths, active remote sensing of long-wavelengths microwaves (RADAR), short-wavelength laser light (LIDAR), or sound waves (SONAR) measures the amount of backscatter from electromagnetic energy emitted from the sensor itself (Bergen et al. 1999).

The contemporary trends, in addition to the applications mentioned earlier, are the 'real time' or 'near real time' data reception through remote sensing. Data or information captured onboard satellites is becoming increasingly available via the Internet in a real time or near real time fashion. Weather data from the European geostationary platform Meteostat or polar orbiting MODIS Aqua or satellite telemetry animal tracking data can now be directly received just few seconds or minutes after the event has happened. Today the application of remote sensing has transcended into tracking animals throughout their seasonal migration since 1992. The need for remote sensing in animal tracking has come up due to low rate of ring recovery (Meyburg et al. 2000). This telemetry information is providing the vital flyways that need critical scrutiny and immediate interventions. The sensation created by the female stork '*Prinzessin'* during her flight to and from Africa (van den Bossche 2002) and the subsequently raised public awareness, spotted eagle and other raptors journey to and from Africa (Meyburg et al. 2000), water bird monitoring (Izhaki et al 2002) are few of the many examples. This application is, though, still concentrated in the hands of a few institutions rich in technological resource.

### 2.1.2 History of GIS

Although its antecedents go back hundreds of years in the fields of cartography and mapping, structured GIS as such started to emerge in the 1960s (Goodchild 1992). Portraying different layers of data on a series of base maps, and relating information geographically has been a practice long before computerized GIS. The technique of superimposing several cartographic maps on one another has been painstakingly used even during the mid 19th century (Foresman 1998).

The blending of computer technology and cartography in the 1960s paved the way for the possibility of using the technique of overlaying and superimposing maps in fields other than cartography. The powerful multiplication which results from the integration of climate, terrain, environmental, agronomic, economic, social and institutional management data, makes available for scientists and managers alike a new and powerful monitoring and modelling tool. However, these early GIS packages were often written for specific applications and required a level of computing power usually found in government or university settings (Foresman, 1998). In the 1970s, private vendors began offering off-the-shelf GIS packages. Intergraph and Environmental Systems Research Institute (ESRI) emerged as the leading vendors of GIS software (Foresman 1998). As computing power increased and hardware prices plummeted in the 1980s, GIS became a viable technology for natural resources managers (Jensen 1996). As Allan (1990) noted the process of adopting GIS was however far from smooth. The *Vector* or *Raste*r map politics along the professional line was the major hurdle. These two groups advocated mutually exclusive procedures that were problem for data integration in the 1970s and 1980s.

> *"The traditional mapping community was certain that the vector system of spatial data management would solve all problems and those that it would not solve were not worth considering. This argument was particularly attractive to the vector group as their approach meant that they need make no change in scope of their mapping activities, since the vector approach was wholly compatible with their conventional system of coordinated geographic control and presentation of detail. They were interested in linear and point data and not at all concerned with providing data on the spaces between lines"* (Allan 1990).

As far as natural resources managers or wildlife ecologists were concerned, vector maps would provide the boundaries of the conservation areas but no data on the structural and physical habitat within the boundary. The strong presence of remotely sensed data in raster format in the 80s forced these GIS developers and vendors to address this part of a market niche too. Specialized groups in raster GIS emerged as a result and the full-fledged competition between raster and vector GIS further pushed the development of GIS into an environment where both systems are supported and function in a way that complement each other. The successful implementation of separate attribute table and location information in the early 80s as well as the successful integration of relational database management systems in small desktop computers to handle attribute tables has given GIS the momentum to reach all sectors of academic, research and development - that includes biodiversity studies, wildlife conservation, land resource management and so on.

The natural resource management and conservation community also played a great role in the development of GIS. Several custom-made products emerged using standard contemporary products. Most of the algorithms for such products function as extensions or plug-ins that have largely been developed within the conservation community. Today the web mapping and multi-user GIS systems are setting the trend of mapping and analysis in the developed world. Real time remote sensing and/or GIS animation is also becoming a common phenomenon (see Riede 2004 for examples of prototypes and details in animation of migratory species movement via web). The emergence and strong acceptance of Open Source products is also making GIS available to many end users. As ssatellite data are generally digital and consequently amenable to computer-based analysis for classifying land cover types, the advance in GIS and its growing availability for the general users is a promising trend for the application of low cost remote sensing in developing countries.

## 2.2 Mapping for Monitoring and Conservation of Natural Ecosystems.

### 2.2.1 The Emergence of Remote Sensing and GIS as a Major Tool for Ecosystems Monitoring.

There are two broad approaches for applying remote sensing to ecosystems monitoring or biodiversity assessments. These are the direct observations of organisms and communities and indirect observations of environmental proxies of biodiversity (Turner et al. 2003). Direct observations apply to monitoring of individual organisms, species assemblages, or ecological communities usually with very high-resolution data. Indirect remote sensing of biodiversity relies on environmental parameters as proxies, such as discrete habitats (e.g. woodland, grassland, or seabed grasses) or primary productivity. This is in other words direct remote sensing of ecosystems.

Making use of satellite remote sensing technology, a wide variety of habitat variables have been assessed for diverse thematic purposes (Herr et al. 1993, Aspinall et al. 1993, Hepinstall et al. 1997, McCloy 1995, Lillesand et al. 2004,) including monitoring of migratory birds (Green et al. 1987, Sader et al. 1991, Rappole et al. 1994).

The potential applicability and suitability of analysing multi-temporal Landsat ETM+ data for wildlife park systems have been shown to be objectively verifiable in Brown de Colstoun et al. (2003) and Poulin et al. (2002). The former study asserts that an overall accuracy of 82% (k=0.80) can be achieved while the latter demonstrates how reliable habitat maps as well as suitability classes can be established. Coops et al. (2002) also provide a promising case of NIR airborne videography for use in detailed habitat studies. Application of fine-banded hyperspectral remotely sensed imagery for habitat studies has also been gaining momentum lately (e.g. Jupiter et al. 2002, Schmidt 2003), as is radar based active remote sensing (Bergen et al. 1999).

Several authors used variables derived from satellite data in forest biodiversity modelling to prepare possible Habitat Suitability (HS) models in ecosystem-scale (Innes et al. 1998, Lauver et al. 2002). Novo et al. (1997) used Landsat TM data to identify and map Amazon habitats into six broad classes, namely clear/mixed water, turbid water, flooded non-forest, flooded forest, human settlements and aquatic vegetation. This classification gave rise to more detailed habitat determination. In many cases, once habitat types are identified from remote sensing or other means, the next step is to relate these habitat types with wildlife distribution information obtained from field survey, local wildlife office archives, published medias and reports. This is often accomplished using species-habitat association models (Debinski et al.1999, Sevaraid et al. 2001, Lauver et al. 2002). However, others like Morrison (2001) argue a habitat, to be fully taken literally, must demonstrate the occurrence of the animal at stake during a stated time using the space. In other words, according to this school of thought, determining habitats merely by the physical appearance of suitable factors for a certain species without actually making sure the presence of the animal is like putting the cart before the horse. In this case the role of RS in predictive habitat determination gets diminished, as the animals are the main focus rather than the land cover and associated characteristics. Contrary to this, Debinski et al. (1999) used Landsat TM data and GIS to categorize habitats and to determine the relationship between habitats and species distribution patterns. A strong correlation between high species richness of plants, birds and butterflies was found. Moreover, 1/3 of animal taxa and the majority of dominant plant species were found to be significantly correlated with one or more remotely sensed derived habitats. In fact, a common approach for the application of RS in habitat studies is to prepare land cover/land use maps using satellite data and to evaluate the known habitat preference and conditions of wildlife species based on field information. Afterwards the physical habitat characteristics and the specific habitat needs of the species in question have to be related (Herr et al. 1993, Osborne et al. 2001, Lauver et al. 2002). There are also attempts made to bypass the mapping phase by utilizing the digital numbers (DN) of pixels in satellite imagery directly as inputs. These are mainly prediction models whose algorithms are based on Bayesian statistics implemented in a GIS (e.g. Aspinall et al. 1993, Hepinstall et al. 1997). In cases of Hepinstall et al. (1997) an attempt has been made to establish a relationship between bird survey data and the spectral values of Landsat TM bands 4 and 5 by using a Bayesian modelling approach. The result was a species presence or absence probability matrix with ostensibly ballpark figures.

The pioneer study specifically dealing with assessing tropical habitats of Nearctic migrants using remote sensing was presented in Rappole et al. (1994). The study managed to come up with an indicating idea on how to identify wood-thrush (*Hylocichla mustelina*) habitat by using remote sensing imagery as well as information on its distribution and habitat use of the migrant.

There are strategically two broad ways to attain the application of Remote Sensing and GIS products and services, which are highly dependent on the resources at the hand of the natural resource manager or similar users.

#### 2.2.1.1 Commercial Remote Sensing and GIS

Commercial GIS and remote sensing refers to those products and services in which users can get access or permission to use only after purchasing the product. The leading GIS and remote sensing product vendors are by and large commercial in nature. The products are usually designed to address a huge market segment to ensure profitability. Such an approach has both advantages and drawbacks for users. A wildlife biologist may be interested in using only a small part of huge commercial GIS software for modelling some species habitat. However, this user may be forced to buy software that has a function of complicated cadastre mapping which is of no interest to the biologist. On the other hand some modelling tasks involve several functions, which are found only in few of the commercial GIS packages.

#### 2.2.1.2 Low-Cost Remote Sensing and Open Source GIS

One of the prohibiting factors for early adoption of modern remote sensing in developing countries has been its heavy reliance on technological sophistication to extract information and the cost of source images. Even though satellite derived remote sensing products are known for their low cost per covered area, one is usually forced to purchase a whole image at full cost even though the area of interest might only represent a small fraction of the image. Access to facilities for processing the images and the necessary know how have been also lacking.

##### a. Low Cost Remote Sensing

The concept and meaning of ‘Low Cost Remote Sensing’ applications differ from place to place. For some users access to imagery and processing facilities at a cost that does not disrupt other activities is ‘Low Cost’ remote sensing and encourages investment. For others a technological set up that restricts receiving only the required area at a lower price can be considered a low cost remote sensing. In this documents context, ‘Low Cost Remote Sensing’ refers to the former definition throughout this research.

In 2001 the US Government, through NASA and USGS, formally announced it would provide a significant amount of archived historical and recent global Landsat data sets to the United Nations for further distribution and use by the international community. These geo-registered data sets of more than 23,000 images, with coverage of the entire earth surface, constitute an important and valuable source of baseline information to document and quantify the present state-of-the-earth and changes to the environment since the early 1970s (USGS/UNEP/UNOOSA 2004).

There are several online and 'on request' data suppliers that provide access to these imageries and other remote sensing products and services at low cost. Some of the selected ones are:

**1.** ***The Earth Science Data Interface (ESDI) at the Global Land Cover Facility.***

This source provides archived data free of charge for downloading or very low handling and shipping costs globally. The database contains orthorectified Landsat images, composite MODIS images, and many other derived products like vegetation cover and NDVI. It is funded by NASA and hosted at the University of Maryland in the USA. It is frequently updated (http://glcf.umiacs.umd.edu/index.shtml, last accessed July 18 2006).

***2. Tropical Rain Forest Information Center (TRFIC).***

TRFIC is a NASA Earth Science Mission Partner hosted at the Michigan State University. The mission of the centre is to provide NASA data, products and information services to the science, resource management, policy and education communities. It provides Landsat and other high-resolution satellite remote sensing data as well as digital deforestation maps and databases to a range of users through web-based Geographic Information Systems.

In support of the NASA Earth Science mission, the centre provides low cost access to the largest archive of Landsat data outside the United States federal government, low cost access to SAR data, derived products in digital formats which depict the spatial extent and rate of deforestation, data broker services for ordering Landsat and other data (http://www.trfic.msu.edu/home.html, last accessed July 18 2006).

***3. DEPHA (Data Exchange Platform for Horn of Africa) supported by the UN***

The data exchange platform focuses on the most basic types of information products (like maps, databases, and technical documents) that are useful to humanitarian and development communities as a whole for the Horn of Africa region. In addition to developing these products, the platform will provide low-cost data and information management services (http://www.depha.org last visited July 18 2006). Even though the platform plans to create a virtual map/imagery warehouse, its present online service is in its infancy as far as satellite imagery is concerned.

**4. *FEWS (Famine Early Warning Systems).***

In several African, Meso-American and Asian countries FEWS has centres or representing nodes where data can be requested. It may be possible to obtain some higher spatial resolution LANDSAT images for countries or localities in question through these institutions. If the images requested are available, they can often be obtained for the cost of reproduction from the Earth Resources Observation (EROS) data centre. In case of absence of regular online access FEWS may be a good local node to receive data from the first two data sources.

**5. *ARTEMIS (The Africa Real Time Environmental Monitoring Information System).***

FAO set the ARTEMIS as a support to its applied satellite remote sensing that is trying to enhance capabilities in the surveillance and forecasting of its Global Information and Early Warning System (GIEWS). Since 1988, the ARTEMIS system has been delivering low resolution, 10-day composite NDVI products as well as other weather and climate data. It also archived ten-day and monthly composites NDVI maps for over ten years developed jointly by NASA and the FAO Remote Sensing Centre.

**6. *Earth Observing System Data Gateway***

Land, water and atmosphere data products from NASA and affiliated centres can be queried from the Earth Observing System Data Gateway (EOS) (http://edcimswww.cr.usgs.gov/pub/imswelcome/). There are very useful high quality satellite products available free of charge or with affordable handling costs. Famous satellite products including AVHRR, MODIS and ASTER can also be obtained.

**7. *UNOSAT***

UNOSAT is a United Nations programme created to provide the international community and developing countries with enhanced access to satellite imagery and Geographic Information System (GIS) services. UNOSAT is the United Nations Institute for Training and Research's (UNITAR) Operational Satellite Applications Programme implemented in co-operation with the UN Office for Project Services (UNOPS). In addition, partners from public and private organizations constitute the UNOSAT consortium.

The goal of UNOSAT is to make satellite imagery and geographic information easily accessible to the humanitarian community and to experts worldwide working to reduce disasters and plan sustainable development. (http://unosat.web.cern.ch/unosat/)

**8.** ***SPOT Vegetation***

Under certain conditions the SPOT Vegetation programme supplies 1 km ground resolution SPOT 5 products for users. Standard 10-day synthesis products older than three months are normally available free of charge for the public (http://free.vgt.vito.be/). However, primary and recent products are commercial except for approved scientist who can receive them, after paying only the processing and shipping costs.

**b. Open Source GIS and low cost GIS systems.**

Even if satellite data is available, it needs to be converted into usable information. Few systems allow the direct utilization of satellite products for practical use. As described elsewhere in this document GIS represents the means to get at this information. Access to commercial GIS software and license is usually expensive for most natural resources management offices in developing countries. Thanks to dedicated spatial analysts and programmers, this generation is seeing numerous Open Source GIS software for a variety of monitoring and conservation tasks. Open Source GIS is nothing but a GIS that uses software whose source code is publicly licensed (available for all). In publicly licensed software the use, distribution and modification of the source code is unlimited. This gives not only the opportunity to get the software free of charge but also provides the freedom to modify the source code for specific tasks to better suit the project of the user. The quest for this freedom is one of the deriving motives for the birth of Open Source systems. Commercial software tends to result in comparatively expensive 'one size fits all' solutions that may not work well for specific end users.

Another low cost GIS application strategy is the effective utilization of shared extensions to commercial and Open Source GIS software and models. GIS users in the natural resource community not only develop a series of extensions, plug-ins and models, they also effectively share custom written software thereby avoiding the duplication of effort and cost to accomplish the same task.  Even commercial developers encourage users to get involved in such development and sharing activities, as they clearly know the system they sold does not do every thing. A typical example is the script and extension-sharing portal hosted by the largest GIS vendor – the ESRI. Users can find hundreds or thousands of ready-made extensions and script for direct use concerning biodiversity, wildlife movement and environmental modelling.

### 2.2.2 Mapping Habitat Ranges in GIS

Migratory species exhibit geographical and temporal variation in their use of resources. They tend to be generalist/opportunist in their wintering habitats and specialized/site specific in their breeding grounds. Rappole et al. (1994) conclude that general declines in Neotropical migrants have resulted from habitat alterations on the wintering grounds. Thus mapping their wintering ground cannot be easily ruled out because of its difficulty; rather it is an important measure. Proper conservation strategies always entail localizing the problem and its level. Riede (2001 and 2004) describe the importance, technical requirement and other details pertaining habitat range mapping for migratory species. Sources and often-used methods of digital map preparation generally fall in one of the following – digitisation, deductive or inductive modelling methods.

#### 2.2.2.1 Digitising and Geo-referencing Existing Traditional Maps

This is probably the most basic and easiest way of procuring digital maps for habitat range determination. The major inputs are readily available paper maps. Nevertheless it requires little or no knowledge of the geographic distribution of the species in question. Automatic, semi-automatic or completely manual data capture procedures can be used to this effect. The outcome is exclusively vector map as the boundaries are of interest during digitisation. Thus, scanning and screen digitising or digitising the paper maps directly from digitised tables results in the desired output if the number of polygons is manageable (i.e. not very numerous in number) or the complication level is relatively low. Experienced users locate lines on the paper map and directly transfer the lines into GIS interfaces with some positional help from the nearby geographic features in both medias. This is a very fast but error prone method. The scanned maps could also be used for automatic or semi-automatic line-tracing procedures. With little supervision, programs that can handle raster maps may be trained to trace the raster lines (series of pixels) and convert them into vector lines or eventually polygons.

The GROMS successfully applied the first method to digitise more than 1200 migratory species maps for the first time (Riede 2004). In the absence of even basic information, this effort has brought about new opportunities to investigate the global distribution and many more spatial facets pertaining migratory species.

#### 2.2.2.2 Prediction/ Modelling Habitat Ranges.

Species' presumed resource requirements or environmental preferences could be used for deductive mapping of the animals' geographic distribution (Peterson et al. 1999). Remote sensing products like the NDVI maps may be used as surrogate for the environmental preference of a species. Rappole (1994) for example used Landsat TM visible and infrared spectral information to determine the wintering ground of some northern American migratory birds in their southern wintering ground. Osborne et al. (2001) mapped the home range of Buzzard through logistic regression of AVHRR NDVI and 8 other socio economic and topographic layers. Lauver et al. (2002) calculated suitability index for a grassland bird species based on the amount of potential and usable foraging habitat and predicted an independent set of observations with 82% accuracy.

#### 2.2.2.3 Extrapolating Sample Surveys or Telemetry Data.

One of the most accurate methods of species geographic distribution representation is mapping the exact areas where the species is occupying. This can be done either through aerial survey, ground survey, radio telemetry or satellite tracking (de Leeuw et al. 2002). However, it is impractical to cover all points in a spatially continuous way. Therefore, extrapolating some observed points into a spatially complete raster map is both cost effective and fairly accurate. The general assumption is if a species is spotted several times in a certain location with certain biophysical attributes, then it will be highly probable that it occurs in areas that fulfil exactly the same attributes. The idea is similar to the other described in section 2.2.2.2 except the attributes may not necessarily be the resource the species in question needs for its survival. As ecological systems are dynamic the removal or addition of some elements that may not be directly related to the species can seriously affect the distribution of these species. Therefore, instead of focussing on the resources, this method tries to accommodate as many environment variables as possible. Ecological inferences from multivariate analysis are usually applied intensively. Sevaraid et al. (2001) and Coops et al. (2002) surveyed some area and extrapolated the survey resulted to the entire research area based on landscape variables and forest inventory parameters.

### 2.2.3 Distribution of Migratory Species Rich Localities and their Conservation Status.

After reviewing the available resources for mapping the distribution of migratory species, an attempt was made to calculate the density of migratory birds in different scales. The methods described in 2.2.2.2 and 2.2.2.3 may not be easily adapted to a global scale, or even to a regional level accurately. To this end, available digitised maps in vector format from GROMS (Riede 2004) and other hard copy maps have been employed. Since mapping density with irregular features leads to outcomes where larger polygons usually appear to have high density, the use of equal area cells is important. Despite their artificial look, hexagonal cells have been found to have simple geometric properties that very well permit a degree of realism and flexibility with reduced corner effect. Corners in a rectangle are far from the center yet they have the same attribute like the center. This problem is reduced in hexagonal cells.

#### 2.2.3.1 Global Scale

So far, Riede (2004) is the only published material that shows the distribution of migratory species globally. Diversity maps are given either by country or broad eco-regions. Extending this initiative and using the same input data, global distribution of migratory birds within equal area cells is given below. This approach allows distinguishing the variability within the countries as well as eco-regions. The cell size in this scale is 7860 km².

Many migrating birds often avoid large desert areas and dense tropical forests as most of the birds are adapted to habitats near to water bodies. Hence coastal areas are rich in migratory species.

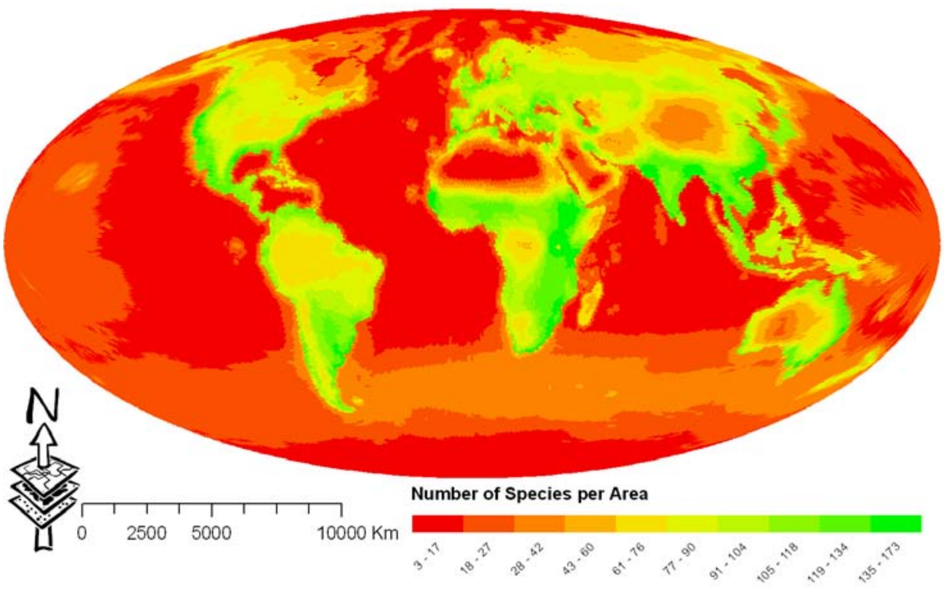


**Fig. 2.1 Global migratory species richness (Source: author)**

#### 2.2.3.2 Continental Scale

The same data source as used in 2.2.3.2 was utilised again. However, the overlaying hexagon cell size has been reduced significantly so that variability within the bigger cell size may be further categorized. To this effect, a 10km base hexagon cell layer was created and each cell was populated by the number of overlapping species map.

In African cases, the destination areas of both inter and intra continental migration are rich in species diversity, if not abundance.

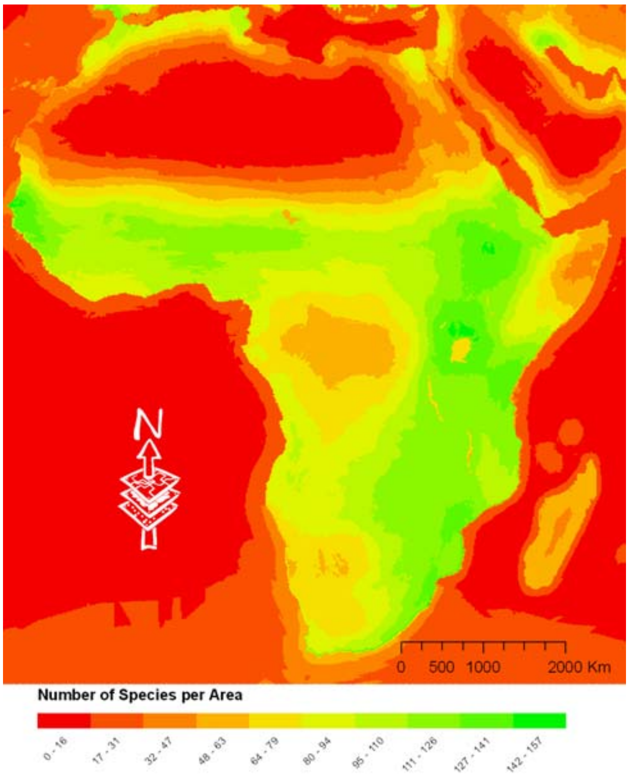


**Fig. 2.2 Migratory species richness in Africa Source: (author)**

### 2.2.3.3 Local Scale

More than 750 individual birds maps from the only source available so far (van Perlo 1995) have been converted into geocoded digital maps. Density is calculated here as the number of species per a hexagonal cell that has 2 km base width. In local scale too, many species avoid extremely dry areas with less access to open waters. The Rift Valley lake regions are the preferred destination to most of the migrating birds.

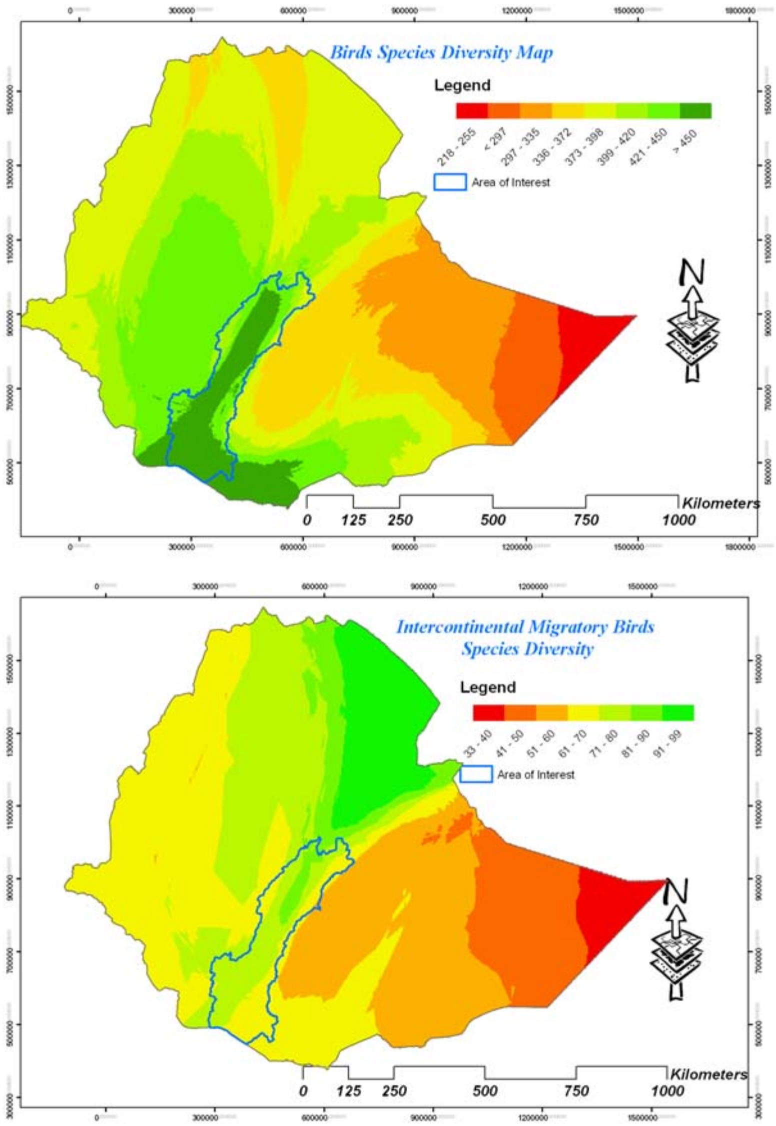


**Fig. 2.3 species richness of Ethiopia a) bird species diversity B) Migratory birds species diversity . Source: (author)**

## 2.3 Conservation Status of Migratory Species Rich Ecosystems.

There are 98 member countries, mostly African and European states, that ratified the Convention for Migratory Species (CMS) or alternatively known as the Bonn Convention. Article III of the convention's document among others requires parties that are Range States of a migratory species to conserve as well as restore habitats that are important for their well being (UNEP/CMS 2004). Nonetheless, there is no enforcing mechanism in place. Like many other global conventions, this one is also more of a far-fetched eco-political agreement than an operational conservation mechanism. There is an acute information deficiency concerning the distribution and habitat range of migratory species. The existence of

GROMS has been largely triggered by this lack of information. Sadly, the structure of conventions Secretariat does not cope with the trivial technical and conceptual requirements of the comprehensive tabular and spatial database assembled by GROMS. In light of this, it is impossible to assume that the cause of CMS - winning countries as member states - leads to any tangible conservation on the ground.

One of the potentially credible systems, which were believed to ensure some sort of conservation, is the national and international protected area network in the form of parks, reserves, sanctuaries and others. According to the digital map of protected areas network (UNEP/WCMC 2006) there are around 20000 protected areas in an IUCN categories I-VI[1] covering a total of 12.5 million km², that is 12% of the total terrestrial earth surface. Irrelevant to their IUCN protected areas category, they vary greatly in protection status, effectiveness and strength of enforcement (Bruner et al. 2001, Chape et al. 2003).

A quick GIS overlay analyses further reveal that there are 4697 protected areas that are home to 100 or more migratory bird species per area[2]. Around 3.26 million km² of the earth surface, that is covered in one of the six IUCN protection categories, are found to have a diversity of 100 or more. While 1% of this area is scattered in 30 different countries, more than 40% is located in only five countries; Australia, Venezuela, USA, Zambia and Ethiopia. Australia is the only CMS member country from the latter group.

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[1] These categories indicate degree of conservation status. Details are given in *The World Conservation Union, Guidelines for Protected Area categories Management. 1994*

[2] Size of the cell is 7860 KM²

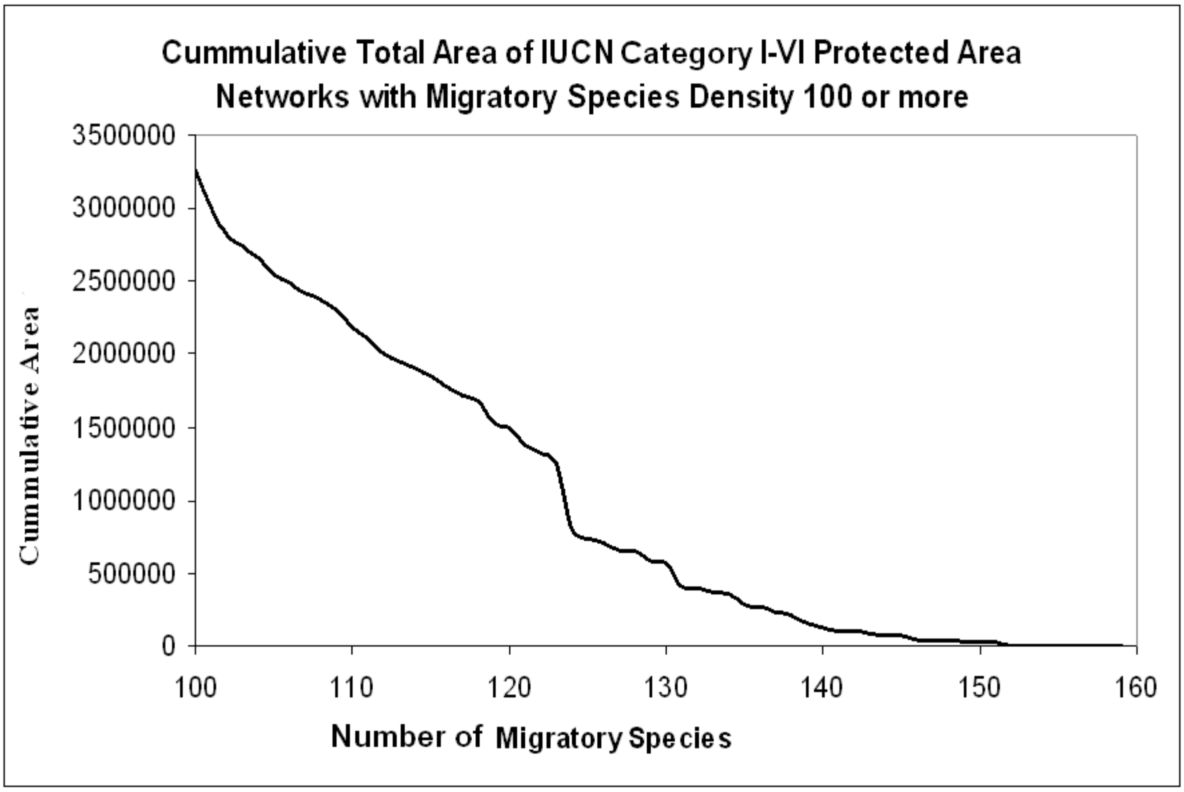



**Fig. 2.4 Total size (Km²) of IUCN Category I-IV protected area networks with significant species richness.**

Only 34000 km² of the whole area that has 150 or more migratory bird species per area is under the protected area network. As far as the current state of protected areas knowledge is concerned, how much of this small area is under effective protection activities remains a puzzle.

# Chapter 3

# Social and physical attributes of the study area

## 3.1 Location of the Study Area and Its Extent

The Great Rift Valley is probably one of the world's greatest geological features. It runs from North Jordan in SW Asia through Ethiopia and other countries to Mozambique in the Southern Africa. In Africa alone it covers more than 5,600 km from the Red Sea to its southern end, practically the length of Africa. Owing to its structural features the Rift Valley in Ethiopia is divided into three geographic zones. These are: a) the Northern Rift System ranging from Fentale to Nazareth (Adama), b) the Central Rift System from Nazareth (Adama) to Awassa and c) the Southern Rift System from Awassa to Chewbahir.

The study areas cover the latter two in varying degree of detail and emphasis. Three levels have been set to facilitate investigating the larger area of interest in low scale, the Zeway-Awassa basin in medium detail and the cores study area - the Abijjata-Shala Lakes National Park as well as its immediate environs - in operational detail and large scale. The core study site is located in the Central Rift Valley, some 200 km south of the capital city Addis Ababa. Its centre is located at 38°30'E and 7°30'N. Circumscribing the core study site is the Zeway-Awassa basin whose biophysical characteristics are of interest in medium scale. The larger area of low interest extends from the northern tip of the Central Rift Valley to the southern end of the Ethiopian Rift System covering the Zeway-Awassa basin.

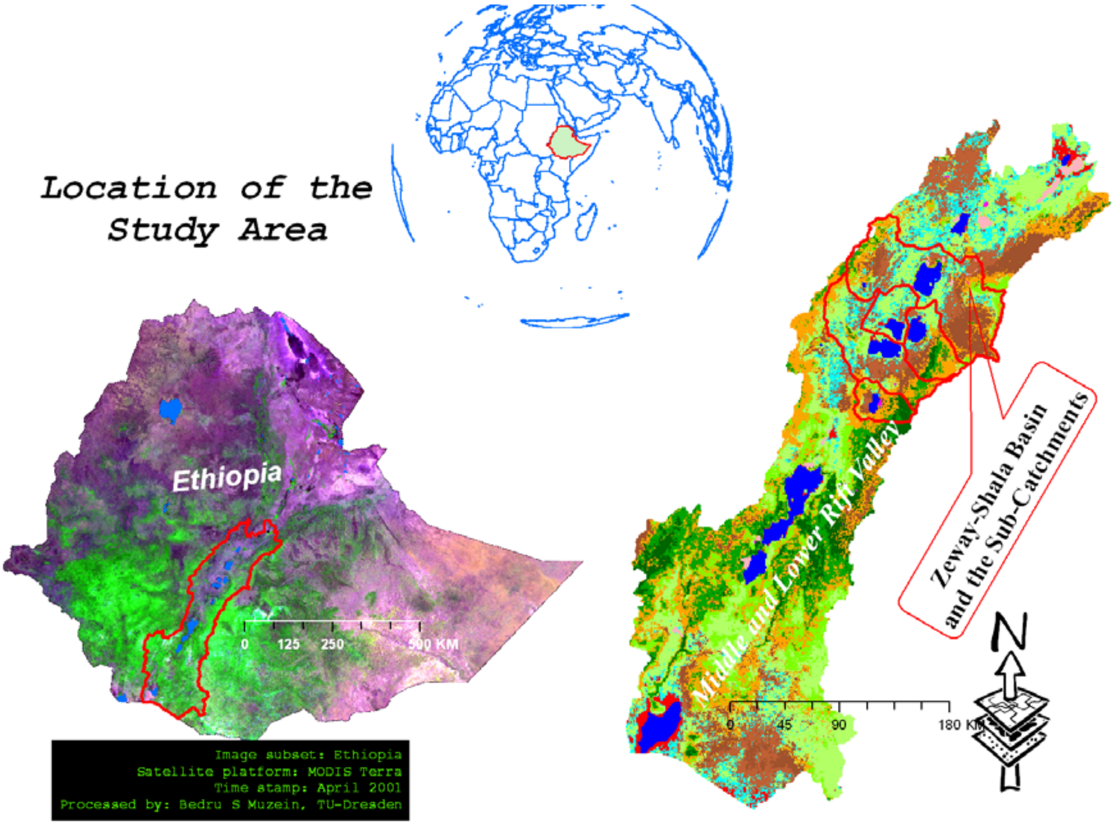



**Fig. 3.1 Location of the Study Area. The country image is prepared from April 2001 MODIS data.**

## 3.2 Physical Attributes

### 3.2.1 Climate

The Ethiopian Rift valley is characterized by its semi-arid climate with a long summer season (late June - mid September) bringing heavy rains from the Indian and Atlantic Oceans, a dry season (October – February) and a small rainy season (March - May) bringing moisture from the Indian Ocean and Red Sea (Ayenew 2004). On the other hand Strahler 1969 (cf. Billi 1998) states that the regions in and around the Zeway-Awassa basin can be classified as tropical wet-dry since it is characterized by a wet season controlled by moist, warm equatorial and maritime tropical air masses at times of high sun and by a dry season controlled by the continental tropical air masses at times of low sun. Long-term monthly climate data for the whole country was obtained from FAO climate database (FAO 2001) and a copy of long term daily precipitation data from all metrological stations of the Ethiopian Meteorology Service was obtained from the GIS-unit of ILRI. Summarizing the databases reveals that rainfall is distributed in three main periods: the short rainy season during March to May (*Belg*), the main rainy season that extends from June to September (*Kiremt*) and the dry spell from October to March (*Bega*). In fact, there is profound local variability owing to their land physiography. In the areas where the elevation is higher (usually > 2000m.a.s.l), the climate is more humid and characterized by low temperatures, allowing the occurrence of denser vegetation and grasslands even during dry periods. Climbing down to the rift floor the precipitation decreases and the temperature rises considerably. Typical lowland species that are adapted to moisture deficit like *Acacia, Balinites* and thorny bushes start to appear. The yearly balance of precipitation around the Abijjata-Shalla National Park and the Vicinities of Lake Langano is that of a delicate one. With yearly average mean rainfall of 650mm and an annual average temperature of 27 °C (determined through the interpolation of metrological data explained elsewhere in this study), potential evaporation around 2000mm/year and potential evapotranspiration of about 900mm/year (Billi 1998), the incoming precipitation as a form of river and stream flow from the nearby higher areas is always important. January to March are usually the hottest months.

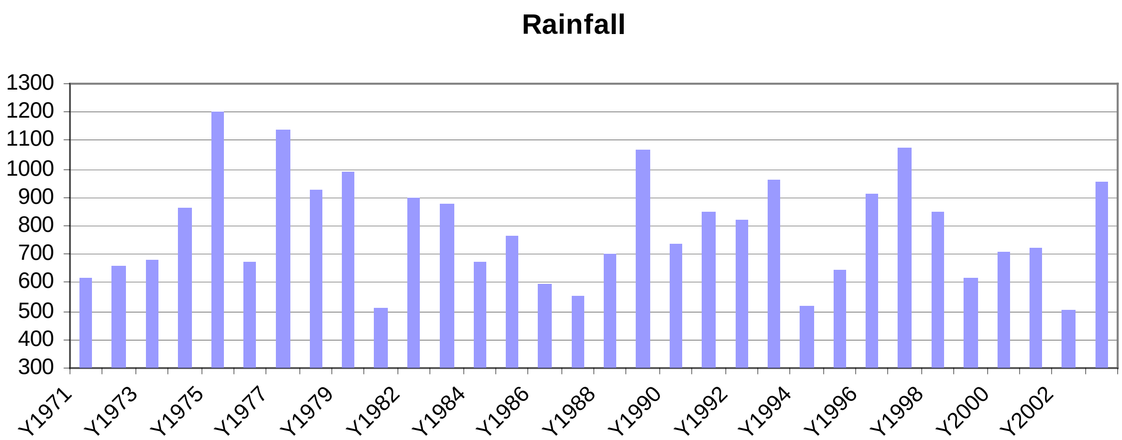



**Fig 3.2 Rainfall pattern at Zeway station. source: (FAO2001)**

### 3.2.2 Hydrology

The Ethiopian Rift Valley in General and the central part in particular is known for its impressive hydrological networks. In the Zeway-Awassa Basin alone there are 5 major lakes (see table 3.1) whose importance for the resilience of ecosystems is immense. Some of them are so hydrologically connected that the fluctuations in one of them creates a conspicuous consequence on the other. The dependence of Lake Abijjata on the outflow of the Lake Zeway is a typical example.

**Table 3.1 Physical and chemical characteristics of major water bodies in the central Ethiopian Rift Valley ([1] after Zinabu et al. 2002, [2] after Billi 1998).**

| | *Altitude* | *Surface area (February 2000) km²* | *Perimeter (February 2000) KM* | *Max depth (m)*[1] | *Mean depth (m)*[1] | *Ph*[2] | *Catchment area (Km²)* | *Livestock density in the catchment (TLU/km²)* |
|---|---|---|---|---|---|---|---|---|
| Abijjata | 1575 | 163.1[3] | 68.3 | 14.2 | 7.6 | 9.9 | 1197 | 123.9 |
| Shala | 1556 | 305.8 | 124.4 | 266 | 87 | 9.6 | 3621 | 167 |
| Langano | 1586 | 229.5 | 111.27 | 48 | 17 | 9.3 | 1811 | 155.8 |
| Awassa | 1680 | 94.6 | 67.9 | 22 | 11 | | 1112 | 243.4 |
| Zeway | 1636 | 418.1 | 162.2 | 7 | 2.5 | 8.5 | 6736 | 120.6 |

According to Grove et al (1971) around 9200 ± 190 years B.C., lakes Abijjata, Langano, Shala and Zeway were all together as a single big water body covering the areas in between too. They were later isolated by faulting and other crustal movements and desiccations (Wodajo et al. 1984). Lake Awassa and the Cheleleka swamp, a small water body near to it, were also a single entity during the last century (Mohr 1971). Some geological layers indicate that Lake Awassa was also probably part of the larger water body that covered the Zeway-Shala basin.

Lake Abijjata is hydrologically connected to Lake Zeway and lake Langano via Bulbula and Horakello Rivers respectively. Abijjata does not have any other inflow except these two rivers. Wodajo et al. (1984) reported that water levels in this lake were very low in early 1981 since the two rivers could not get water from the two lakes. This occurrence can be linked to the 1981 event when River Meki was complete dry (Billi 1998). Lake Zeway has two major sources of inflow, the Meki River from west and Ketar River from east. Tesfaye (1982) estimates the catchment area of the former to be 1780 km² and the latter 2631 km², which is different from the figures (2313 km² and 3415 km² for Meki and Ketar catchments respectively) calculated through DEM analysis in this study. Lake Zeway is for the most part bordered by swamp: discontinuous blocks of *Typha* spp. and *Cyperus papyrus* fringe the shoreline. However, much of the shoreline and open water has now been invaded by *Eicchornia crassipes* (EWNHS 1996). Lake Langano receives its inflow solely from the eastern escarpment via the Teji-Gedemso streams network. The total catchment area of this network alone is more than 350 km². Lake Shala is also a terminal water body like Abijjata. It receives its water from the Dijo River that covers a catchment area of around 1200 km² in

[3] In January 2006 the surface area and perimeter of this lake dropped to 84.7km² and 37.9 km² respectively.

the western lower areas and escarpments. Other small rivers and streams also play a role. There is an unconfirmed hypothesis that the position and depth of lake Shala allows the infiltration of water from lake Abijjata.

### 3.2.3 Soils

An important soil survey for the southern and central part of the rift valley except for some irrigation areas is generally lacking. If there are any soil studies in the region, they are usually about buried soils to assess the geological history of the area rather than agricultural importance. One mentionable exception is the low scale FAO soil map. According to FAO digital soil map (FAO 1997), there are up to 24, 12 and 7 different soil units in the Central and Southern Rift, the Zeway-Awassa basin and the National Park including its environs respectively. While Eutric vertisol is dominating the former two categories, Vitric andosol covers more than 1/3 of the park and its 10km radius. This has wide range implications in agriculture and land use and natural resources conservation. In fact more than half of the terrestrial land is covered solely by Andosols in the park area. It is usually associated with virtisols forming virtic andisols. In this particular locality this soil type in general is highly basic. The Leptosol soil type is equally important in the larger regional scale along with vertisols, which are also the most important at the basin level. The fertility of vertisols and their exaggerated response to water fluctuations has a remarkable importance to agriculture in Ethiopia. Leptosols are characteristically shallow with high gravel content.

In general soils around the lake areas tend to have high PH. As high PH means more nitrification, these soils are expensive to maintain for agriculture through fertilization. In spite of this fact there are increasing agriculture activities and settlement, particularly in the Park area. Loss of soil through wind erosion is an increasing problem (preventing regeneration or rehabilitation) as the vegetation around the lake is removed or degraded.

### 3.2.4 Vegetation

The phytogeography (distribution of plants) of the whole study area is highly influenced by elevation that also dictates the rainfall pattern. The climate condition of the rift floor permits semi-climax perennials that are adapted to dry conditions or wet season vegetations that perish during the dry spell. Early biogeography studies (Grove et al. 1975, Bolton 1969), recent qualitative botanical investigations (Zerihun et al. 1990, Simon et al. 2006) and quantitative studies (Feoli et al. 2000) indicate the rift valley floor has been largely dominated by woodland and wooded-grasslands that are increasingly becoming more open. The most common tree species along the rift floor belong to the deciduous *Acacia* while the cooler escarpments on both sides support a wide diversity of both broadleaves and conifers. According to Zerihun et al. (1990), prior to intensive anthropogenic, the Zeway-Awassa basin woody vegetation composition was dominated typically by *Acacia albida.* Today, the rift floor around the Abijjata-Shala Lakes National Park is highly dominated by *Croton dichogamus* and *Solanum schimperianum*. The abundance of these species is a typical indicator of the occurrence of recent land degradation processes. Around the southern edge of the park and its outer peripheries, a remnant of *Euphorbia candelabrum* is also present. In relatively protected areas through fencing, like the head quarter of the Park Administration and the Abernossa Cattle Ranch, the natural dominance tends towards juvenile specimen of acacia species. The low altitudinal deciduous vegetation type is dominated by *Acacia tortilis, Acacia etbaica*, *Acacia seyal* and *Balanites aegyptiaca* with sparsely scattered *Maytenus senegalensis* bushes.

The escarpments on both sides of the low-lying rift floor are rich in plant composition and density. Broadleaf species like the pioneer species *Croton macrostachyus* as well as the climax species like *Ficus vasta* and *Cordia africana* are common. The Munessa-Degaga National Forest Priority Area, which is comprised of natural woody vegetations like podocarps, junipers and forest plantations that are highly dominated by few exotic species like eucalyptus, cypresses and pines, is also located at the centre of the eastern shoulder of the Zeway-Awassa Basin.

Irrigation farms, perennial plantations and orchards are distributed along the Bulbula River between Zeway and Abijjata. They play a great role in abstracting a considerable volume of water that would otherwise flow to lake Abijjata.

## 3.3 Wildlife and Tourism

### 3.3.1 Protected Areas

There are six protected areas designated for conservation of wildlife in the Rift Valley where this study covers at lower scale. These areas from north to south are; part of the Awash National Park, Abijjata-Shala Lakes National Park, Senkelle Swayne's Hartebeest Sanctuary, Nechsar National Park, Chelbi Wildlife Reserve and tiny part of the Yabelo Wildlife Sanctuary. While the others are discussed in broad scale pertaining their terrestrial productivity and livestock impact, the Abijjata-Shala Lakes National Park is the central point of this study for several reasons. In addition to its geographical position as a 'bottleneck' spot for migration flyway, it is the Abijjata-Shala Lakes National Park that supports the highest bird life form among these protected areas (Hillman 1993, Fekadu et al. 2002). The two lakes inside the theoretical demarcation of the park and the adjoining lake Langano provide the feeding and roosting grounds for migrating birds. Favourable conditions for abundant zooplankton and phytoplankton were better in lake Abijjata (Wodajo et al. 1984). Recently lake Abijjata has shrunk dramatically and no fish-eating birds were seen as before (EWNHS 1996). Fish and aquatic plants now regularly occur only around the mouth of the Bulbula and Horakello rivers where the water is relatively less alkaline. However, the existence of these rivers is also very much affected due to decrease in the water outflow from Zeway and Langano lakes respectively.

An inventory based report on this research area concluded that species and numbers are decreasing from year to year in Abijjata-Shalla (EWNHS 1996). Reasons remain unidentified, though the lake has been disturbed by human-related activities like irrigation and water diversion for soda ash extraction. EWNHS (1996) reported that even though the lake level in 1995 had been better than the years before, bird numbers have decreased, especially flamingos, waders and ducks. Northern shoveler *Anas clypeata*, ruff *Philomachus pugnax* and greater flamingo *Phoenicopterus roseus* numbers have decreased by 83%, 78% and 56% respectively compared to the preceding year. Satellite image analysis further reveals that in January 2006 the lake has lost nearly 50% of it surface area since 2000. However, contrary to the intuitive assumption, Sharew (1996) found that the number of flamingos was slightly higher in years when lake Abijjata was 2/3 of its original size while pelicans exhibited a sharp reduction in number. According to the raw data obtained from the Ethiopian Wildlife and Natural History Society and personal communication with the Abijjata-Shala managing staff, this phenomenon does not appear to have reoccurred during the lake decline in the past six years.

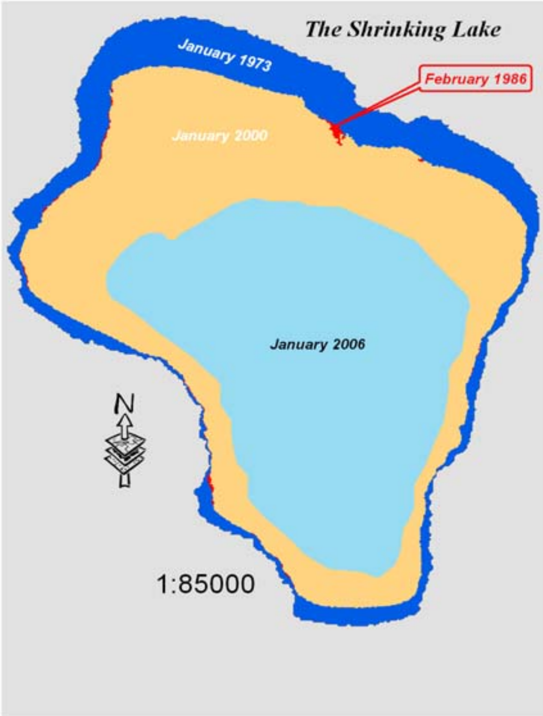



**Fig. 3.3 The Shrinking Abijjata Lake. Will it bounce back? (map prepared from several sources: MSS 1973, Landsat 1986, ETM+ 2000 and ASTERA 2006)**

### 3.3.2 Important Bird Areas (IBAs)

The Important Bird Areas (IBAs) are sites whose global importance for bird conservation is vital at both national and international levels. IBAs have been selected after fulfilling stringent criteria and periodically monitored by the IBA Programme of BirdLife International (Arinaitwe 2001, Fishpool 2001, Birdlife International 2005). Among other criteria, IBAs are selected when it is scientifically proved that bird species which are threatened with extinction occur regularly there or that the site holds exceptionally large numbers of congregatory birds (EWNHS 1996, Arinaitwe 2001, Birdlife International 2005).

Nonetheless, there is no legally (or institutionally) structured conservation mechanism in place unless these sites by chance overlap with some of the national protected area networks. Only 57% of the 1230 IBAs in Africa (Arinaitwe 2001) and only 15% out of the 69 IBAs in Ethiopia are actually located in the so called protected area of which many exist only on paper. Sixteen IBAs exist in the larger study area and six in the Zeway-Awassa Basin and two in the ASLNP. The Ethiopian Wildlife and Natural History Society (EWNHS) has made a regular bird count since 2000 in some 23 of the IBAs. All six sites in the basin have been counted in the past six years and the entire semi-processed data was generously made available by this organisation for study.

## 3.4 The Socio-cultural and Economic Situation of Abijjata Shala National Park and its Surroundings

### 3.4.1 Population

The population of Ethiopia is growing exponentially at a rate 2.5-2.9%. Due to the prevalence of low land diseases and inconveniency for cultivation agriculture, the rate is slightly lower in the Rift Valley. The central Rift Valley however, has a geographical proximity to major roads and densely populated towns. Thus, population influx and high input agriculture are not uncommon. According to the Woody Biomass Inventory Strategic Planning Project's final report (WBISPP 2000), the average population density per km² of total land and arable land is around 48 and 211 respectively in the Zeway-Awassa basin. Since the exponential population increase is not accompanied by equally growing agricultural productivity, there is always expansion of agriculture land. Even in the mid 70s, referring to an earlier estimate, Zemede (1998) reported the very high density of population per area of arable land was the same as it is now. That means the increase in population is not absorbed into the already available arable lands, but new lands are cleared for agriculture. Mohammed (1993) counted 67 people per km² inside the park. According to the national census a year later, the population density of the lower administrative regions adjoining the park was a maximum of 94 and a minimum of 53 (CSA 1996). Earlier surveys by Stephenson (1978) estimated the population density in the park to be 7-8 people per km². From the 49 people asked in ASLNP and its surroundings whether their agricultural land was expanding, only one responded negative. One quarter of the respondents described the expansion as 'very much' while the others simply acknowledge the expansion. Land containing semi-natural ecosystems that are theoretically designated as protected areas are common targets of such expansions (Nishizaki 2004).

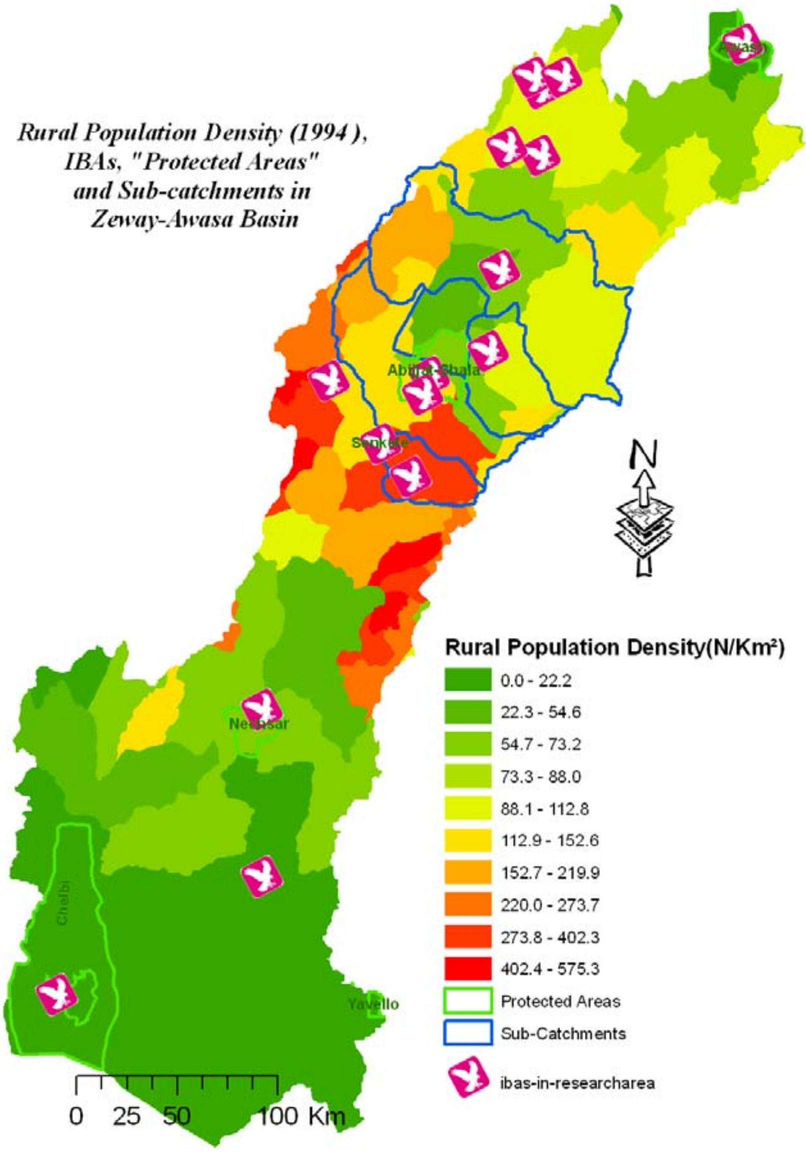



**Fig. 3.4 Location of IBAs and density of rural population (prepared from the data given in CSA 1996 and EWNHS 1996)**

### 3.4.2 Farming Systems and Land Use

The mainstay of the population is agriculture, even though the land is not that suitable for agriculture (EWNHS 1996, Jacobs et al. 2001). Most farmers rely on horizontally expanding rain fed crop production. Large-scale commercial plantations around the source of Bulbula River from Zeway Lake have been practicing irrigation for decades. The surface area of these farms is always increasing and recently, upland farmers are reported to have started using the river Bulbula, main fresh water feeder of lake Abijjata, for small-scale irrigation agriculture (Zinabu 1998). Cutting acacia trees for charcoal production has also become a common phenomenon, as it is an easy cash source for some farmers. The Main road that connects Addis Ababa to the Southern Regions provides an opportunity for roadside charcoal and wood sellers. Fishing was also practiced in the lakes before it had become economically unattractive due to the scarcity of fish.

Livestock centred semi-pastoralism is the center of many rural households around the rift floor even though it is loosing its importance to cultivated agriculture. According to the household survey conducted in the ASLNP and its immediate surroundings, there is resentment that the current generation has significantly fewer livestock per household. Among the reasons suggested feed shortage and population increase are the most frequent ones. Herders are reacting to the changing environment by modifying their herd composition, raring more goats at the expense of cattle in recent years. Goats are known for their ability to survive even in a degraded environment.

### 3.4.3 Relationship of the Inhabitants to the Protected Area System

The National Parks, Wildlife Reserves and Forest Priority Areas were established all over Ethiopia without the consent or approval of the people whose livelihood depend on them. They have been usually imposed on the local people without any significant benefit. Therefore the inhabitants both in the protected area and its surroundings see them as symbols of government–imposed restrictions that hinder their daily activities (Jacobs et al. 2001, Nishizaki 2004).

The case in Abijjata-Shala is even more striking. During the brief political turmoil of 1991, the ASLNP was the target of bitterness. As a result infrastructure was looted and destroyed, government vehicles were burned down (Jacobs et al. 2001). Since then the human population in the park has increased dramatically. Now, there are 11 legally organized peasant associations that have divided the entire park into small administrative areas.

The charcoal industry has become an important source of livelihood, albeit not sustainable, to many communities residing in or adjacent to the park. Removal of salty soil from the lakeshores is also expanding.

### 3.4.4 Government Policies and the Natural Ecosystem

As far as important land policy that affects the relation of local populations to the natural habitat of wildlife is concerned, 1965 is the starting point of influence (Hailu 2000, Hillman 1993). This is the year when the Abijjata-Shala Lakes National Park was established.

Before the rise of the military dictator government, there was only low-level interaction between the surrounding people and the park. Few landlords owned the land and it was their responsibility to regulate resources usage. When the military government came to power, they forced strict exclusion of people from the park area, which created levels of resentment that are still running high. In fact this administration policies were driven more by political imperatives than by biodiversity conservation objectives. A variety of coercive measures were taken to discourage the local people from 'trespassing' in designated park areas. In general local movements were highly restricted (Jacobs et al. 2001). The current so-called federal system has no clear policy on administration and management of protected lands. Confusion over whether the federal government or the local government rules are enforced is still unsettled. Widespread encroachment has been observed as a result of this confusion or reluctance of politically appointed administration officers to intervene. The consequences in terms of biodiversity are clearly detrimental though not yet precisely defined by any systematic study.

In the name of attracting foreign investment, ecologically sensitive and historically important lands are being given away. The Soda ash factory near Abijjata Lake is widely reported to be a cause of water shortage problem in lake Abijjata. Now that the water has receded so far away from their pump, the owners of the factory are seeking ways to divert the neighbouring lakes into Abijjata, without any insight into the huge consequences this sort of intervention may bring. Until now, concerned professionals have resisted the move. To make matters worse, the Ethiopian investment bureau has begun an extensive advertisement campaign to give what remains of the surrounding land to other soda ash extractors. This is an era in Ethiopia where ecological reasoning is regarded as both untimely and irrelevant.

# Chapter 4

# Data Organization and Methodology

## 4.1 Materials Used

Different kind of satellite imageries and diverse ancillary data have been collated in order to identify historical and recent land cover /land use including the seasonal development of vegetation - as manifested by their temporal phenology. There are several options of strategies and techniques to process these input data to come up with the desired result efficiently and economically. In fact, the choices of general methodology and specific technical arrangements are largely guided by the availability of the desired input data, the quality of available information, the strength of logistic support as well as the necessary fund allocated for the task. The materials used and the general and specific methods applied are described in this section.

### 4.1.1 Satellite Imagery

#### 4.1.1.1 Landsat MSS

The oldest available datasets for the study area are Landsat MSS archive data at the EROS Data Center. These data sets were taken by Landsat 1 (ESAT1) on 30 and 31 January 1973 at WRS1 path/row 180/55 and 181/55 respectively. They were obtained from the Global Land Cover Facility (GLCF) online imagery portal. Landsat 1, the satellite that carries the MSS instrument on board, was orbited at 920km height with repetition cycle of 18 days. The MSS onboard Landsat 1 had swathing pattern with an IFOV being 56 meters in the across-track direction and 79 meters in the along-track direction. The image data from MSS consists of four spectral bands that cover the visible green, visible red, and near-infrared wavelengths. Each band has a radiometric depth of 7 bits (0-127). The resolution for all bands is 79 meters, and the approximate scene size is 185 x 170 kilometres. The data received from the GLCF was resampled to 57m by 57m at the EROS Data Centre.

#### 4.1.1.2 Landsat TM and Landsat ETM+

A single scene, path/row 168/55, taken in February 1986 by TM sensor on board Landsat 5 is used as mid study-period image. The same path/row image taken in January 2000 was used as a recent data. The monthly MODIS data continue from this time on wards until September 2005. All Landsat data are obtained from the online archive of the GLCF.

The TM and ETM+ sensors are advanced, multispectral scanning devices designed to achieve higher image resolution, sharper spectral separation, improved geometric fidelity and greater radiometric accuracy and resolution than the MSS sensor. Like the MSS, these sensors primarily detect reflected radiation from the earth's surface in the visible and near-infrared (IR) wavelengths, but the TM and ETM sensors with their six multispectral bands and one thermal infrared band (ETM carries an additional panchromatic band with 15-metre ground resolution) are capable of providing more spectral information than the MSS sensor. They also have more radiometric depth as the data are captured in 8 bits (0-255).

The wavelength of the TM and ETM+ sensor ranges from the visible, through the mid-IR, into the thermal-IR portion of the electromagnetic spectrum. These sensors have a spatial resolution of 30 meters for bands 1 to 5, and band 7, and a spatial resolution of 120 meters for band 6 in TM. The ETM+ has an additional panchromatic band with 15 meters spatial resolution. This band may be used to increase the ground resolution of the 6 multispectral bands through image fusion. All TM and ETM+ bands are quantised as 8 bit data. (Farr, 1999, http://edc.usgs.gov/guides/landsat_tm.html, Last visited Feb. 1. 2006). The satellites orbit at an altitude of 705km and provide a 16-day repletion, covering 185km swath.

All Landsat imageries collect remote sensing data by detecting reflected energy from objects at the earth surface. The sun is thus the only energy source required in the visible and reflective infrared remote sensing. The reflectance behaviour of objects varies along the range of the electromagnetic spectrum. Guyot (1990), Jensen (1996), Huang et al (2002) and many others reported that at 0.45 - 0.52 µm range (blue range, ~ Band 1 of ETM and TM) characteristics of water bodies, sedimentation and turbidity are observed with high accuracy. Reflectance of healthy vegetation is better observed at 0.52 - 0.60 µm range (green range, ~ Band 2 of ETM and TM). At 0.63 - 0.69 µm range (red range ~ Band 3 of TM and ETM+) chlorophyll absorbs a considerable portion of the incoming energy (Guyot 1990 and Jacquemoud et al. 2001). Hence this band is important for identification of healthy green vegetation. The near infrared spectrum ranges from 0.76 to 0.90 µm in Landsat TM and

ETM+ images (known as Band 4). As opposed to the previous range, reflectance from green plants sharply increases in this range. Several indices, which attempt to quantify vegetation attributes, primarily use these two ranges due to this contrasting reflectance behaviour of plants at these spectral ranges.  At the far mid-infrared (1.55 - 1.75 µm ~ Band 5 in TM and ETM+), the moisture content of plants is detected. This property is especially important in agricultural crop observation studies because some signs of plant stress, which cannot be seen by naked eye, are readily discerned. Features those look similar in visible ranges like clouds, snow and ice are also clearly identified. The other distinct mid infrared range band (2.08 - 2.35 µm ~ Band 7 in TM and ETM+) is particularly effective in identifying zones of hydrothermal alteration in rocks and soils. The thermal infrared at the electromagnetic spectral range 10.4 - 12.5 µm constitutes the band 6 of both TM and ETM+. This band detects the radiant heat emitted by objects from ground surface. Similar objects have different radiant emission when they are different in their thermal state. Soil moisture studies, land cover classification and similar land resource remote sensing activities can be augmented by the IR-thermal band in addition to the above mentioned multispectral range detections.

At the spectral coverage gap between Band 3 and Band 4 (0.69-0.75 µm), very important chlorophyll dependant plant activities could have been identified. For some unfortunate reason, the Landsat satellites do not scan imageries at this range.

#### 4.1.1.3 MODIS Terra

The MODIS image product as a form of 32-day composites covering a period of 57 months were obtained from the GLCF archive. These data have been derived from an 8-day MODIS Surface Reflectance product and provided in Julian Date of Year (DOY) calendar dating system.

**Table 4.1. Date of Year (DOY) calendar system**

| *Julian Day* | *Calendar Day* | *Notes* |
|---|---|---|
| 001-032 | Jan.1-Feb.1 | |
| 033-064 | Feb.2-Mar.5 | |
| 065-096 | Mar.6-Apr.6 | |
| 097-128 | Apr.7-May 8 | |
| 129-160 | May 9-Jun.9 | |
| 161-192 | Jun.10-Jul.11 | |
| 193-224 | Jul.12-Aug.12 | |
| 225-256 | Aug.13-Sep.13 | |
| 257-288 | Sep.14-Oct.15 | |
| 289-320 | Oct.16-Nov.16 | |
| 321-360 | Nov.17-Dec.26 | |
| 361-365 | Dec.27-31 | (Included in 001-032) |

Note that at the end of the year two periods were created which cover 40 days (321-360 and 361-032) as 365 (days in the year) is not evenly divisible by 32 - the number of days in the composting period.

At the imagery depot of the data provider, MODIS bands 1 through 7 (red, NIR, green, blue, SWIR, SWIR, SWIR) are available in single band GeoTIFF files in continental subsets free of charge. The MODIS (Terra) sensor provides high radiometric sensitivity in 12 bits. The data procured for this study was limited to 7 channels though the entire MODIS instrument has 36 spectral bands ranging in wavelength from 0.4 µm to 14.4 µm. Two bands are imaged at a nominal resolution of 250m at nadir, with five bands at 500 m, and the remaining 29 bands at 1 km. A ±55-degree scanning pattern at the EOS orbit of 705 km achieves a 2,330-km swath and provides global coverage every one to two days. This study used the MODIS terra products that have a ground resolution of 500m or better. That means only the first seven channels were considered, with the first two degraded to 500m resolutions.

The MODIS imageries supplied from the GLCF are spectral radiance data. These spectral radiance data are cloud filtered, atmospherically and topographically corrected to yield an accurate surface reflectance as part of the unique procedures that are in place for MODIS data processing system (Justice et al. 1998). This is supposed to allow users to use the MODIS data in customized applications instantly. However, the MODIS Terra image as obtained from data providers always has some inherent problems that must be addressed before further analysis is performed.

**Replacing Erroneous Pixels.**

There are a number of randomly scattered erroneous pixels all over the MODIS image. This is especially prevalent around water bodies and wetlands. A pixel in the middle of a water body with high infrared reflectance is obviously a problem that needs a systematic solution without affecting the integrity of the entire image. There are also pixels with no value and extremely bright individual pixels that highly impair visualisation of the MODIS image. Since MODIS Terra is a 12-bit image and usually handled as 16-bit format by image processing systems, the unknown or wrong pixels are assigned to ($2^{16}$). However, the maximum data value of correct pixels is considerably less than the value assigned to the erroneous pixels. This makes the normal distribution pattern of most images drift to one side. As a result the originally received image appears completely dark or very bright.

To this end, a graphical model that was able to find pixels that did not satisfy certain criteria of a 'normal pixel', and then to replace them with a new value was developed. The new value was calculated from the statistical attributes of the neighbouring pixels under specified moving windows. Running this operation on each and every image would be time consuming, as there were 5 years-monthly data, each with seven bands. Therefore, a procedure that automates this operation was developed for this study.

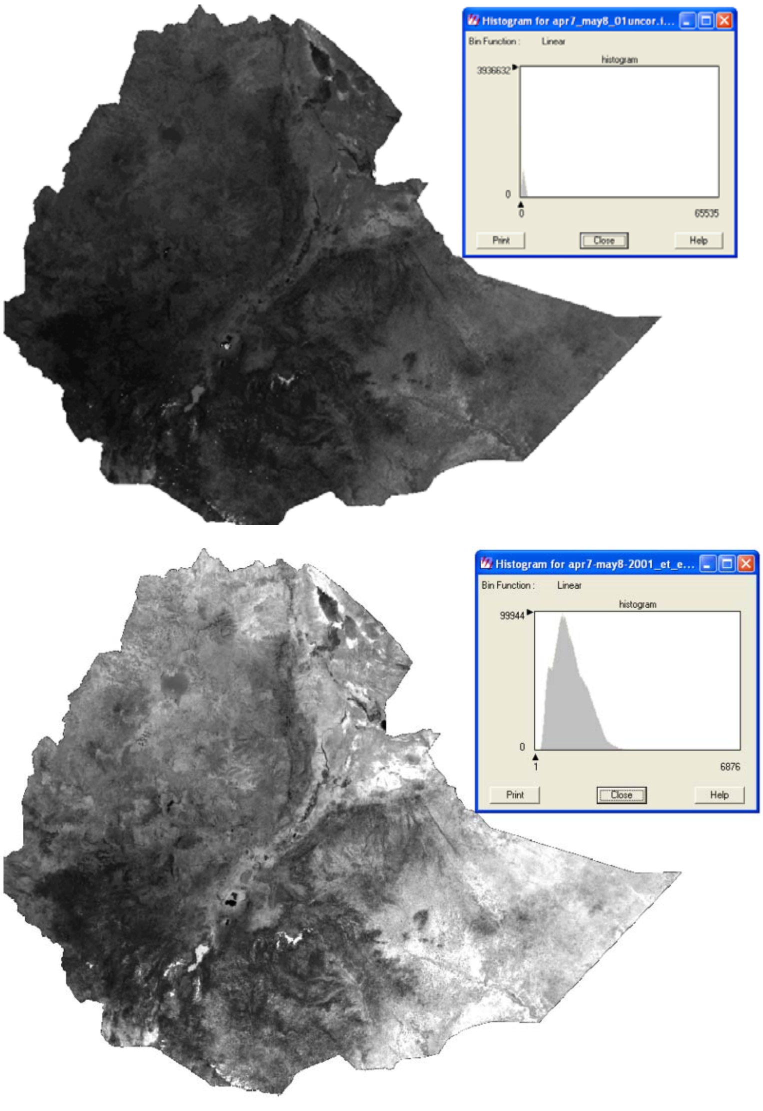



**Fig. 4.1 Uncorrected (top) and corrected (bottom) MODIS Data, April 2001 images**

### Conversion of Dataset Calendar

As mentioned previously in this section, the original composite data are given in Julian DOY system that may not be readily understandable by readers or users, which have low knowledge of remote sensing terminologies. These groups of users are usually the ones that make political decisions and set management standards in developing countries. As part of simplifying remote sensing products so that a wide range of users may easily adapt it to other data sets available to them, converting the DOY into Gregorian calendar was found to be useful. Weighted average values of the preceding and succeeding images were resampled so that the composite value of each month might be accurately estimated. The weighting method as shown below is essentially following the number of days each image in DOY contains from the preceding or succeeding month. A thorough crosschecking proved that the conversion did not result in any significant radiometric alterations.

***Conversion method.***

**Table 4.2. Calendar conversion method (from DOY to Gregorian)**

| *Gregorian Month* | *Weighting Functions to convert from DOY* | *Remark* |
|---:|---|---|
| January | Jan.1-Feb1 | |
| February | ((Jan.1-Feb1)+ (27*Feb2-Mar5))/28 | |
| March | ((5*(Feb2-Mar5)+ (26*Mar6-Apr6))/31 | |
| April | ((6*Mar6-Apr6)+ (24*Apr7-May8))/30 | |
| May | ((8*Apr7-May8)+ (23*May9-Jun.9))/31 | |
| June | ((9*May9-Jun.9)+(21*Jun10-July11))/30 | |
| July | ((10*Jun10-July11)+(21*Jul.12-Aug.12))/31 | |
| August | ((12*Jul.12-Aug.12)+(19*Aug13-Sept.13))/31 | |
| September | ((13*Aug13-Sept.13)+(17*Sept.14-Oct15))/30 | |
| October | ((15*Sept.14-Oct15)+(16*Oct16-Nov.16))/31 | |
| November | ((16*Oct16-Nov.16)+(14*Nov17-Dec.26))/30 | |
| December | ((26*Nov17-Dec.26)+(5*Jan1-Feb1))/31 | De27-31 is included in 001-032 |

### 4.1.2 Topographical Maps

Topographic maps at the scale of 1:50000, which cover the park and its environs, were purchased from the Ethiopian Mapping Agency. These maps were originally prepared from an aerial photo series acquired from November 1972 to January 1973 (Ethiopian Government's Ministry of Lands and Settlement 1976). Thus they are to some extent comparable to the January 1973 MSS data sets obtained from the GLCF. In the absence of other historical land use and land cover information these maps proved to give an important insight about the historical situation in terms of land cover in better details than the historical imagery.

### 4.1.3 Digital Elevation Models (DEM)

All elevation data and subsequent derivations like slope and aspect were calculated from the Digital Elevation Model (DEM) acquired by the Shuttle Radar Topography Mission

(SRTM) aboard the Space Shuttle Endeavour, launched in February 2000. The unfinished SRTM product (version 1), which covers most part of the globe, has been released for general users free of charge since 2001 (http://www2.jpl.nasa.gov/srtm, last visit January 2006). This unfinished version was acquired from NASA-JPL at the start of this study and all the necessary enhancement works has been performed in order to upgrade its quality to usable level. By now the finished SRTM product (version 3), which requires little or no upgrading, is available at several European and North American data providing portals.

The SRTM DEM is a high quality product with a horizontal ground resolution of 90 meters. A stereoscopical pair of optical imageries like the ASTER data has a good potential to produce DEM with better ground resolution. However, it is rarely possible to find dust or cloud free image pairs in tropical conditions. Moreover, critical information such as their exact location is not readily available. Ground control points can be used to get around this problem. The SRTM data does not required any ground control, which was an advantage in mapping inaccessible areas (http://www2.jpl.nasa.gov/srtm, last visit January 2006).

The unfinished SRTM data acquired from NASA contained unfilled pixels and few overtly erroneous pixels (around forests and water bodies). These anomalies must have been overcome either through replacing them with external data or correcting the SRTM itself through triangulation. Since the topographic maps purchased for this study were not enough to cover the Zeway-Awassa Basin, the first option was not applicable. Therefore, the unfinished SRTM data product needed to be first converted into point data, each point representing the location of the centre of the pixel. Unfilled, wrong or out-of-range pixels were removed and the remaining point data was used to create a TIN (Triangular Irregular Network) layer. Once the TIN was successfully set up, it was resampled to create a new DEM raster. Fortunately, the number of bad pixels was proportionally too low to have any influence on the triangulation result.

### 4.1.4 Metrological Station Data and Climate Map Formation

Climate or weather data collated from meteorological stations literally represent only the measurement of the location where the instruments are located. A rainfall data recorded by a rain gauge installed in the Addis Ababa metrological station by no means represents the rainfall measure of the whole Addis Ababa. However, uncountable number of natural resources studies use the value of the nearest metrological station data as representative of their study site. In fact there is always tremendous variability in climate with horizontal and vertical distance. Thus simply using the nearest available station data is not only oversimplication of spatial data variability but also misleading.

#### 4.1.4.1 Climate Map Formation through Spatial Interpolation Techniques

Spatial interpolation is the procedure of estimating the value of variables at unsampled or ‘no-data-record’ from other sampled or measured nearby sites. Generally, Tobler’s ‘Law of Geography’ dictates that objects that are closer together tend to be more alike than things that are farther apart. The theory and practice of spatial interpolations base this fundamental geographical principle. There are many interpolation methods available (Watson 1992, Mitas et al. 1999, ESRI 2005). For a given data set, a certain interpolation method may work better than the others. For example some interpolators create a smooth surface by distributing the estimation error throughout the area, while other spatial interpolators result in spatial contiguous maps that are very accurate around the measured sites and the error increase the farther one goes from the measured points. Thus, knowing the inherent assumptions and algorithms of the interpolators is an important factor to select the best method that fits the geographic condition as well as the objective of the study.

There is still no interpolation method, which will guarantee the best results for all data sets (Burrough 1986, Mitas et al. 1999, ESRI 2005). Therefore, the selection of a particular method should depend upon characteristics of data set as well as study objectives. In a nutshell, they can be largely grouped into two groups of interpolation techniques; namely deterministic and geostatistical ones. Both categories rely on the similarity of nearby sample points to create the surface. Deterministic techniques use mathematical functions for interpolation. Geostatistical or stochastic methods rely on both statistical and mathematical methods, which can be used to create surfaces and assess the uncertainty of the predictions (Burrough 1986, Mitas et al 1999).

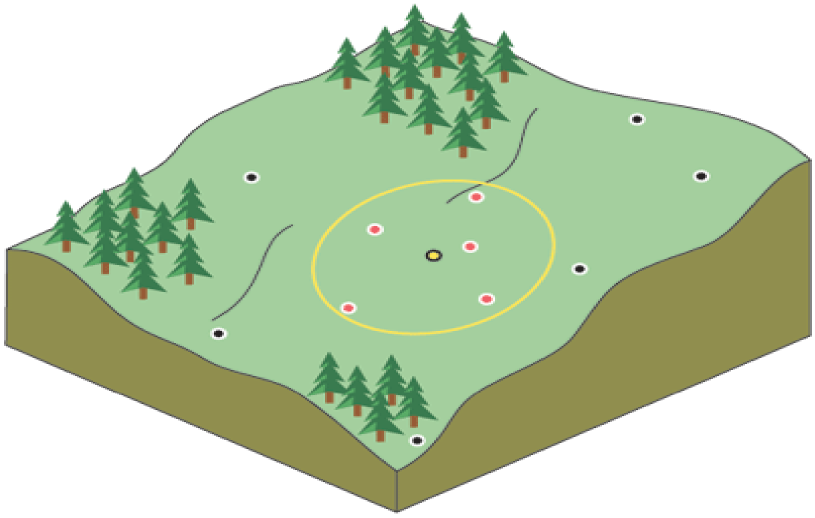


**Fig. 4.2. Schematic presentation of the concept of spatial interpolation (Source: ESRI 2005)**

***A. Deterministic Interpolators (Data Smoothing Algorithms)***

Deterministic interpolation techniques apply an established mathematical formula to the sample points. A deterministic interpolation can either force the resulting surface to pass through the data values or not. An interpolation technique that predicts a value that is identical to the measured value at a sampled location is known as an exact interpolator while an interpolator that predicts a value that is different from the measured value in order to avoid sharp picks or deep depressions is called inexact interpolator (Mitas et al 1999). Some of the most common interpolators in this category are:

***i. Inverse Distance Weighted Average (IDWA)*:** This is an exact interpolator. IDWA interpolation determines cell values using a linearly weighted combination of the desired set of sample points. The weight is a function of inverse distance. Distance-based weighting methods have been used to interpolate climatic data (Legates et al 1990). IDWA allows the user to control the significance of known points on the interpolated values, based on their distance from the output point. By defining the higher (power) option, more emphasis can be put on the nearest points. Thus, nearby data will have the most influence, and the surface will have more detail (be less smooth). Specifying a lower value for power will provide a bit more influence to surrounding points slightly farther away. The power is a positive real number. A common value is 2. The characteristics of the interpolated surface can also be controlled by limiting the input points for calculating each interpolated point. The input can be limited by the number of sample points to be used or by a radius within which there are all points to be used in the calculation of the interpolated points (ESRI 2005). Unknown value is calculated in IDWA according to the given formula.

$$Z(X_0) = \sum_{i=n}^{n} W_i \times Z(X_i) \quad \text{.........................................................................} \mathbf{4.1}$$

Where:
$Z(X_i)$ = the climate variable data at location $X_i$
$Wi$ = the weight

$$W_i^p = \frac{\left(\frac{1}{r_i}\right)^p}{\sum_{i=1}^{n}\left(\frac{1}{r_i}\right)^p} \quad \text{.........................................................................} \mathbf{4.2}$$

$P$ = the ID exponent (power), an arbitrary power value, usually set 2
$r$ = the distance between estimated and the $i^{th}$ sample
$n$ = number of samples.

***ii. Local Polynomial/ Global Polynomial*****:** This is not an exact interpolator, i.e. it creates a smooth surface, as its output does not necessarily result in the exact value at the input data locations. A polynomial model from the known variables is fitted and the unknown ones are accordingly estimated.

Global techniques calculate predictions using the entire dataset. Local techniques calculate predictions from the measured points within neighbourhoods, which are smaller spatial areas within the larger study area. Global Polynomial Interpolation is useful for creating smooth surfaces and identifying long-range trends in the dataset. However, in earth sciences the variable of interest usually has short-range variation in addition to long-range trend. When the dataset exhibits short-range variation, Local Polynomial Interpolation maps capture the short-range variation (ESRI 2005).

***iii. Spline:*** This is a deterministic interpolation method that is similar to the above one except that known locations retain their original vale even though the resulting surface is smooth. The known climatic variables are forced to keep their magnitude. Thus the spline bends a sheet of rubber that passes through the input points while minimizing the total curvature of the surface. It fits a mathematical function to a specified number of nearest input points while passing through the sample points. This method is best for generating gently varying surfaces such as elevation, water table heights, or pollution concentrations.

***iv. Triangulation**:* It is one of the most frequently used interpolation method for DEM generation. It is also provided in several GIS packages. Every location with known variables (e.g. meteorological station) is joined with its nearest neighbours to form non-overlapping triangles. A uniform value is calculated for all the locations situated inside each triangle. Thus sufficiently high number of known points distributed regularly in the landscape are required to produce large numbers of triangle and eventually capture the variability in the landscape.

***B. Geostatistical (Stochastic) methods***

This category of interpolators assumes that some of the spatial variation of natural phenomena like climate may be modelled by random processes with spatial autocorrelation. Hence, these interpolators consist geostatistical methods, which are based on statistical models that include autocorrelation (statistical relationships among the measured points). This kind of interpolators not only produces prediction surfaces, but they also provide information about the accuracy of the interpolation process. Most widely used stochastic/geostatistical interpolators are all in one form or another Kriging. However, there are fundamental tasks in geostatistical interpolation methods that almost all follow. These are chronological put, 1) calculating the empirical semivariogram 2) fitting a model 3) create the matrices and 4) making the prediction surface.

Among the many possibilities, the two most important geostatistical/stochastic interpolation methods are:

**i. *Kriging***: Kriging is an explicitly geostatistical form of interpolation that uses the local spatial structure of a variable to predict values for nearby locations. The weights used to predict neighbouring values are based on a fitted semivariance plot. Semivariance is a measure of the degree of spatial dependence between samples. The magnitude of the semivariance between points depends on the distance between the points. A smaller distance yields a smaller semivariance and a larger distance results in a larger semivariance. The plot of the semivariance as a function of distance from a point is referred to as a semivariogram. Thus, Kriging requires the prior estimation of a model semivariogram by fitting an empirical semivariogram to a theoretical form. The range of the semivariogram essentially dictates the size of the window for prediction, and the shape of the model semivariogram dictates how strongly the weights decrease with increasing distance. That means, based on the semivariogram used, optimal weights are assigned to known values in order to calculate unknown ones. Since the semivariogram changes with distance, the weights depend on the known sample distribution.

***ii. Cokriging:*** This method is similar to simple Kriging except the known variables are two or more in this case while the predicted variable is still one. It uses information on several variable types. The main variable of interest, the autocorrelation between the main variable of interest, cross-correlations between the main variable and all other variable types are used to make better predictions. Cokriging involves intensive computation as autocorrelation and cross-correlation must be estimated for each variable and between each variable.

For most of the interpolation works in this study where topographic influence was found out to be important, Cokriging was used in ArcGIS® software.

#### 4.1.4.2 Spatially Explicit Climate Map

Spatially contiguous data are the basic for modelling biophysical feature that cover wide area. However, it is practically impossible to measure physical, biological and climatic data from every bit of the study area. Even if it were technically possible, the information generated by measuring the whole area would not justify the cost and time incurred. As described in the previous section, discrete or point based data, from far apart located metrology stations, randomly distributed soil sampling points or similar information can successfully be interpolated to produce a spatially contiguous (image) data.

FAO has compiled and made available a 'many-years' metrological station databases for Africa and others (FAO 2001). This database, along with additional several-years daily precipitation data for the entire Ethiopia, was used to produce a monthly average climate maps that are spatially contiguous in coverage. Both data sources contained inconsistent and incomplete entries distributed in the databases without pattern. The primary aim of developing spatial contiguous climate map was to provide a reliable monthly climate data input for the biomass productivity model in the next chapter. Thus, outliers and null entries, which would influence the long-term averages, had been removed manually. After having structured the precipitation and temperature variables in a monthly average for each meteorological station, a series of vector point GIS layers were created from the database. Each and every vector layer was then interpolated to create a raster surface data that covers the whole central and southern part of the Ethiopian Rift Valley.

The influences of altitude on distribution of precipitation and temperature is substantial in Ethiopia. Therefore, this facet must be addressed beforehand. The DEM, derived from the

SRTM data, is high-resolution elevation map capable of sufficiently represent altitude. Consequently, an interpolator that allows the use of this additional variable was selected from the options described in the previous section. Even though no attempt was made to evaluate the accuracy of the estimation in robust statistical methods, the Co-Kriging interpolator provided a very good result that agrees very well with meteorological station measurements.

#### 4.1.5 Field Surveying

Field investigations either to collect training data for digital classification or for ground verification or validation is part and parcel of applied remote sensing. Land cover mapping activities without the support of field investigation is most likely prone to incorporate errors. Field surveying is a time consuming and expensive task. A carefully planed and executed fieldwork phase comprises some commonly followed procedures.

##### 4.1.5.1 Sampling

Decision about where to collect ground sample data is important step in remote sensing ground verification phases. It is highly dependent upon the design of the sampling scheme (Justice et al 1981), though the availability of very high spatial, spectral and radiometric resolutions of satellite images is minimizing the importance nowadays. A careful selection of samples in any way is undoubtedly an important fact, if sampling should capture the variability of land cover and land use in the landscape at issue.

A number of sampling option are available that can be applied pertinent to the project tasks and the homogeneity or heterogeneity of the population data as well as the logistic available to conduct the sampling. Random point sampling, random area sampling, nested sampling, systematic sampling are some of the most widely used designs. A combination of these approaches is also possible. As far as this study is concerned, stratified random sampling, has been found to be fast, feasible and cost effective. Congalton (1988) asserted that simple random and stratified random samplings provide satisfactory results, after having made three independent tests. However, simple random sampling tends to over sample some classes at the expense of others. It is expensive and sometime impracticable especially in areas with fewer infrastructures and in areas where transportation is expensive.  Sampling method becomes more important, when there are unique or important categories that are relatively small in coverage. Simple Random Sampling has a tendency to miss such classes. On the other hand stratified random sampling selects a certain number of samples from each designated stratum.

The size of samples is also of great importance, as it is the base, together with frequency, for providing representative results. Justice et al (1981) suggested the application of a model that makes use of the attributes of the spatial image to define a sampling size. The model estimates the size of any sample quadrant as function of the pixel size and the expected geometric accuracy of the images.

$$L = P(1+2G) \quad \textbf{4.3a}$$

Or

$$A = P(1+2G)^2 \quad \textbf{4.3b}$$

Where:
L = length of any side
A = area to be sampled
P = pixel size
G = geometric accuracy of the image.

TM or ETM+ image with 1-pixel geometric accuracy, the size of sample area becomes 0.81 hectare. This is equivalent to a 3 by 3 pixel kernel area that is suggested by various other studies. Since variability within the pixels themselves is very high, the same analogy may not be appropriate for MODIS images.

#### 4.1.5.2 Data Collection for Development of Digital Signature.

Digital signature of each land cover classes is a function of their spectral property. In land resources remote sensing studies; a representative ground data is a prerequisite to associate this reflectance property to the object. Afterwards these signatures may be used to train programmes/classifiers to facilitate accurate automatic classification. In this study, the first step for unbiased data collection was stratifying the study area according to a presumed land cover classes. This was limited only to the core study site. These strata are not land cover classes rather a certain area where the presumed land cover material was seen to be obviously dominant. In each stratum sufficiently large number of random points were distributed. A road map and DEM latter revealed not all points in the strata were accessible. It was assumed that 3-5 km from road would be reasonably accessible owing to the high number of samples to be visited within a relatively short fieldwork time. To this end, an access map was prepared and points, which were located in the access map, were considered as feasible sample points. With the help of a hand held Garmin® III GPS, sample points were located. Within area equivalent to 0.81 ha, available objects and their attributes were recorded then after.

#### 4.1.5.3 Selecting Sample Plots for Collection of LAI and Green Biomass Specimens

The biophysical mapping in this study covers the entire study area in the rift valley. Hence only the MODIS Terra image was used. The same sampling system like the one in the core study site would be not only infeasible but also inappropriate. Three interdependent approaches were followed.

1. Ground material observation: left and right along the roads in the study area a large number of random observations were recorded.
2. A half-meter by half-meter quadrants were demarcated from few of those stratified random samples. Grasses and herbs were harvested just above the ground, weighed at the site. Moreover, the collected leaves were scattered on a flat plate without any of them overlapping in order to measure LAI.
3. Two monitoring sites were set up in Abijjata-Shalla National Park administration compound after securing permission from the Oromia Wildlife Conservation Bureau. The distribution of the plots was not considered optimal, since the compound was too small to find diverse sites. Other locations outside the park were ruled out, as they would be highly subjected to external influences and result in a misleading data. A plot with a dimension of a 20m by 20m represented each site. Each plot was divided into four equal quadrates. Monthly green grass and herb biomass was then measured from each quadrant during the rainy period of 2005.

**Fig. 4.3. Field trial plot to estimate productivity in ASLNP (Photo: Maria Scurrell)**

### 4.1.6 Ecological Important Areas

#### 4.1.6.1 Bird Data

Given the short time span of the field surveying time and tremendous logistic requirement, onsite bird counting could not be conducted. The generous supply of this essential data by Ethiopian Wildlife History and Natural Society (EWNHS) and the further verification of the Ethiopian Wildlife Conservation organisation (EWCO) staff were sufficiently enough to offset this need. General yearly counts (usually conducted at December to January) for the entire five years were procured from EWNHS and the diversity and abundance indices were subsequently calculated. Spatial representations of these indices were approximated after having thorough discussion with EWCO and ASLNP experts who were involved in the counting programme.

There is no comprehensive species diversity map in Ethiopia except for some description of the diversity situation for certain localities. A spatially contiguous 'Bird Species Diversity' map for the entire Ethiopia was prepared for this study through digitisation of individual bird maps. The major input has come from East African Bird Guide (van Perlo 1995) with subsequent refinement of the data using digital terrain models.

#### 4.1.6.2 Important Bird Areas

The location of Important Bird Areas (IBAs) is available for public at the Birdlife International web site (http://www.birdlife.org/datazone/sites). Unfortunately the spatial data is limited to only point data, omitting the most important information about extent and border of the IBA. Discussions with EWCO staff and ASLNP management teams helped to find appropriate representative points. Buffer zones surrounding the point at 10, 20 and 30 km have been delineated for use in impact analysis at the latter stage.

#### 4.1.6.3 Spatial data on Protected Areas

The World Conservation Monitoring Center (WCMC) regularly complies national and international protected areas. These valuable data are available for the general public in different spatial data portals. A digital copy of ‘National Protected Area Networks’ acquired from the WCMC’s World Data Base on Protected Areas (WDPA) consurtium and the Ethiopia part was clipped. However, it was quickly realized that the data suffers serious location and boundary error. Keeping the underlying important attribute data as it was, the geographic data was heavily edited using printed maps from other reports (e.g. Fekadu et al 2002).

### 4.1.7 Livestock Data

Lack of reliable livestock data was one of the bottlenecks during this study. Historical data are difficult to find due to the fact that several low level and high-level administration boundary changes have happened in the last three decades. Some of the data tested were overtly unreliable as there were obvious exaggerations in the number. These exaggeration were mostly a deliberate action to get more fund allocation or other benefits. The recent livestock survey by the Ethiopian Central Statistical Agency (CSA 2003) was found to follow the scientific standard for reliable data collection. To this end, this tabular data set was converted into GIS layer for further analysis along with the land cover information. More detail on adjusting the livestock data according to land cover classes is given in Chapter 6. The household survey conducted by this study also revealed some pattern of livestock holdings in households now and in the past. Since it was conducted only in the core study area, where the population number suddenly inflated due to settlement in the park, the result was not used for extrapolation to cover the larger study area.

## 4.2 Pre-Classification of Digital Image Processing

### 4.2.1 Radiometric and Atmospheric Correction

As described before, ground objects have specific absorption and reflection properties at different radiation wavelength. Such properties are properly documented for several objects and included in several image management software packages as spectral libraries. In a laboratory setting it is relatively easy to determine the reflectance properties of a material because one can easily measure the intensity of the light energy when it reaches the target material (Markam et al. 1986). The light path is controlled so that not much energy is lost between the light source and the target or the target and the detector. Also, the illumination and target orientation are known with high accuracy and precision. In the world of satellite remote sensing, the situation is very different. It is possible to know the intensity of the light before it enters the atmosphere but as it passes through the atmosphere, it interacts with particulates (i.e., water vapour, dust, smoke) and significantly alters the signal before and after interacting with the object (Guyot 1990, Chavez 1996, Lillesand et al 2004). A remarkable progress has been made in removing these atmospheric effects from an image, but it is still difficult to consistently and easily remove them. Some of the available and technically feasible radiometric and atmospheric correction methods tested for this study area described below.

#### 4.2.1.1 Image-Based Correction

Since some procedures require the actual in-situ atmospheric measurements during the data capture by remote sensing operations, atmospheric correction tasks are difficult and costly. Chavez (1996) simplified the whole complex issue of atmospheric correction purely based on information either extracted from the image itself or the accompanying metadata. The concept of image-based atmospheric correction relies on the fact that dark objects should have a minimum or zero reflectance in certain space of the electromagnetic spectrum. The reflectance magnitude of this dark objects registered by remote sensors is therefore largely due atmospheric interference or haze (Chavez, 1996 and Moran et al 1992).

According to Schowengerdt (1997), ignoring the diffused radiation, the total at-sensor solar radiation ($L_\lambda^s$) is the sum of surface-reflected beam radiation ($L_\lambda^b$) and atmosphere-scattered path radiation ($L_\lambda^p$).

$$L_\lambda^s = \rho_\lambda \frac{\tau_\lambda^v \tau_\lambda^s E_\lambda^0}{\pi} \cos(\theta^s) + L_\lambda^p \quad \text{......} 4.4$$

Where:
$E_\lambda^0$ = the mean solar exoatmospheric irradiance at the top-of-atmosphere (W/m$^2$-sr);
$\rho_\lambda$ = the spectral reflectance at-surface;
$L_\lambda^b$ = surface-reflected beam radiation;
$\theta^s$ = solar zenith angle in degrees; (= 90 – solar elevation angle)
$\tau_\lambda^s$ and $\tau_\lambda^v$ = atmospheric transmittance in solar path and view path, respectively.

Chavez (1996) in his COST model proves $\tau_\lambda^s$ and $\tau_\lambda^v$ can be successfully estimated by a cosine function of $\theta^s$ and $\theta^v$, respectively. Thus the COST model which uses dark object subtraction for correcting atmosphere interference and retrieving surface reflectance can be written as;

$$\rho_\lambda = \frac{\pi \times (L_\lambda^s - L_\lambda^p)}{E_\lambda^0 \times (\cos(\theta^s))^2 \times \cos(\theta^v)} \quad \text{......} 4.5$$

Where:
$E_\lambda^0$ = mean solar exoatmospheric irradiance for each MSS, TM and ETM+ spectral band.
$L_\lambda^p$ = atmosphere-scattered path radiation. The 1% dark object subtraction technique (Moran et al 1992) was used to estimate this radiance. Areas with clear water in deep lakes were identified in the image and used as dark objects.
$L_\lambda^s$ = at-sensor solar radiation (equation 4.4),
Or calculated as a function of image variables usually given in the metadata;

$$L_\lambda^s = gain \times \cdot DN_\lambda + Bias \quad \text{......} 4.6$$

#### 4.2.1.2 Empirical Line Calibration Method.

The basic assumption behind Empirical Line Calibration method is that the effects of the atmosphere are uniformly distributed across the image and there is empirical relationship between at-satellite reflectance and ground-measured (or estimated) reflectance (Jensen 2004). This method forces image data to match selected field reflectance spectra.

$$\rho_\lambda = slope \times L_\lambda + offset \quad \text{......} 4.7$$

Where:

$\rho_\lambda$ = the insitu surface reflectance,

$L_\lambda$ = the digital brightness value,

*'slope'* = a multiplicative term associated primarily with atmospheric transmittance and instrumental factors,

*'offset'* = an additive term associated to atmospheric path radiance and instrument offset (Jensen 2004).

This method entails a relatively easy process if one bright target such as sand and one dark target such as deep clear water body are readily located in the image.

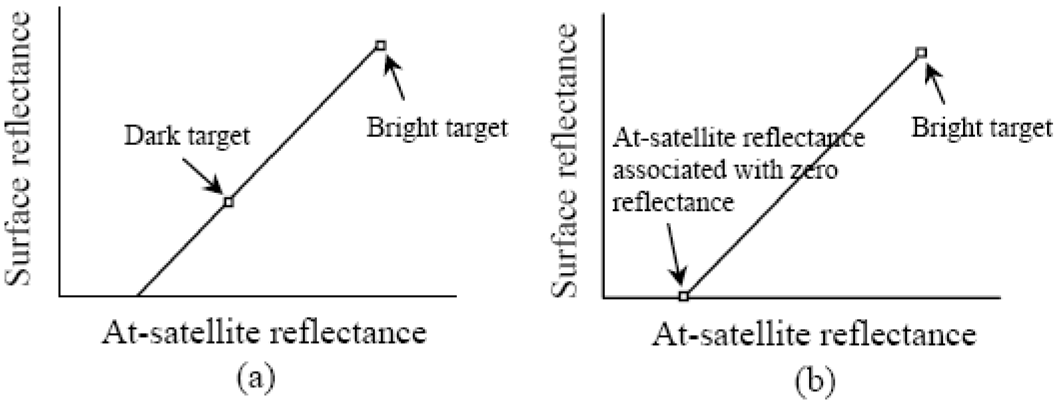



**Fig 4.4 typical composition of a) atmospherically uncorrected image b) corrected image**

Spectral pairs (pixel values from the image to be corrected and an *a priori* known reflectance value from e.g. spectral libraries or filed measured) are used to plot a regression line that is used to modify the input dataset. Since the goal of this algorithm is to define the required regression line, spectra from both bright and dark areas must be used. Ideally, the in-situ surface reflectance should be measured exactly when the satellite passes through the location where the material is situated. However, this is not usually possible for several reasons. In built spectral libraries in several remote sensing computer programs provide the equivalent of surface reflectance, which are not contaminated by atmospheric interference. The challenge is to match this laboratory measured values to real world situation in different parts of the world.

The draw back of this technique is that the library values that are constructed for a certain environmental set up do not fit others. Locating the darkest pixel and the brightest one is also a problem. The assumption is easily violated in a heterogeneous environment or in imageries that contain areas with great elevation difference.

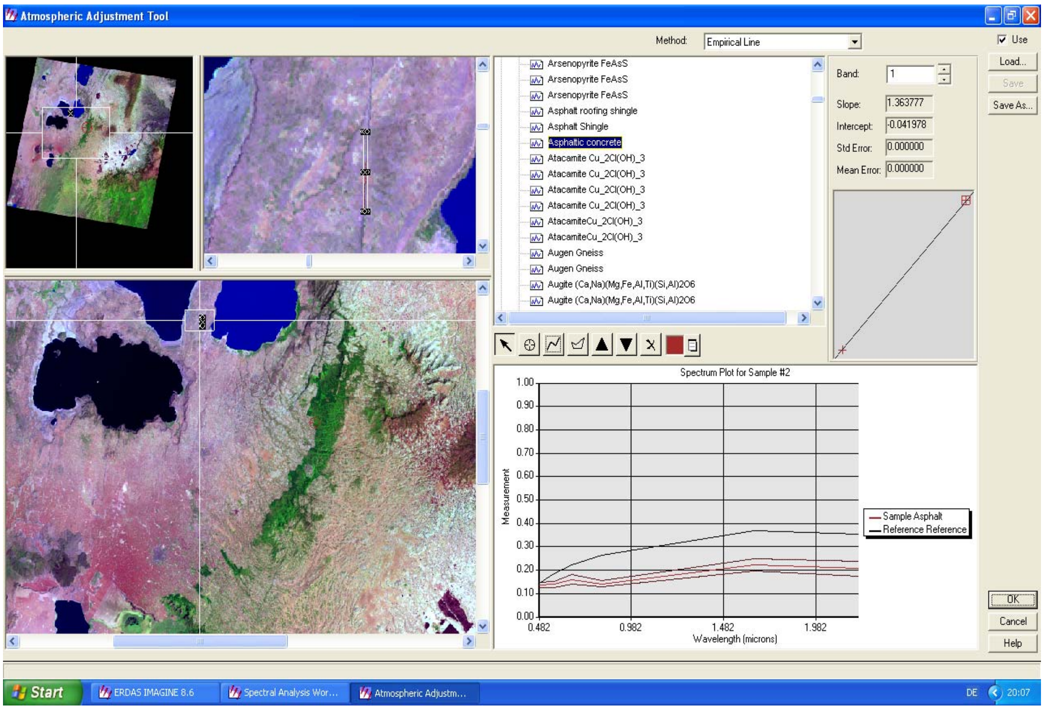



**Fig. 4.5 Empirical Line Calibration interface in ERDAS IMAGINE®**

### 4.2.1.3 Modified Flat Filed (MFF)

Like the ELC this method also requires knowledge of *a priori* surface reflectance for the material in the field and the corresponding values of spectral libraries. While any spectrum of the material in the selected pixel can be used, the best results are obtained if the library spectrum is a field-determined spectrum of the actual material as it occurs in the selected pixel (Green 1990, in Leica 2002b). Each input pixel spectrum is divided by the field spectrum that is topographically and spectrally flat and then multiplied by the spectrum. This should remove the atmospheric effects on the image. In general this method is used to normalise images to an area of known flat reflectance (Leica 2002b).

In a heterogeneous landscape like the core study site in the Abijjata-Shala lakes area, MFF performs poorly.

### 4.2.2 Temporal Normalisation.

Temporal Normalisation or Pseudoinvariant Normalisation is bringing historical MSS and TM images to the radiometric level of the ETM+ image.

*ETM (DN) = slope * TM (DN) + intercept* ..........................................................**4.8**

A sufficient number of pseudoinvariant objects, which were considered Lambertian and radiometrically stable through time, were located throughout both images. Then a regression function was developed assigning the recent image values as dependent and the historical ones as independent. First, mean digital number (DN) values were extracted from the dark and bright targets from the 1986 TM and 2000 ETM+ datasets. Large water bodies were used for the dark targets, whereas sand beaches were chosen for bright targets. The coefficient of fit, 0.88 to 0.95 for the regression model was not as high as the usual value suggested by many studies (Vogelmann et al. 2001).

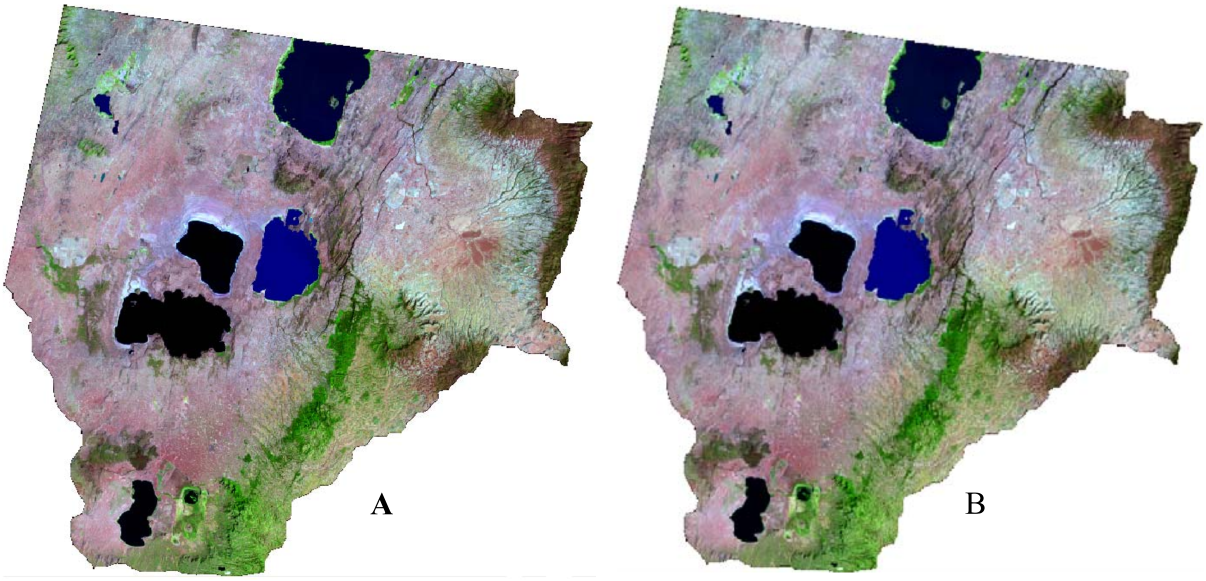



**Fig. 4.6 Temporally normalised images. (A) before and (B) after normalisation**

The same way a regression equation was developed to estimate the radiometrically superior ETM+ equivalent of the 1973 images. Not all spectral ranges correspond directly between the two different data sets. As suggested by Vogelman (2001), the nearest ranges were compared for slope and constant factor calculation. However, the result was not encouraging to make direct change detection. The highest $R^2$ that was calculated for the short wave band was only 0.82.

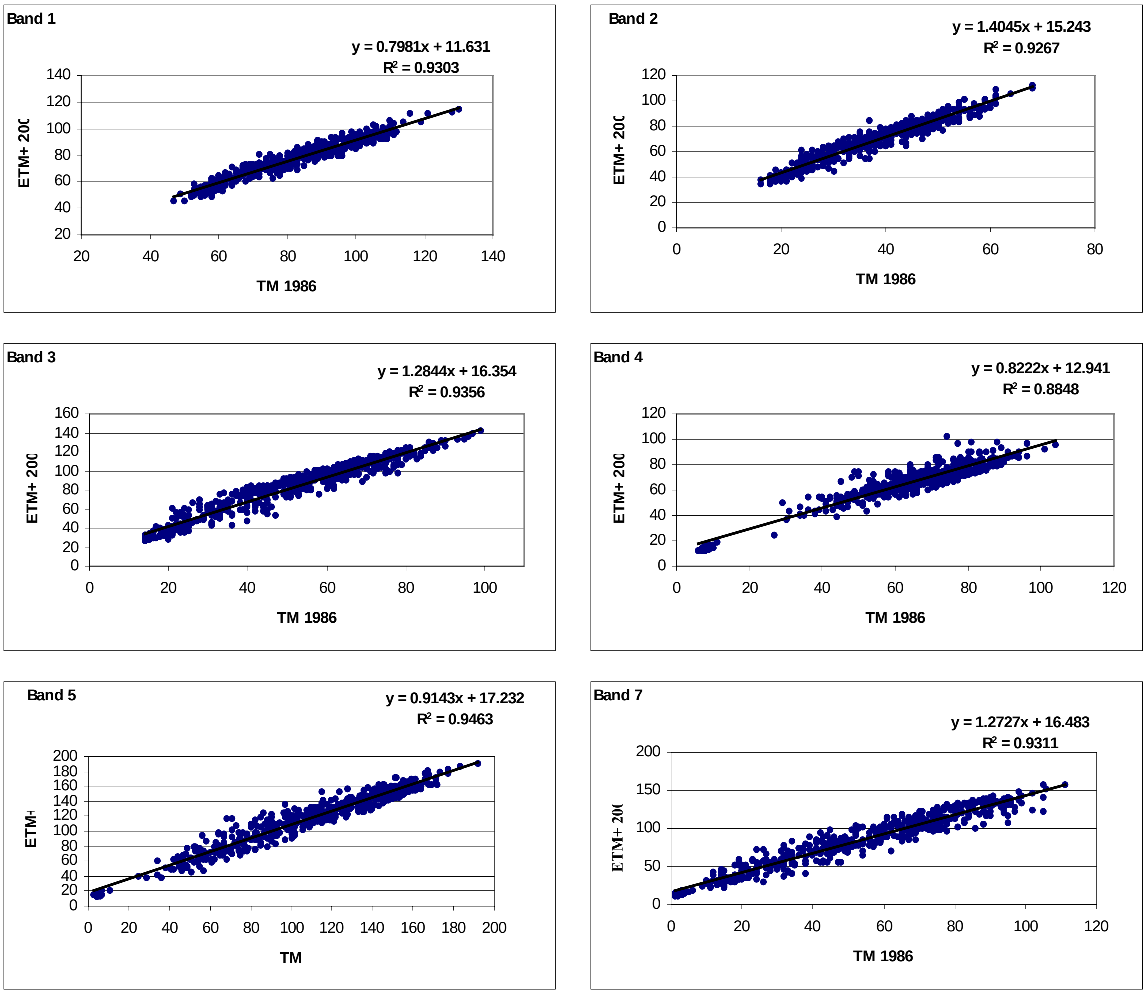



**Fig. 4.7 Regression functions constructed from pseudoinvariant variable in TM and ETM+**

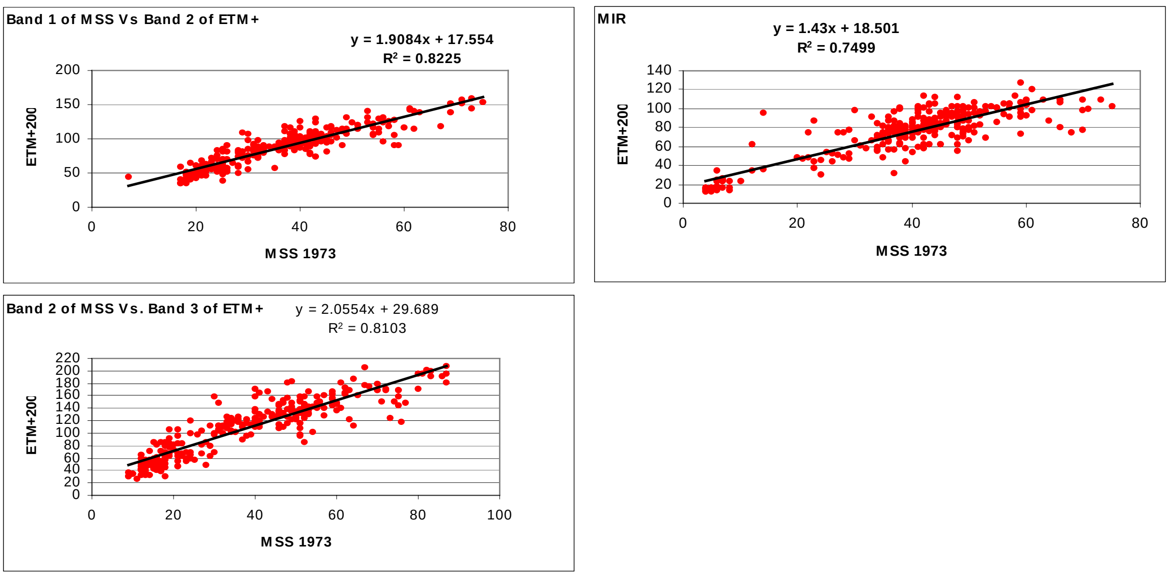



**Fig. 4.8 Regression functions constructed from pseudoinvariant variable in MSS and ETM+**

### 4.2.3 Geocoding and Georeferencing

Raw remotely sensed image data that are collected by sensors on satellite platforms or aircrafts are not directly referenced to a known map projection. The location information they contain is simply the row and column where the pixel is located in the image. Moreover the images are taken as if the earth was plane surface. In order to use satellite images for mapping or other purposes, these data must be rectified by associating the center of the pixel to a point on the earth surface in one of the map projection systems. This rectification process is known as Geocoding or Georeferencing.

#### 4.2.3.1 Landsat Image Geocorrections

The Landsat images obtained for this study had been already orthorectified by the image supplier. However, the model used for orthorectifing is too broad (global) to be in the state of usable precision. Orthorectified images are difficult but not impossible to georeference them again, since the pixel position has already been moved formerly. From the 1:50000 scale topographic map and ground GPS readings, sufficient number of GCPs was collected. The exact position of these points were located on the image and Geocoding was performed using second-degree polynomial function.

#### 4.2.3.2 MODIS Images Reprojection

The MODIS images obtained from the GLCF had been projected by the vendor into the Goode's Homolosine Projection with continental subsets. The Goode's Homolosine Projection does not conform to the other ancillary map and image data that are widely in use in Ethiopia. The Ethiopian Mapping agency (EMA) uses Clarke 1880/UTM (different zones) in most of its mapping products. Therefore, following this national system was found out to be beneficial not only for the current analysis during the study but also for future use by other users. To this end, a simple automatic reprojection routine was assembled and the whole 5-year monthly images were converted to the desired reference system all at once.

### 4.2.4 Topographic Normalisation

Satellite images which cover mountainous regions often contain a radiometric distortion known as topographic effect. In flat areas with Lambertian surfaces, reflectance properties represent the pixel intensities of the surface. This ideal condition is hardly present in real world. Topographic effects result from the differences in illumination due to the angle of the sun and the slope of the terrain, causing a variation in the image brightness values due to shading.

Two types of topographical normalisation were tested to improve the low radiance record along the shaded terrain around lake Shala cliffs and the eastern escarpments. The algorithms are based on the Lambertian reflectance model (Cosine Correction Method) and the correction approach suggested in Civco (1989). Both approaches require the use of slope and aspect values of a DEM**.**

#### 4.2.4.1 Lambertian Reflectance Model or The Cosine Correction Method

The Lambertian Reflectance Model assumes that the surface reflects incident solar energy uniformly in all directions, and that the variations in reflectance are due to the amount of incident radiation. Thus, the Lambertian Correction Function attempts to correct only for differences in illumination caused by the orientation of the surface (Leica 2002a). For the Lambertian assumption, the most widely used correction is this cosine method (Teillet et.al. 1982, Meyer et al 1993).

$$Cosi = (\cos\varepsilon \times \cos\delta) + (\sin\varepsilon \times \sin\delta \times \cos(\psi - \rho) \quad \textbf{4.9}$$

$$Ln(\lambda) = \frac{L(\lambda)}{\cos i} \quad \textbf{4.10}$$

$$L_h = L_t \times \frac{\cos\delta}{\cos i} \quad \textbf{4.11}$$

Where:
$L$ = radiance
$\psi$ = Solar azimuth
$\delta$ = Solar zenith angle
$\varepsilon$ = Slope inclination
$\rho$ = Surface aspect of the slope angle
$L_h$ = radiance for horizontal surface
$L_t$ = radiance observed over the inclined terrain

#### 4.2.4.2 Normalisation Method

The normalisation method as proposed by Civco (1989), consists of two stages. Firstly, shaded relief models, corresponding to the solar illumination conditions at the time f the satellite image are computed using the DEM data. This requires the input of the solar azimuth and altitude provided by the metadata of the satellite image. The resulting shaded relief model would have values between 0 and 255. After the model is created, a transformation of each of the original bands of the satellite image is performed to derive topographically normalized images using the equation:

$$\delta DN = DN + \left[ DN \times \frac{(\mu - X)}{\mu} \right] \quad \textbf{4.12}$$

Where:

$\delta DN$ = the normalized radiance value of the pixel,
$DN$ = the original digital number of the pixel,
$\mu$ = the mean value of the entire scaled shaded relief model,
$X$ = the scaled illumination value of the pixel (0-255).

These corrections were expected to provide satisfactory results in such moderate relief as the Abijjata Shala National Park and its environs. The Cosine Normalization Method altered the illumination values of pixels where it was not required at all. This over-correction made most of the image unreliable for classification. The second normalisation method - as suggested by Civco (1989)- improved most part of the shore cliffs. A universal application of the method to the entire image was found out to be not useful though. Therefore, the output of topographic normalisation exercises was limited to usages around the lake Shala shores.

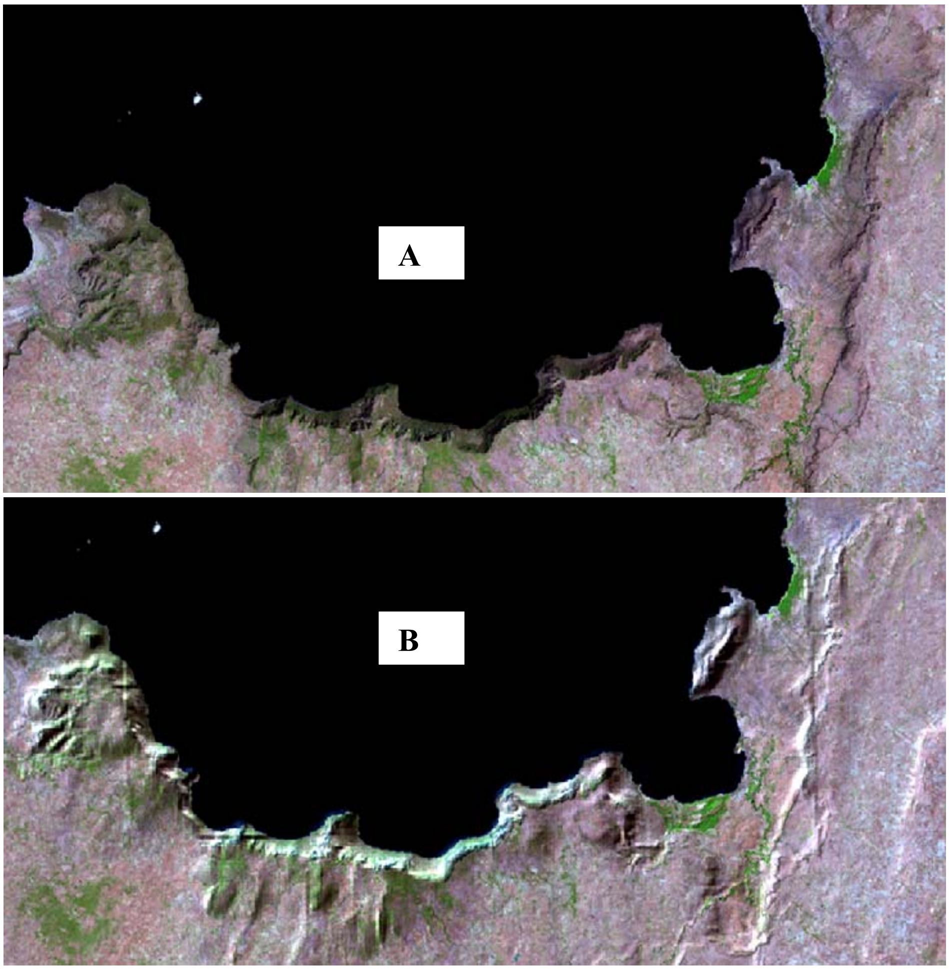



**Fig. 4.9 Topographic Normalisation as suggested by Civco (1989). A) uncorrected ETM+ 2000 image, B) the same image after topographic correction**

### 4.2.5 Tasselled Cap Transformation

The tasseled cap transformation (TCT) provides a mechanism for data volume reduction with minimal information loss and its spectral features can be directly associated with the important physical parameters of the land surface (Zhang et al 2002).

After performing a principal component analysis from a MODIS global land cover training data, (Zhang et al 2002) produced seven principal components, of which the first three were taken as the initial axes used to define planes very similar to the TM tasseled cap planes. They made several test by rotating these planes and a MODIS tasseled cap coefficient was generated. Though the output looks more of a prototype than a finished piece, so far this is the only attempt to provide the remote sensing community with MODIS tasseled cap coefficients. Accordingly those suggested coefficients for MODIS images were used to generate a monthly Brightness, Greenness and Wetness information for the whole study area.

**Table 4. 3 Tasselled Cap coefficients of MODIS (After Zhang et al 2002)**

| *Band* | *Red* | *Near-IR* | *Blue* | *Green* | *M-IR* | *M-IR* | *M-IR* |
|---|---|---|---|---|---|---|---|
| MODIS (nm) | 620-670 | 841-876 | 459-479 | 545-565 | 1230-1250 | 1628-1652 | 2105-2155 |
| Brightness | 0.3956 | 0.4718 | 0.3354 | 0.3834 | 0.3946 | 0.3434 | 0.2964 |
| Greenness | -0.3399 | 0.5952 | -0.2129 | -0.2222 | 0.4617 | -0.1037 | -0.4600 |
| Wetness | 0.10839 | 0.0912 | 0.5065 | 0.4040 | -0.2410 | -0.4658 | -0.5306 |
| Fourth | 0.4527 | 0.4480 | -0.3869 | -0.1277 | -0.3164 | -0.4993 | 0.2829 |
| Fifth | 0.6478 | -0.2448 | -0.3705 | 0.0068 | 0.1385 | 0.2564 | -0.5461 |
| Sixth | -0.2332 | 0.3348 | -0.2764 | 0.3516 | -0.5986 | 0.5032 | -0.1515 |
| Seventh | -0.1930 | -0.2052 | -0.4725 | 0.7049 | 0.3107 | -0.2935 | 0.1334 |

### 4.2.6 Thermal Bands for Use in Land Cover Classification

The thermal band given along the TM and ETM+ imageries is rarely used for biophysical mapping since it is conceptually not easy to understand and technically not straight forward. The conversion procedure from DN to degree Kelvin is:

$$T = \frac{K_2}{\ln\left(\frac{K_1}{L_\lambda} + 1\right)} \quad \text{.........} \mathbf{4.13}$$

Where:
***T*** = effective at satellite temperature in Kelvin,
$\boldsymbol{K_1}$ = calibration constant (666.09 and 607.76 watts/m²*ster*µm for ETM+ and TM respectively),
$\boldsymbol{K_2}$ = calibration constant (1282.71 and 1260.56 Kelvin for ETM+ and TM respectively),
$L_\lambda$ = the spectral radiance in watts/(m²*ster*µm).

A simple mathematical relationship that totally avoids the need to make several conversions has been assembled for this research area. This relationship that allows the conversion of the DN values of the thermal band in to radiant temperature in Degree Celsius at the sensor is believed to alleviate the resource and time consuming procedure that probably hindered the application of thermal band for land cover classification and biophysical information extraction in low cost remote sensing environment.

$$T^{O}C = -50.742 + 0.6621DN - 0.0008DN^2 \quad \text{.........} \mathbf{4.15}$$

Where:
$T^{O}C$ = radiant temperature in Degree Celsius at the sensor and
*DN* = digital number of the thermal band pixels.

Given below is the relation ship of Tasseled Cap transformed image values to temperature calculated according to the above relationship in the study area. These important relationships were used to prepare additional thermal layers for use in the land cover classification. This process supplies additional variability that enhances accurate classification of subtle differences between ground objects. As the preliminary result given below refers to January image – a month that is mostly dry in the research area- this effort is expected to increase our understanding on the moisture situation of heterogeneous semi-dry land. A second-degree polynomial relationship was calculated to determine the relationship of this variable to Tasseled Cap outputs of ETM+ and TM images.

| | b0 | b1 | b2 | $R^2$ |
|---|---|---|---|---|
| BRIGTNES | -235.09 | 20.2867 | -0.2886 | 0.634 |
| GREENESS | 49.4465 | 7.0130 | -0.1541 | 0 .216 |
| WETNESS | 346.854 | -13.104 | 0.1803 | 0 .687 |

$$Tasseledcap = b_o + b_1 \times^o C + b_2 \times^o C^2 \quad \text{.........4.16}$$

Where $^o$C is radiant temperature in degree centigrade.

Emmisivity is difficult to model in such a highly heterogeneous landscape (Lillesand et al 2004). Moreover, the use of kinetic temperature over radiance temperature adds insignificant value as long as its aid for classification is concerned. Hence estimating the surface kinetic temperature is considered not worth the time and effort needed to achieve it.

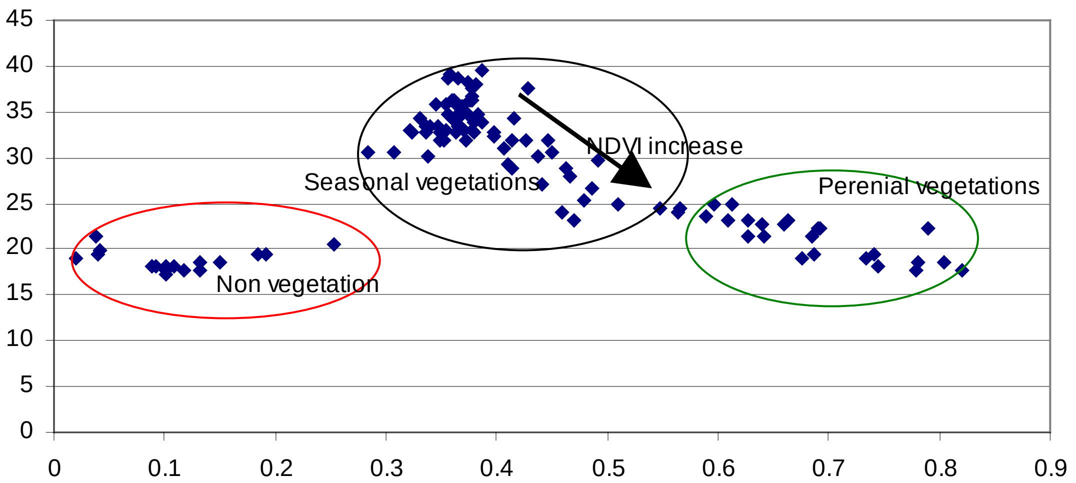



**Fig 4.10 Temperature vs NDVI**

## 4.3 Land Cover Classification Methods and Their Applicability to this Study

Image classification is one of the ancient and basic tasks of applied Remote Sensing. It sounds simple and sometimes it is. However, the effort to improve our land cover classification ability will not stop in foreseeable future as the need for spatially explicit detail always grows and new generation remote sensing practices continue to develop. Construction of sophisticated and latest scanning technologies such as the hyperspectral scanners have been derived by the need to explicitly identify and classify special targets, periodical events, and other needs of the user community. There are several classification strategies and techniques that attempt to satisfy certain remote sensing product conditions and end use requirements. These can be generally categorized into two broad categories; deterministic and fuzzy classifications.

### 4.3.1 Deterministic Classification

Deterministic classification entails the isolation of certain pixel information into few defined classes. A pixel will fall into one and only one category devoting 100% of its information to the class it is assigned. On the other hand the fuzzy classification system tries to retain the multiple facets of a single pixel (Kruse 1993). A pixel more often not is composed of several materials. In fuzzy classification methods, a pixel may fall under certain classes with certain degree of contribution. For example, there is not as such a clear line between a grassland and open woodland in natural conditions. Fuzzy classification tries to retain such natural phenomena.

Deterministic/crisp classification can be further divided into four broad categories. These are: 1) Manual classification, 2) Semi-automated (supervised) digital classification 3) Automated (unsupervised) digital classification and 4) Knowledge Base Classification.

#### 4.3.1.1 Manual Classification

Manual classification of remotely sensed data is delineating polygons along pixels that the interpreter believes belong to the same class based on the colour, tone, texture, shape, pattern, and relationship to other objects. This can be achieved through on-screen digitisation or classifying hard copies. It is an effective method of classifying land cover especially if the analyst has a previous knowledge of the area. Knowledge of reflectance properties of ground materials is also useful.

The advantage of manual interpretation is the use of human judgement to relate the attribute of a group of pixels to features on the ground. As it can be done without having computer at hand, field classification along with the inhabitants in the area is possible. However, it is a tedious, subjective and slow process, which may not be exactly repeated if other interpreter does it. Moreover, only three bands at a time are used for classification, thereby by loosing the huge potential of information stored in the other bands.

### 4.3.1.2 Automated Supervised Classification

Supervised classifications require *a priori* knowledge of the scene area in order to provide the computer with unique material groups or what are called "training classes". Regions containing a material of interest within a scene are delineated graphically and stored for use in the supervised classification algorithm. It is the job of the user to define the original pixels that contain similar spectral classes representing certain land cover class. The most common supervised classification techniques are the Maximum Likelihood classifier for parametric input data and Parallelepiped classifier for non-parametric data.

Maximum Likelihood Classifier (MLC) assumes that a pixel has a certain probability of belonging to a particular class. These probabilities are equal for all classes and the input data in each band follows the gaussian (normal) distribution function (Lillesand et al 2004). Maximum Likelihood Classifier functions by using the band means and standard deviations from field collected data in order to project land cover classes as centroids in feature space. These centroids of each land cover classes are circumscribed by probability contours. The probability density function assumes that the sample values for each class are normally distributed. The unclassified pixels are plotted in the same feature space and get a posteriori probability. Usually the pixels are then assigned to the class for which they have highest membership probability. But it is possible to soften the maximum likelihood classification by using the a posteriori membership probability values as indices of class membership (Bastin1997).

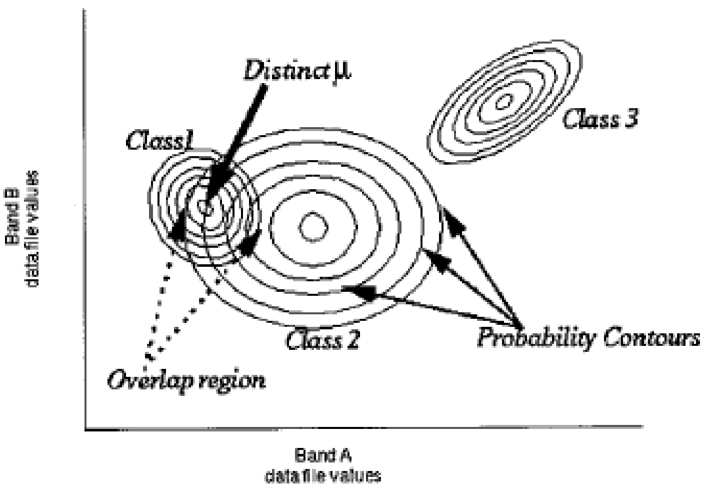



**Fig 4.11 Maximum Likelihood Classifier. Source: ERDAS IMAGINE® 1997.**

The strong advantage of Maximum Likelihood method is its use of well-developed probability theory. However, it has also serious known drawbacks under certain circumstances. First, if the histogram of the image does not follow normal distribution curve, the basic assumption of this classifier is violated and results in poor or misleading result. Moreover, insufficient ground verification data leads to wrong estimation of the mean vector and the variance-covariance matrix of population, thereby resulting in poor classification. In case of high correlation between two bands, as it usually occurs in Landsat images, or when the data used for signature development is not sufficiently heterogeneous, the covariance matrix becomes unstable. Such redundancy should be removed through using PCA or other robust statistical method before proceeding to classification.

Input images do not always contain a normally distributed data value. In such cases, instead of MLC, the other classifiers with non-parametric decision rules like the Parallelepiped method perform better. In the parallelepiped decision rule, the data file values of the candidate pixel are compared to the *a priori* set higher and lower limits of every signature in every band (Leica 2002a).

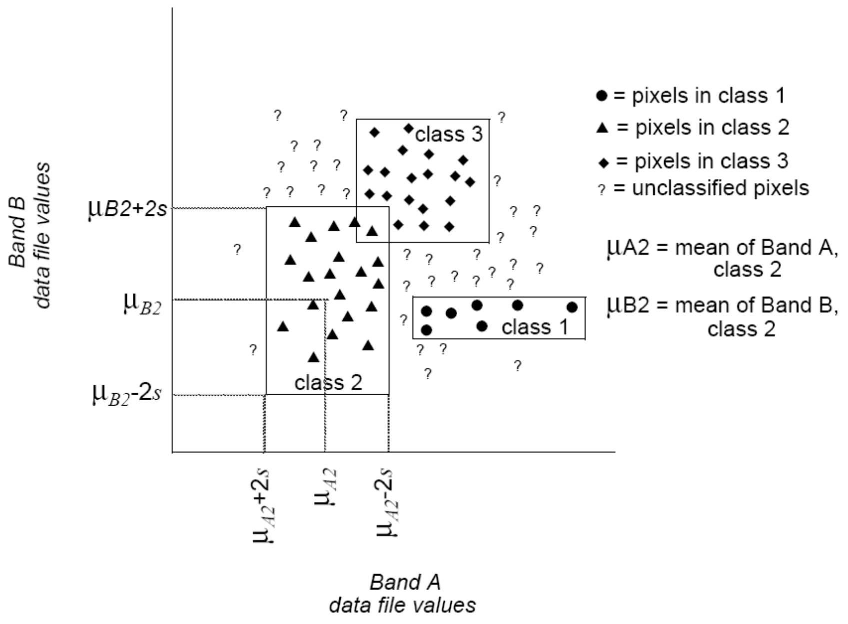



**Fig 4.12 Parallelepiped Classification using ± 2 Standard Deviations as Limits. Source (Leica 2002a)**

When the data values of a pixel fall in between the threshold values in the signature data for each band, then that pixel is automatically assigned to the class that corresponds the signature. As shown in fig 4.12, all the pixels inside the rectangle (parallelepipeds) are member of the same land cover class. In reality those pixels far from the center and near to corners do not usually have the same attribute as the other member of the class. It also happens that several pixels fall outside the parallelepipeds. In this case either, the user defines some parametric decision rule and distribute them into the available land cover classes or they are assigned as unclassified.

#### 4.3.1.3 Automated Unsupervised Classification

Unsupervised classification algorithms compare pixel spectral signatures to the signatures of computer-determined clusters and assign each pixel to one of these clusters. Knowledge of the materials contained within the scene is not needed beforehand as the computer assesses the inherent variability and determines cluster identification Jensen (1996). Classified land cover maps then require knowledge of the area in order to label each cluster with its equivalent in real world.

There are several clustering methods that can be used for unsupervised classification. The *Iterative Self-Organizing Data Analysis Technique* (ISODATA) is by far the most used method. ISODATA clustering method uses spectral distance of pixels and iteratively clusters pixels, redefines the criteria for each class, and classifies again, so that the spectral distance patterns in the data gradually emerge (Leica 2002a). ISODATA is iterative in that it repeatedly performs an entire classification and recalculates statistics. *Self Organizing* refers to the way in which it locates clusters with minimum user input. The ISODATA method uses minimum spectral distance to assign a cluster for each candidate pixel. The process begins with specified number of arbitrary cluster means or the means of existing signatures, and then it processes repetitively, so that those means shift to the means of the clusters in the data. The ISODATA classifier refines clustering by splitting and merging of clusters (Jensen 1996). Clusters are merged if either the number of members (pixel) in a cluster is less than a certain threshold or if the centres of two clusters are closer than a certain threshold. Clusters are split into two different clusters if the cluster standard deviation exceeds a predefined value and the number of pixels is twice the threshold for the minimum number of members (Leica 2002a).

Several drawbacks are reported in the past. The most serious one is that some of the clusters may be meaningless as they represent a mix of different land covers. It is also not unusual that a single land cover class is split into more than one spectral clusters. Unsupervised classification requires considerable knowledge in order to assign proper land cover lass to each of the clusters. Sometimes it is impossible to do so without post classification ground survey.

#### 4.3.1.4 Knowledge Base Classification

Knowledge Base Classification (KBC) is a classification method where a series of ancillary data, expert knowledge and a series or a hierarchy of decision rules that aid classification are easily incorporated. It is especially applicable when spectral information alone is not adequate for proper classification (Hansen et al. 2000, Defries et al. 2000). For example, a forest in a lowland or highland responds almost similarly to the incoming radiation in all spectral ranges. Elevation information may be required to mark out these two classes. Knowledge Base Classification method easily accommodates such additional information. This method involves building the knowledge base by an expert with first hand knowledge of the data and the application to identify the variables, rules and output classes of interest and create the decision rules. Once these are accomplished a non-expert can simply use similar data and get the images classified by using the already developed knowledge base. Knowledge base classification is mostly used as a post classification procedure to refine previously classified images with additional data.

It is also convenient for land cover classification that involves fine scale temporal resolutions. The monthly MODIS images in this study successfully resulted in a land cover map based on the seasonal phonological changes of vegetation.

### 4.3.2 Fuzzy/Soft Classification

Fuzzy Classification is a relatively new method of classification in which attempts are made to address the problem of mixed-pixels or to represent the hydrogenous nature of land cover through employing the fuzzy logic concept. In conventional classification techniques described above every pixel is treated as full member of one of the classes in the thematic map or completely excluded from that classes (Kruse 1993). Fuzzy logic on the other hand assigns the degree of member ship of each pixel to each land cover class. Thus a pixel may have a membership of 60% to forest, 20% to grassland and 20% to agriculture field.

# Chapter 5

# Multi-Temporal and Multi-Scale Land Cover Classification and Biophysical Information Extraction by Means of Low-Cost Remote Sensing.

## 5.1 Results of Land Cover Classification

### 5.1.1 Derivation of Land Cover Classes from MODIS Datasets

The availability of monthly composite MODIS image data for the entire study area in the rift valley provided an opportunity to observe the change in vegetation characteristics throughout the year for 5 successive years. The logical consequence in the process of land cover classification using such a data set is to make use of the vegetation variability through out the seasons (Zhang et al 2003). The NDVI is the universally accepted and computationally not intensive indicator of vegetation. To this effect, 5 NDVI based plant phonological variability were selected. These are:

- Total sum: the sum of all 5 year NDVI layers
- The average NDVI difference between growing period and non growing seasons[4]
- Sum of NDVI when the monthly rainfall drops below some threshold and when the temperature is above average.
- Yearly mean NDVI
- Overall average NDVI

The chart given below is the temporal NDVI characteristics of the 5 years average value of some randomly selected points from the agriculture class.

[4] The growing period and dry seasons are different for the northern and southern part of the study area.

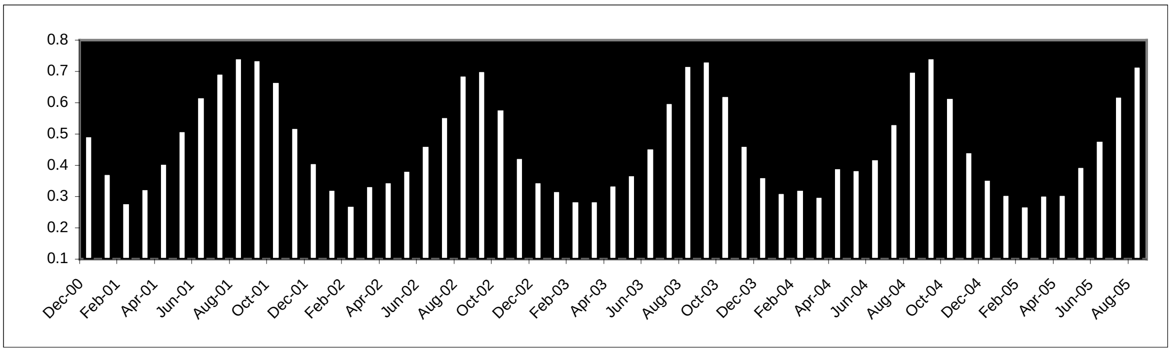



**Fig 5.1 Temporal NDVI pattern in the agriculture fields of the study area. (Prepared from five years MODIS data averages).**

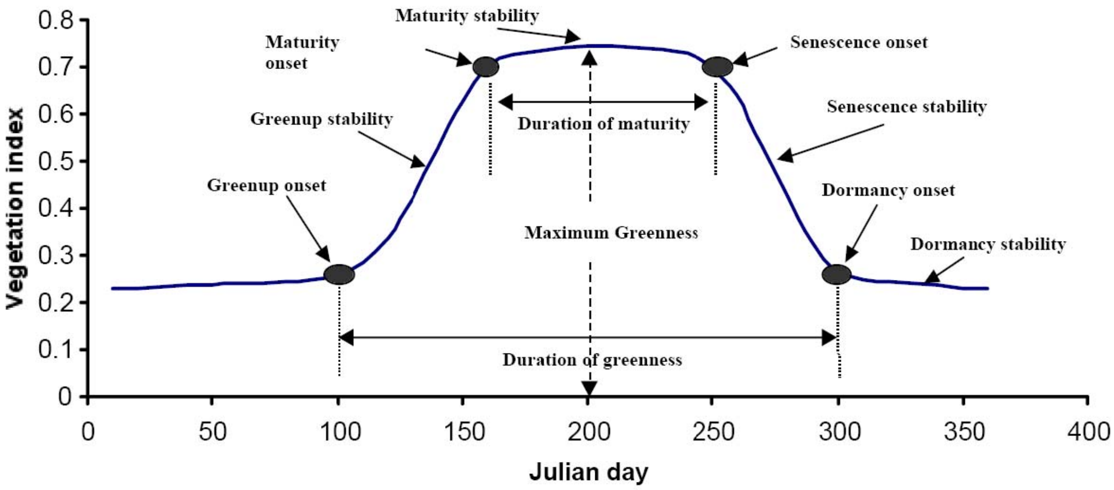



**Fig. 5.2 Temporal pattern of vegetation in a season. ( Zhang et al 2003)**

These phenology metrics were used in tandem with climate layers to develop a knowledge base where a non-parametrical decision rule might be employed for classification (Hansen et al. 1996, Defries et al. 2000). ERDAS IMAGINE ® software provides an easy to handle graphical interface to develop the knowledge base, to determine the hypotheses (outputs) and construct decision rules. Decision rules may be expressed simply in upper or lower thresholds of each input layer in the knowledge base or a chain of logical or conditional expressions may be used.

Based upon the characteristics of the phenology metrics, ten land cover lasses (termed as hypothesis in KBC) have been assumed to be correctly discerned. Two classes namely the irrigation agriculture and urban areas were directly masked from ancillary data and incorporated in the knowledge base. The final KBC output resulted in 12 distinctly classified land cover classes.

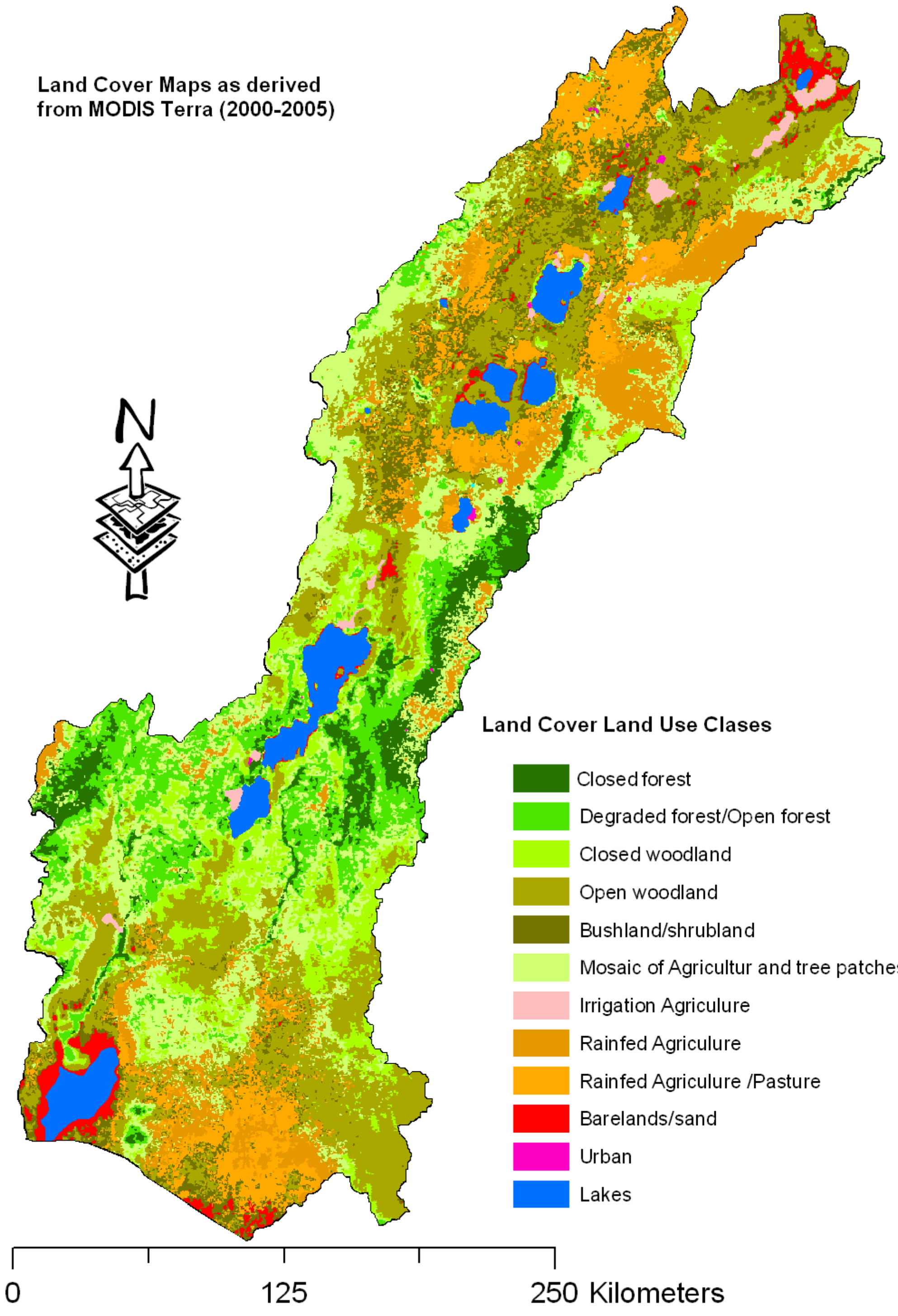
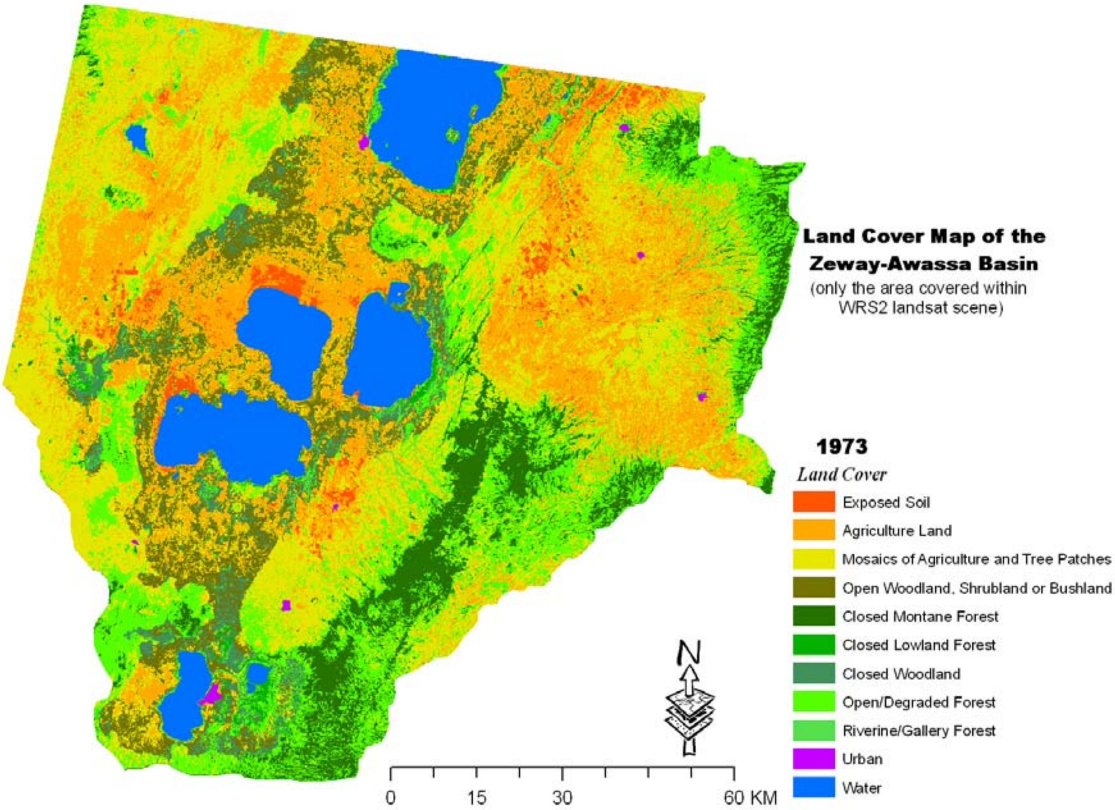


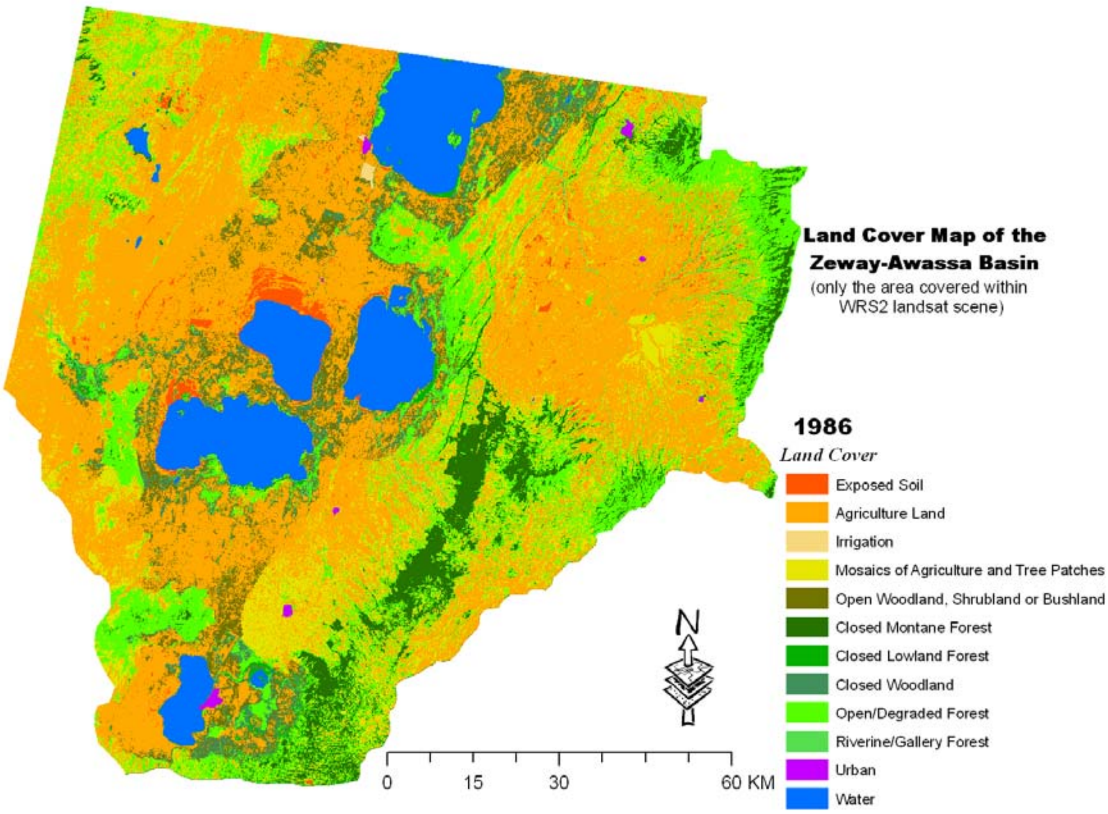

**Fig. 5.3 Land cover map of the central Rift Valley as derived from MODIS monthly composites**

### 5.1.2 Classification of Landsat Imagery

The three period Landsat imageries were classified using the supervised classification technique. The histogram of all imageries at each band showed acceptable normal distribution pattern. Therefore, employing the Maximum Likelihood classifier was found out to be appropriate. Since three different kinds of radiometric and atmospheric corrections had been tested to facilitate change detection, along with the original imageries, there was four possible input options. Moreover, the addition of calibrated thermal layer provided extra combination. Initial thematic quality was made only on the recent image, so that only the best method might have been implemented to the other periods too. Imageries that passed through the Empirical Line Calibration and Modified Flat Field calibration methods offered no added value to classification. In fact, these imageries failed to accurately differentiate between shaded area and saline water bodies. Direct classification of the original image with out any radiometric and atmospheric adjustment coupled with calibrated thermal layer resulted in a thematic map that was competitive to image based atmospherically adjusted imageries.

After the supervised classification, it was realized that a refined classification to further discriminate the forest types was necessary. The service of Knowledge Base Classification was called again. Vector maps that represent rivers and streams, urban areas and current large-scale irrigation fields along with DEM were entered into the knowledge base. A preliminary legend was already attached to the supervised classified maps. A decision rule on proximity to rivers and elevation was set. For example, the boarder between lowland and highland was set to be 1800 meters above sea level. Riverine forests were also delineated according to their nearness to rivers and streams. A forest area in the supervised maps, which were located within 100 meters of distance to rivers and streams, therefore reassigned to be riverine forests. Such refined classification was deemed necessary in order to determine what kind of forest classes were subjected for degradation or deforestation through out the study period. Supplementary details are given in the section where change processes are further recounted.


Land Cover Map of the
Zeway-Awassa Basin
(only the area covered within
WRS2 landsat scene)
1973
Land Cover
Exposed Soil
Agriculture Land
Mosaics of Agriculture and Tree Patches
Open Woodland, Shrubland or Bushland
Closed Montane Forest
Closed Lowland Forest
Closed Woodland
Open/Degraded Forest
Riverine/Gallery Forest
Urban
Water
N
0
15
30
60 KM


Land Cover Map of the
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1986
Land Cover
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Open Woodland, Shrubland or Bushland
Closed Montane Forest
Closed Lowland Forest
Closed Woodland
Open/Degraded Forest
Riverine/Gallery Forest
Urban
Water
N
0
15
30
60 KM

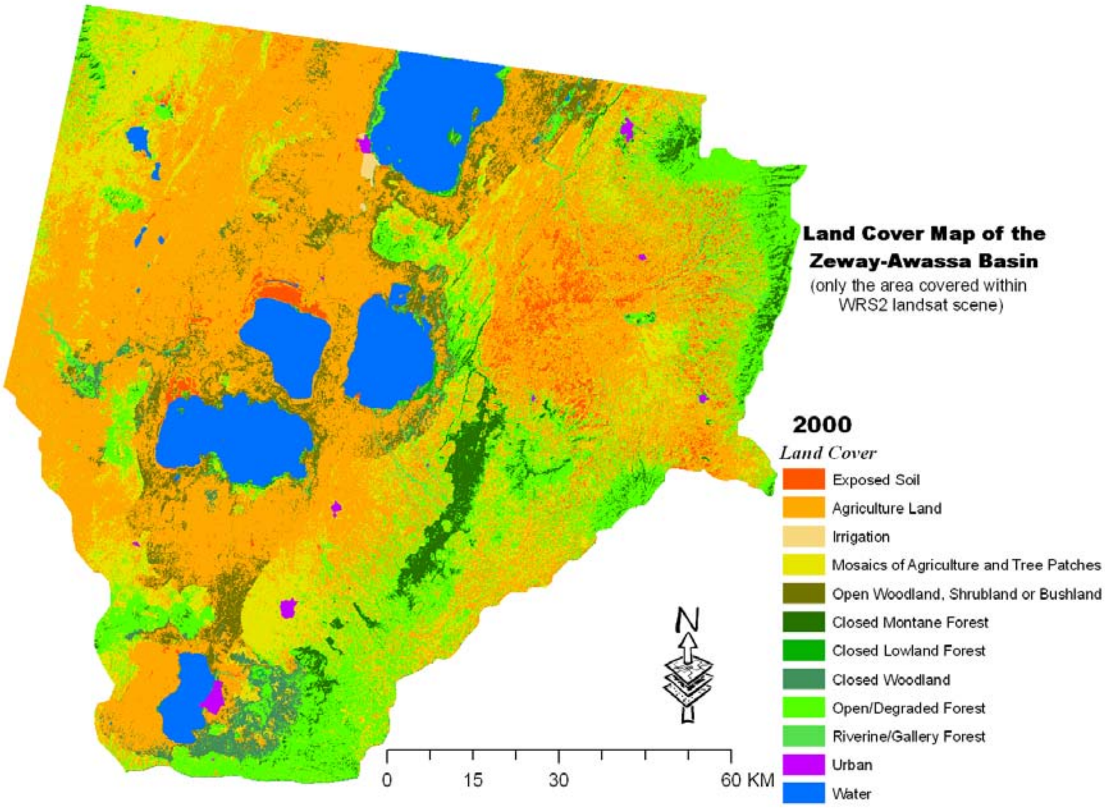


**Fig 5.4 Land cover maps derived from a) 1973 Landsat MSS, b) 1986 TM and c) 2000 ETM+**

The extent of each land cover class was limited to the portion of the basin that was covered by one WRS2 (world reference stem of the Landsat satellites).

**Table 5.1 Size and proportion of land cover classes from 1973-2000**

| | *Y1973* | | *Y1986* | | *Y2000* | |
|---|---|---|---|---|---|---|
| | Area (Ha) | % | Area (Ha) | % | Area (Ha) | % |
| Agriculture Land | 275677.2 | 21.22 | 586134.6 | 45.11 | 591542.0 | 45.53 |
| Closed Lowland Forest | 8641.93 | 0.67 | 6916.1 | 0.53 | 2619.6 | 0.20 |
| Closed Montane Forest | 97989.26 | 7.54 | 69223.2 | 5.33 | 35233.6 | 2.71 |
| Closed Woodland | 45691.61 | 3.52 | 35496.8 | 2.73 | 25099.5 | 1.93 |
| Exposed Soil | 26134.46 | 2.01 | 19383.6 | 1.49 | 33782.2 | 2.60 |
| Irrigation | | | 732.2 | 0.06 | 1249.3 | 0.10 |
| Mosaics of Agriculture and Tree Patches | 383515.38 | 29.52 | 171501.0 | 13.20 | 208704.2 | 16.06 |
| Open Woodland, Shrub land or Bush land | 108680.33 | 8.36 | 66956.4 | 5.15 | 60778.9 | 4.68 |
| Open/Degraded Forest | 222147.81 | 17.10 | 215434.6 | 16.58 | 210302.2 | 16.19 |
| Riverine/Gallery Forest | 5723.67 | 0.44 | 5979.3 | 0.46 | 5974.2 | 0.46 |
| Urban | 1997.61 | 0.15 | 2103.1 | 0.16 | 3952.7 | 0.30 |
| Water | 123142.61 | 9.48 | 119464.1 | 9.19 | 120115.5 | 9.24 |

## 5.2 Accuracy Assessment

Land cover maps derived from remote sensing always contain some sort of errors due to several factors which range from classification technique to method of satellite data capture. In order to wisely use the land cover maps which are derived from remote sensing and the accompanying land resource statistics, the errors must be quantitatively explained in terms of classification accuracy. Whether the output meets expected accuracy or not is usually determined by the users themselves depending on the type of application the map product will be used latter. Accuracy levels that are acceptable for certain task may be unacceptable for others.

The most common and typical method used by researchers to assess classification accuracy is the use of an error matrix (Congalton et al. 1999). It is also sometimes referred as confusion matrix or contingency table. An error matrix is a square assortment of numbers defined in rows and columns that represent the number of sample units (i.e., pixels, clusters of pixels, or polygons) assigned to a particular category relative to the actual category as confirmed on the ground. The rows in the matrix represent the remote sensing derived land use map, while the columns represent the reference data that were collected during fieldwork. These tables produce many statistical measures of thematic accuracy including overall classification accuracy, percentage of omission and commission error and the kappa coefficient, an index that estimates the influence of chance (Congalton et al. 1999).

Error of omission is the percentage of pixels that should have been put into a given class but were not. Error of commission indicates pixels that were placed in a given class when they actually belong to another. These values are based on a sample of error checking pixels of known land cover that are compared to classifications on the map. Errors of commission and omission can also be expressed in terms of user's accuracy and producer's accuracy. User's accuracy represents the probability that a given pixel will appear on the ground as it is classed, while producer's accuracy represents the percentage of a given class that is correctly identified on the map. One of the problems with the confusion matrix and the kappa coefficient is that it does not provide a spatial distribution of the errors (Foody 2002).

The quality and sufficiency of reference data is important if reliable accuracy assessment is sought. A reference data that is not verified thoroughly should not be expected to set accuracy standard. Insufficient number of verified data also affects the quality of the assessment Congalton et al. (1999).

**Table 5.2 An error matrix for ETM derived land cover map and ground verified land cover**

| | Reference | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Land Cover | Closed forest | Open/Degraded forest | Closed Woodland | Open Woodland/ Shrubland | Mosaic of Agriculture and Trees Patches | Agriculture Land | Exposed Soil | Water | N | User's accuracy |
| Classified Image | Closed forest | 5 | 2 | | | 1 | | | | 8 | 0.63 |
| | Open/Degraded forest | | 6 | | | 1 | | | | 7 | 0.86 |
| | Closed Woodland | | | 10 | 1 | | | | | 11 | 0.91 |
| | Open Woodland/Shrub land | | | | 15 | | | | | 15 | 0.8 |
| | Mosaic of Agriculture and Trees Patches | | | | | 7 | 1 | | | 8 | 0.88 |
| | Agriculture Land | | | | 2 | 1 | 19 | | | 22 | 0.86 |
| | Exposed Soil | | | | | | 1 | 6 | | 7 | 0.86 |
| | Water | | | | | | | | 5 | 5 | 1 |
| | N | 5 | 8 | 10 | 18 | 10 | 21 | 6 | 5 | 83 | |
| | Producer's accuracy | 1.00 | 0.75 | 1.00 | 0.8 | 0.58 | 0.86 | 1.00 | | | |

The Overall accuracy of the whole classification is 0.83, which is comparatively not bad as the differentiating between vegetation types is always difficult at the ETM+ resolutions in such dry environment. The Kappa coefficient is calculated to be 0.74 according to the formula given by Congalton et al. (1999).

$$\kappa = \frac{N \sum_{i=1}^{r} X_{ii} - \sum_{i=1}^{r} (X_{i+} \times X_{+i})}{N^2 - \sum_{i=1}^{r} (X_{i+} \times X_{+i})} \qquad \textbf{5.1}$$

Where:
$r$ = the number of rows in the error matrix,
$X_{ii}$ = the number of observations in row i column i (along the major diagonal),
$X_{i+}$ = is the marginal total of row i (right of the matrix),
$X_{+i}$ = the marginal total of column i (bottom of the matrix),
$N$ = the total number of observations included in the matrix.

It is not uncommon that the Kappa coefficient appears to be low, giving the impression that the classification of remote sensing performed better than chance only by K point of proportion. There are researchers who oppose the use of kappa for performance determination of land cover classification based on satellite because it underestimates the actual classification accuracy (Congalton et al.1999).

Note that in the table given above, it was only tried to assess the classification accuracy of the supervised classification output from the ETM+ images. The refined classification that was given as final product incorporates actual field collected data, DEM and hydrology information. It would lead to wrong conclusion if the final refined data product were used for accuracy assessment. That is why some classes are missing from the error matrix. Since there was no means to find reference data for the older images, the accuracy assessment for the other periods was omitted.

## 5.3 Procuring Biophysical Information through Low-Cost Remote Sensing

### 5.3.1 Spectral Characteristics of Plant Leaves

The energy-gas exchange activity of plants primarily takes place in leaves. Leaves are also the main plant parts whose reflectance property is predominantly detected by earth-observing remote sensing systems. Due to the unparalleled importance of leaves in the food chain, optical properties of leaves have been the subject of scientific interest since the beginning of laboratory remote sensing (Guyot 1990, Jacquemoud et al. 2001). Today, the relationship between leaf spectral properties and chlorophyll concentration, water content, dry matter production and their anatomical structure is well-defined and documented for certain species and environment. This advance in remote sensing allows users, be it in agriculture or environmental monitoring, to quickly identify changes, estimate yield expectation and cope with other needs. For instance, plant stress resulting from an insect attack or a nitrogen deficiency induces degradation of the leaf chlorophyll content, which has repercussions on the leaf optical properties. A number of studies have associated spectral reflectance responses of plant leaves to plant productivity under given environmental conditions (Tucker et al. 1984, Justice 1986, Guyot 1990, Nemani et al. 1993, Gower et al. 1999).

The visible range (400-700 nm) of the electromagnetic spectrum is characterized by a strong absorption of light through chlorophyll pigments in green leaves. Except for the yellow-green region (550 nm), these pigments absorb the major part of incident radiation. Leaf reflectance is usually lower than 15% and the amount of transmittance is comparable to the amount of reflectance (Guyot 1990). According to Guyot (1990) and Jacquemoud et al (2001), in the near infrared plateau at 700-1300 nm, observed absorption is limited to a maximum of 10%. Leaf pigments and cellulose cell walls appear transparent in this range. Reflectance reaches up to 50% depending on the anatomical structure of the leave (Grant 1987). The middle infrared (1300-2500 nm) is also known for its strong absorption, primarily by water in a fresh leaf and secondarily by dry matter when the leaf wilts. In this range there are strong water absorption bands at 1450, 1950 and 2500 nm wavelengths and leaf reflectance is the lowest. The ranges in between these three absorption maxima are important for vegetation remote sensing as water content of the leaf highly influences the reflectance property in these regions (Tucker 1980). Bands 6 and 7 of the MODIS sensors on board the Terra as well as bands 5 and 7 of Landsat TM and ETM+ are appropriately centered to collect the reflectance information in these ranges. Therefore, understanding these optical characteristics of leaves either under laboratory conditions or field trials is one of the prerequisite for any attempt to extract biophysical information from remote sensing products (Guyot 1990, Asrar et al. 1992, Jacquemoud et al 2001, Goetz et al. 2003).

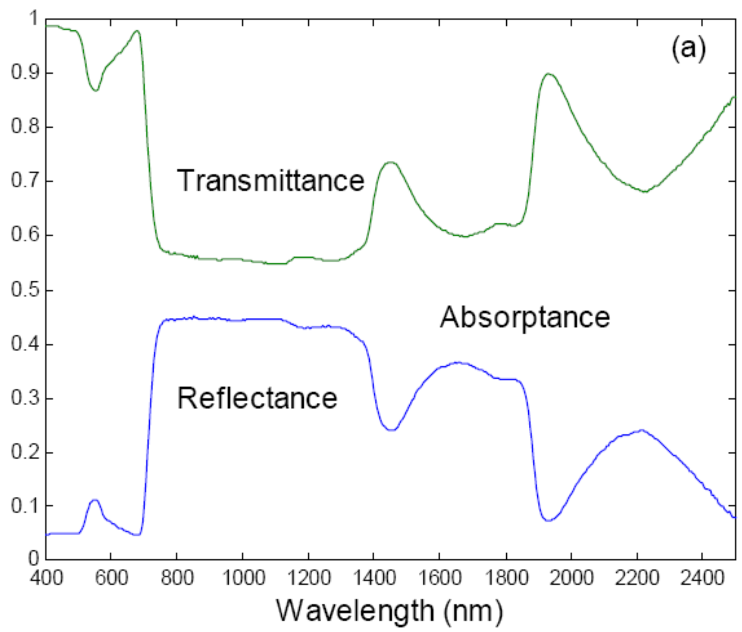


**Fig 5.5 Spectral characteristics of fresh leaves. Sources: (Guyot 1990 and Jacquemoud et al 2001)**

### 5.3.2 Estimating Leaf Area Index for Wide Area Coverage

Leaf Area Index (LAI) is defined as one-sided green leaf area per unit ground area in broadleaf canopies (Stenberg 1996). LAI is one of the important structural variables to understand the process of plant ecosystems performance and estimate productivity (Justice 1986, Baret et al. 1991, Curran et al. 1992, Gower et al. 1999). It is directly related to several physical processes of the vegetation, for example the fraction of photosynthetically active radiation that is absorbed by the canopy (Wiegand et al. 1990). Since plant canopies are composed of leaves- which is a direct source of the energy-matter interactions and which are observed by earth-observing remote sensing systems- LAI has been an attractive variable of interest in vegetation remote sensing.

Since the early stage of space borne remote sensing, many attempts have been made to estimate LAI for large areas using various types of remote sensing products (Tucker 1980, Wardley et al. 1984, Turner et al. 1999). Remotely sensed estimation of LAI has been primarily based on the empirical relationship between the field-measured LAI and sensor-observed spectral responses (Curran et al. 1992, Peddle et al. 1999). Remotely sensed spectral responses of green leaves are usually represented by proxy measurements or spectral vegetation indices. Normalised difference vegetation index (NDVI), for example, is one of the most widely used indices to indirectly estimate LAI. According to Justice (1986), the maximum NDVI value in a season corresponds to the maximum LAI of vegetation cover.

However, vegetation indices are sensitive to the combined effect of the canopy structure and the sun-sensor geometry (Goetz 1997, Deering et al. 1999), making it difficult to develop a universal model to estimate LAI. Adequate ground-collected LAI data acquired in the study area during the satellite pass is therefore a fundamental prerequisite in remotely sensed estimation of LAI. Measuring LAI on the ground is very difficult and requires a great amount of time and efforts (Gower et al. 1999). This is particularly prevalent in forests and densely wooded areas where the canopy structure is much more complex than grasslands and agriculture systems.

There are at least four widely used methods for ground based LAI estimation.

1. Cut and Measure: This is a destructive harvesting method and directly determining the one-sided leaf area, using squared grid paper, planimeter, photographing the harvested leaves arranged in single layer and digitising, or measuring area optically based on an automatic area measurement system. This method is rarely used for large sample areas or for forest LAI estimation.

2. Proxy Parameters: This method involves the collection of other parameters that have direct connection to the LAI, for example, collecting and weighing leaf litter fall of the area and then converting to leaf area by determining specific leaf area (leaf area/leaf mass) for sub-samples. The weight leaf area relationship is determined *a priori*.

3. Allometry: It is commonly used in forest LAI, estimation of carbon assimilation and productivity estimation studies. This method is based on simple physical dimensions, such as stem diameter at breast height, using species-specific or stand-specific relationships based on detailed destructive measurement of a sub-sample of leaves,

branches, or whole individuals. It is expensive and time consuming to develop the relationship.

4. Non-contact methods: This method largely relies upon optical instruments to measure the LAI without direct contact. If the cost of the equipments is justifiable for the study, this method is easy and efficient. Some of the instruments and techniques often used are, e.g. the Decagon Ceptometer, the LICOR LAI-2000. Analysis of hemispheric or wide-angle photographs may also be used to determine LAI.

There are also other indirect-contact LAI estimation methods such as plumb lines and inclined point quadrates, which are not widely used. Gower et al. (1999) reported that a comparison of direct and indirect estimates of across a wide variety of ecosystems resulted in discrepancies of LAI in a range of 25-30% for most canopy types.

### 5.3.3 Establishing Empirical Relation Ship Between Remote Sensing Variables and LAI

Once the ground LAI of representative areas is known, the next step is to extrapolate this value to a wide area by means remotely sensed imageries. Several authors used different type of vegetation indices to develop an empirical relationship between the ground collected and satellite-derived variables. Peterson et al. (1987), Curran et al. (1992), Nemani et al (1993) and Turner et al. (1999), used NDVI and Simple Ratio (SR) to estimate allometric-based ground LAI with varying success. Nemani et al. (1993) reported the estimation strength ($R^2$) of NDVI to be only 0.32, while Peterson et al (1987) showed that an $R^2$ of 0.91 was achievable. The allometric method itself makes use of the empirical relationship between parameters in order to determine LAI, thereby incorporating uncertainties in the relationship. In addition to the influence of the selected appropriate vegetation index, the specific type of mathematical or statistical approach applied to establish the relationship matters.

Nemani et al. (1993) found that the addition of a SWIR reflectance to NDVI improves its ability to estimate leaf area in open forest canopies. The SWIR observation improves the delineation of background materials (e.g. soil, litter), whose influence on the vegetation index increases with decreasing canopy closure. Using a geometric-optical model, Brown et al (2000) found that simulated Reduced Simple Ratio (RSR) has a reduced range of LAI compared to SR for a variety of realistic background reflectance conditions in the boreal forest. Their results suggest that improved LAI estimates can be obtained using the RSR in place of SR observations.

### A. Calculating VIs

This study tests some of the widely used VIs derived from MODIS Terra imagery to find out the most suitable one for estimation of LAI in the Ethiopian Rift Valley and its immediate surroundings. The indices selected, the required MODIS bands to calculate them and their unique characteristics are summarised in the table below.

**Table 5.3 Summary of VIs**

| *The index* | *Formula* | *Remark* |
|---|---|---|
| Naturalized Differential Vegetation Index | $\frac{NIR - RED}{NIR + RED}$ | Sensitive to green vegetation. Normalization reduces the effect of sensor calibration. |
| Corrected Naturalized Differential Vegetation Index | $\frac{NIR - RED}{NIR + RED} \times \left[1 - \frac{MIR - MIR_{MIN}}{MIR_{MAX} - MIR_{MIN}}\right]$ | Nemani et al 1993 |
| Percent Vegetation Cover | (Standardized NDVI)$^2$ | Carlson et al 1997 |
| Simple Ratio | $\frac{NIR}{RED}$ | |
| Reduced Simple Ratio: | $\frac{NIR}{RED} \times \left(1 - \frac{MIR - MIR_{MIN}}{MIR_{MAX} - MIR_{MIN}}\right)$ | Brown et al., 2000 |
| Soil Adjusted Vegetation Index: | $\left(\frac{NIR - RED}{NIR + RED + L}\right) \times (1 + L)$ | Minimizes the secondary backscattering effect of canopy-transmitted soil background reflect radiation. Describes both vegetation cover and soil background. (Heute 1988) |
| Greenness (Tasselled cap) | See chapter 4 section 4.4.5 | It contains information from all bands in the image. |

Where:
NIR = Reflectance in Near Infrared Band
RED = Reflectance in the RED Band
MIR = Reflectance in the Mid Infrared Band (Use MODIS band 6 as MIR)
$MIR_{MIN}$[5] = the lowest MIR value in the image
$MIR_{MAX}$[6] = the highest MIR value in the image
L depends on LAI, but 0.5 is a suggested value for many land cover conditions

[5] $MIR_{MIN}$ corresponds to MIR reflectance from completely closed canopies.

[6] $MIR_{MAX}$ corresponds to MIR reflectance from open canopies.

### B. Ground Collected LAI

A half-meter by half-meter quadrants were demarcated in the 44 stratified random samples Grasses and herbs were harvested, their green biomass was weighed at the site and the area of each leaf in the sample was measured digitally. The sampling was only applied to land cover classes dominated by grass and herbaceous plant as well as to agriculture fields that are fairly homogeneous to represent a MODIS pixel. Because the aim of this study emphasises on investigation of ecosystem productivity in terms of animal feed, wooded areas were of no particular interest during biomass modelling. The influence of few scattered trees on the entire pixel is assumed to be too insignificant to interfere in the empirical modelling process. Random samples, which were found to contain sizable woody vegetation components, were excluded from data collection.

**Fig 5.6 Sampling Quadrate,**
**Photo by the Author. August 2005**

**Fig 5.7 Leaves ready for area measurement,**
**Photo by the Author. August 2005**

### C. Establishing the Relationship

There are many statistical and mathematical options to develop a regression model to establish the relationship between the field collected LAI and VIs. A regression method that fits a curve with a minimal deviation from all data points is desired. The best fitting curve to this effect may be obtained through Least Square approach (Lancaster et al 1986). For each observation the distance between the measured and the predicted value can be thought as an error, since, the measured value is not likely to be predicted exactly but differs by some amount ($X_{measured}$ - $X_{estimated}$). This error may be due to difference in moisture content of grasses and agricultural crops, the level of soil spectral interference or simply because of sensor properties. Because the squares of the errors are minimized, the term “Least Squares” regression analysis is used.

Suppose that the data points are $(x_1,y_1)$, $(x_2,y_2)$,………, $(x_n, y_n)$, where x is the independent variable and y is the dependent variable. The fitting curve f(x) has the deviation (error) *d* from each data point, i.e.,

$d_1 = y_1 - f(x_1)$,

$d_2 = y_2 - f(x_2)$ and

$d_n = y_n - f(x_n)$,

Then the sum of least square of the deviation is:

$$d_n^2 = \sum_{i=1}^{n} d_i^2 \quad \text{……………………………………………………5.2}$$

Since $d_i^2 = (y_i - f(x_i))^2$,

$$d_n^2 = \sum_{i=1}^{n} (y_i - f(x_i))^2 \quad \text{……………………………………………………5.3}$$

There are different varieties of Least Square method.

***i. Linear Least Square***

The Linear Least Square method assumes the two different variables follow a straight line. A straight line is given as:

$$y = a + bx \quad \text{……………………………………………………5.4}$$

By substituting f(x) in the equation ***5.2*** by the straight line formula, a linear least square is fitted.

$$d_n^2 = \sum_{i=1}^{n} (y_i - (a + bx_i))^2 \quad \text{……………………………………………………5.5}$$

The unknown coefficients **a** and **b** are calculated from:

$$\left.\begin{array}{l} \sum_{i=1}^{n} y_i = a + b\sum_{i=1}^{n} x_i \\ \sum_{i=1}^{n} x_i y_i = a\sum_{i=1}^{n} x_i + b\sum_{i=1}^{n} (x_i)^2 \end{array}\right\} \quad \text{……………………………………………………5.6}$$

Then:

$$a = \frac{\left(\sum_{i=1}^{n} y_i \times \sum_{i=1}^{n} (x_i)^2\right) - \left(\sum_{i=1}^{n} x_i \times \sum_{i=1}^{n} x_i y_i\right)}{n\sum_{i=1}^{n} (x_i)^2 - \left(\sum_{i=1}^{n} x_i\right)^2} \quad \text{……………………………………………………5.7}$$

$$b = \frac{\sum_{i=1}^{n} x_i y_i - \left( \sum_{i=1}^{n} x_i \times \sum_{i=1}^{n} y_i \right)}{n \sum_{i=1}^{n} (x_i)^2 - \left( \sum_{i=1}^{n} x_i \right)^2} \quad \text{..........5.8}$$

***ii. The Polynomial Least Square***

A simple second-degree polynomial is given as:

$$y = ax^2 + bx + c \quad \text{..........5.9}$$

By replacing the f(x) in the equation *5.2* by the respective polynomial formula above, the least square function becomes:

$$d_n^2 = \sum_{i=1}^{n} \left( y_i - (ax_i^2 + bx_i + c) \right)^2 \quad \text{..........5.10}$$

Solving the following simultaneous equations gives the unknown coefficients **a**, **b**, and **c**.

$$\left. \begin{aligned} \sum_{i=1}^{n} y_i &= c \sum_{i=1}^{n} 1 + b \sum_{i=1}^{n} x_i + a \sum_{i=1}^{n} x_i^2 \\ \sum_{i=1}^{n} x_i y_i &= c \sum_{i=1}^{n} x_i + b \sum_{i=1}^{n} x_i^2 + a \sum_{i=1}^{n} x_i^3 \\ \sum_{i=1}^{n} x_i^2 y_i &= c \sum_{i=1}^{n} x_i^2 + b \sum_{i=1}^{n} x_i^3 + a \sum_{i=1}^{n} x_i^4 \end{aligned} \right\} \quad \text{..........5.11}$$

***iii. Logarithmic Least Square***

The linear Least Square is not always appropriate to fit the optimum curve. Especially in remote sensing, as the VIs approach their highest point, the dependent variable usually increase exponentially. This phenomenon is well explained by using the Logarithmic Least Square method.

$$y = a + b \ln x \quad \text{..........5.12}$$

Then:

$$d_n^2 = \sum_{i=1}^{n} \left( y_i - (a + b \ln x) \right)^2 \quad \text{..........5.13}$$

The unknown coefficients **a** and **b** are given by:

$$a = \frac{\sum_{i=1}^{n} y_i - b\sum_{i=1}^{n} \ln x_i}{n} \quad \text{……5.14}$$

$$b = \frac{\sum_{i=1}^{n} (y_i \ln x_i) - \left(\sum_{i=1}^{n} y_i \sum_{i=1}^{n} \ln x_i\right)}{n\sum_{i=1}^{n} (\ln x_i)^2 - \left(\sum_{i=1}^{n} \ln x_i\right)^2} \quad \text{……5.15}$$

**D. Goodness of Fit ($R^2$)**

It makes no sense to use empirical relationship of two variables unless the independent variable explains the dependent variable at least to some acceptable degree. The correlation coefficient (**r**) or regression goodness of fit (**$r^2$**) may be used to determine the strength of the relationship. The regression coefficient is more informative since it indicates the degree of change between the estimated LAI or green biomass and the field measured green biomass or LAI, whereas the correlation coefficient indicates only whether or not the two variables move in the same or opposite directions and the degree of their linear association. However this additional information obtained from regression function is only at the cost of a more restrictive assumption, namely- the dependent variable is a function of the independent variable (Lesschen et al 2005). It is not necessary to designate which is the dependent and which is independent variable when a correlation coefficient is obtained.

Regression should be used if one has a clearly directional hypothesis, with an independent and dependent variable. Correlation is chosen if one is simply interested in how the two variables are related.

The $r^2$ statistics measures closeness as the percentage of total variation in the dependent variable explained by the regression line. Formally the measure is defined as:

$$R^2 = \frac{\sum_{i=1}^{n} (y_i - x_\mu)^2}{\sum_{i=1}^{n} (x_i - x_\mu)^2} \quad \text{……5.16}$$

Where:
$x_i$ = the measured variable at the $i^{th}$ location
$y_i$ = the estimated value for the $i^{th}$ location and
$x_\mu$ = the mean measured variable.

### E. Result of Curve Fitting

#### *i. Correlation of LAI and VIs*

Leaf Area Index was found to correlate strongly with all vegetation indices calculated from the MODIS image and with green biomass harvested at the same time. Only the Tasseled Cap greenness index and SAVI exhibited correlation coefficients less than 0.8 with both LAI and green biomass. Though it was expected that SAVI might not be performing like the others owing to the prevalence of green vegetation during the month the MODIS image was acquired, Tasseled Cap greenness presumed to perform better than it did. Probably the prototype MODIS Tasseled Cap coefficients that are used in this study still need further investigations before they are applied globally (Zhang et al 2002). The 'corrected' NDVI (NDVIc) excelled marginally in its correlation with biophysical measures of LAI and biomass.

**Table 5.4 Correlation coefficients LAI, biomass and VIs**

| *Correlations* | *LAI* | *Standing Foliage biomass* | *NDVI* | *NDVI_C* | *PVC* | *RSR* | *SAVI* | *SR* | *Greenness* |
|---|---|---|---|---|---|---|---|---|---|
| LAI | 1 | | | | | | | | |
| Standing Foliage biomass | 0.886 | 1 | | | | | | | |
| NDVI | 0.861 | 0.812 | 1 | | | | | | |
| NDVI_C | 0.887 | 0.832 | 0.938 | 1 | | | | | |
| PVC | 0.863 | 0.818 | 0.999 | 0.938 | 1 | | | | |
| RSR | 0.881 | 0.845 | 0.955 | 0.965 | 0.961 | 1 | | | |
| SAVI | 0.793 | 0.724 | 0.937 | 0.802 | 0.941 | 0.879 | 1 | | |
| SR | 0.855 | 0.823 | 0.973 | 0.918 | 0.980 | 0.982 | 0.939 | 1 | |
| Greenness | 0.725 | 0.633 | 0.823 | 0.673 | 0.829 | 0.767 | 0.933 | 0.842 | 1 |

N = 44 and Correlation is significant at the 0.01 level (2-tailed).

#### *ii. Results of Least Square Regression Analysis.*

After having tested several combinations of LSR, the natural logarithmic LSR was found to be better than the others for LAI estimation. Saturation of standardized indices (NDVI, NDVIc and SAVI) saturate as they approach higher points may be the reason. However ratio based VIs (SR and RSR), which do not saturate at all, also demonstrated a better accuracy when natural logarithmic LSR was used to estimate LAI.

The NDVIc excelled marginally to estimate LAI.

**Table 5.5 Regression models to estimate LAI from MODIS derived variables**

| *Input variable* | *Regression model* | *$R^2$* |
|---|---|---|
| NDVIc | LAI = 3.4596*ln(input) + 5.0523 | 0.753 |
| RSR | LAI = 2.1675*ln(input) – 0.5431 | 0.747 |
| SR | LAI = 2.5846*ln(input) - 2.3358 | 0.745 |
| PVC | LAI = 5.4868*ln(input) + 4.2804 | 0.735 |
| NDVI | LAI = 5.0338*ln(input) + 3.9351 | 0.726 |
| SAVI | LAI = 4.8367*ln(input) + 6.0077 | 0.691 |
| Tasseled Cap Greeness | LAI = 2.8056*ln(input) - 19.699 | 0.536 |

In almost all cases, the regression models have been observed to estimate lower LAI values better than the higher ones. This property is most likely due to higher remote sensing variables as a result of the spectral reflectance of scattered trees which were not included in the ground collected data.

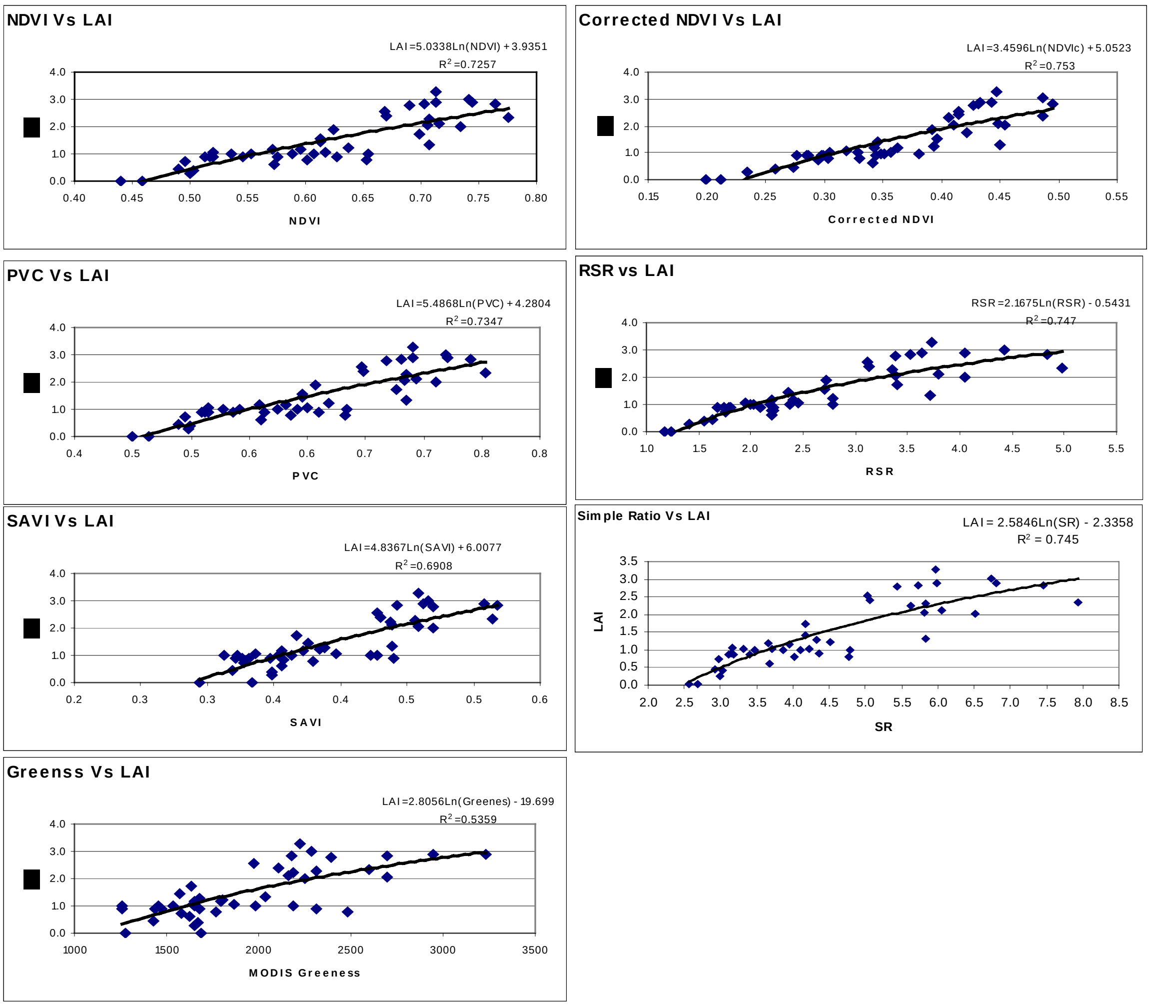


**Fig. 5.8 Results of Least Square Regression**

The measured LAI and the values of the estimated LAI by using the NDVIc were found to be encouragingly comparable. Accordingly, the NDVIc was used to create a monthly LAI raster for the entire study area.

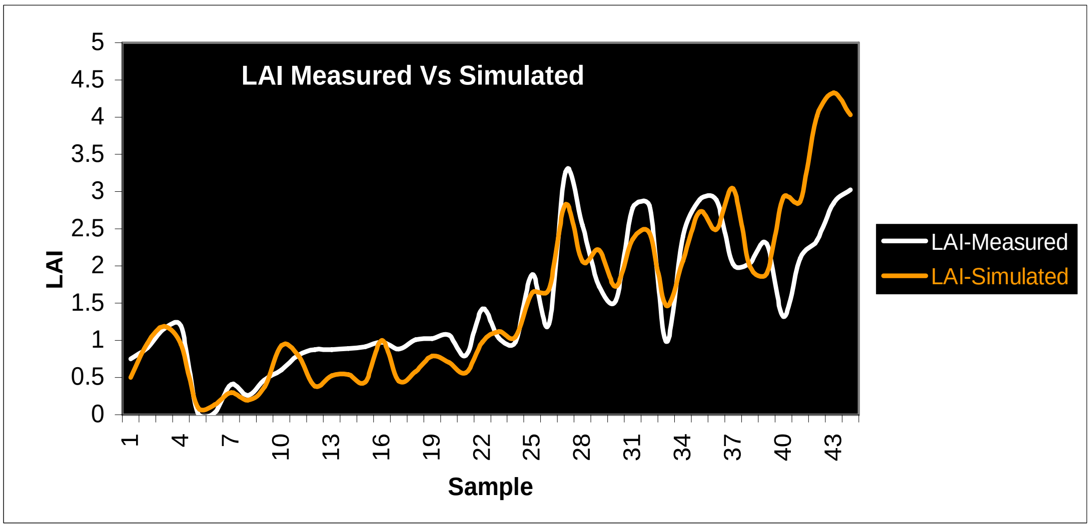


**Fig. 5.9 Comparison of measured and estimated LAI**

### 5.3.4 MODIS-LAI Product

There is a global level 'of the shelf' type of MODIS LAI product. For use in global scale terrestrial ecological models a group of scientist at NASA have been working on project to provide users with a LAI map derived from the MODIS data (NASA 2006). The LAI products are at 1-km resolution and at an 8-day interval. The product was made public in August 2000 through the Earth Resources Observation System (EROS) Data Center Distributed Active Archive Center (Privette et al. 2002). Its accuracy is expected to be ±0.5 LAI (Myneni et al., 2002).

This global product was not used for this study because for a specific site, empirical approaches work well to produce a better ground resolution and reliable LAI map quality from satellite data as the Least Square error regression process finds the best fit between field measurements and satellite data and eliminates the problem of systematic bias (Wang et al. 2004).

### 5.3.5 Standing Biomass and NPP Estimation through Low-Cost Remote Sensing Products.

Basically there are two approaches to estimate the vegetation productivity of an ecosystem by using remote sensing data. These are a) establishing a direct empirical relationship between the green biomass (standing biomass) and remotely sensed vegetation indices (Csaplovics 1992) and b) estimating or predicting the potential biomass by using the physical properties of the area and spectral reflectance data at the visible range (Choudhury 1987, Running et al. 2004, Richters 2005, Hill et al. 2004). Both approaches were tested in this study. The methodology followed and results obtained are given in 5.3.2 and 5.3.3 for method *a* and *b* respectively.

#### 5.3.5.1 Relationships of MODIS Driven Indices versus Biological Variables.

Several recent and old studies in different spatial scales and environment have demonstrated that standing biomass is directly correlated to LAI as well as to several vegetation indices derived from remote sensing (Tucker et al. 1983, Csaplovics 1992). Although the NDVI is the most common index for such operations, the other VIs (see section 5.2.1a) are also reported to demonstrate superiority in some particular environmental settings (Nemani et al. 2003, Carlson et al. 1997, Brown et al. 2000, Zhang et al. 2002). Running et al. (1993) and others showed the importance of LAI in biochemical process modelling to estimate the NPP of an ecosystem in certain environmental settings. It has also been shown that field measured biomass and its corresponding LAI provide a statistical baseline to develop an empirical relationship between the two variables (Grier et al. 1977, Neilson 1995).

#### 5.3.5.2 Estimating Standing Green Biomass Directly from MODIS Variables.

As it is described in section 5.2.1 and presented in fig. 5.4, the strong relationship between the MODIS derived VIs and LAI permitted the retrieval of reliable LAI information for the entire study area in the Rift valley. The presence of field collected LAI data along with its corresponding green biomass weight allowed the development of a relationship model for the two variables. As the two variables were measured from the same specimen, it was not unexpected that the two variables correlate better than the other proxy variables from the remote sensing product. In addition to the correlation test shown earlier, further exponential regression was tested to prove the estimation power of LAI to determine the green biomass/standing biomass.

#### 5.3.5.3 Result

Green biomass was estimated by using a slight different form of LSR from the previous case. Instead of natural logarithm function, exponential function resulted in good agreement.

The goodness of fit ($r^2$)[7] between LAI and green biomass was calculated at 0.82 (n=44, p<0.001), which was better than all the other variables. Accordingly the green biomass for the entire study area was directly estimated from the simulated LAI. Since the estimated LAI used the NDVIc as input, the estimated green biomass is practically the function of MODIS NDVIc. Note the goodness of fit between LAI and NDVI is identical to goodness of fit between NDVI and standing biomass.

**Table 5.6 Regression models to estimate Biomass from MODIS derived variables**

| *Input variable* | *Regression model* | *$R^2$* |
|---|---|---|
| LAI | Standing biomass = $128.91*(input)^{1.3287}$ | 0.82 |
| NDVIc | Standing biomass = $72404*(input)^{6.0035}$ | 0.74 |
| RSR | Standing biomass = $5.7484*(input)^{3.4705}$ | 0.66 |
| SR | Standing biomass = $0.5052*(input)^{3.834}$ | 0.55 |
| PVC | Standing biomass = $11952*(input)^{8.6229}$ | 0.59 |
| NDVI | Standing biomass = $7427*(input)^{8.047}$ | 0.60 |
| SAVI | Standing biomass = $67524*(input)^{6.5652}$ | 0.42 |

The relatively low performance of NDVI is in agreement with Asner (2000) who examined the effects of potential remote sensing error on CASA[8] model and found out that annually estimated values of NPP from the CASA model showed significant sensitivity to NDVI, with errors of up to 30% in modelled NPP values due to plausible errors in NDVI estimation.

[7] The square of the correlation (r) does not yield the regression $r^2$ because the regressions used here to estimate LAI and latter green biomass are not linear (as opposed to the assumption in the correlation function).

[8] Carnegie-Ames-Stanford Approach (CASA) biosphere model

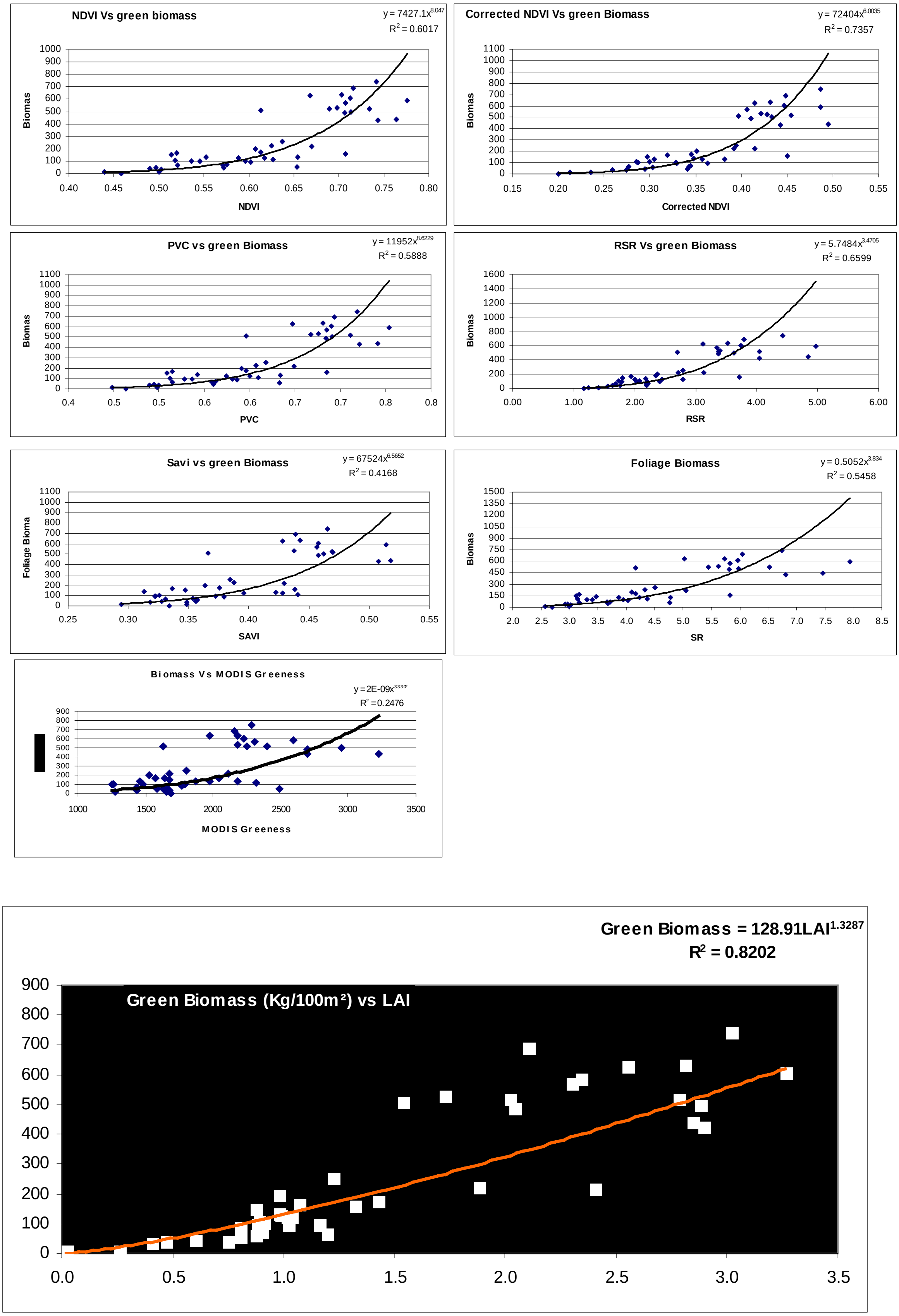


**Fig. 5.10. Least Square Regression results for biomass estimation**

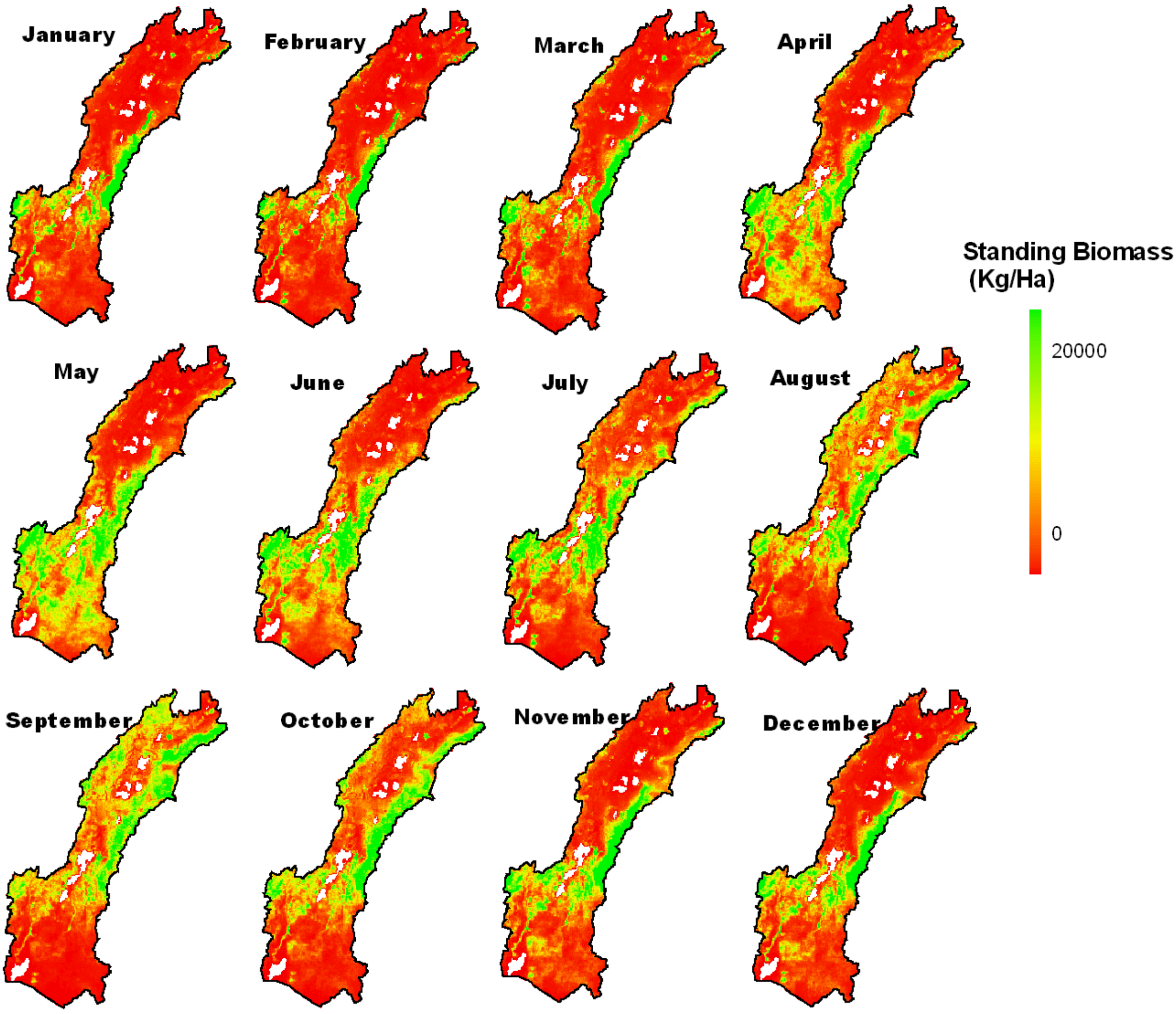


**Fig 5.11 Estimated monthly biomass by land cover class (MODIS derived land cover class)**

The standing biomass differs spatially and temporally throughout the year. More than 80 tons per hectare was estimated to be available during the peak agricultural periods in rainfed agriculture areas of the Zeway sub catchment. During the drier periods from January to March the same area has almost no standing biomass at all. In semi natural ecosystems areas in Lake Abijjata and Lake Shala sub catchments too, the standing biomass fluctuates considerably high. Around August and September, the 5 year average standing biomass estimated to be 13 and 22 tones per hectare for Abijjata and Shala catchments respectively. In drier months, Lake Abijjata catchment supports only 0.25 ton per hectare while the Lake Shala catchment is estimated to have as low as 0.8 tons per hectare. In both the dry and wet seasons, the contribution of woody plants is assumed to be noticeably high, even though it was not thoroughly examined.

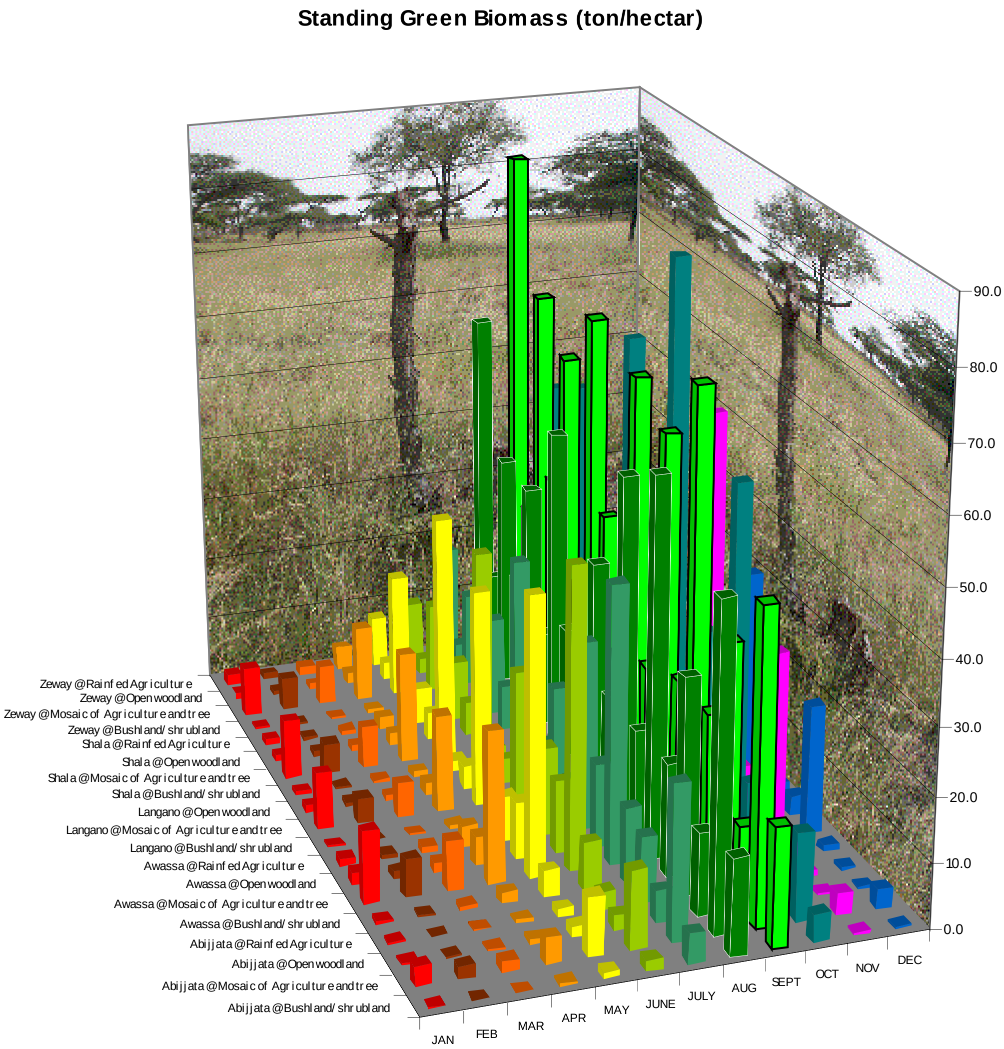


**Fig 5.12. Average monthly standing biomass of selected land cover classes at sub catchment level in Zeway-Awassa Basin.**

### 5.3.5.4 Limitations and Applicability in the Context of This Study

Though the overall estimation performance is found to be very good, there is no means of assessing whether this method is working in acceptable degree for densely wooded areas and forestlands. In fact the model was not intended to estimate the biomass of such classes. Thus the estimation is assumed to be certainly correct only for areas dominated by grass and herbaceous plant as well as for agriculture fields. Since the MODIS imagery has unfortunately very coarse pixel resolution, finding a pixel with one land cover class is hardly possible. Selecting the proper quadrant on the ground that was supposed to represent a 500m by 500m pixel influenced the objectivity of sampling to some degree. Yet again, it was not possible to avoid a situation where a pixel was designated as herbaceous or grass even though some trees were present. The influence of the woody vegetation was not accounted for.

On the positive note, the method is very cheap, fast and the output in small scale is very reliable. For monitoring the monthly vegetation situation in large areas be it for conservation or production purposes, this approach is appropriate, relevant and cost efficient.

### 5.3.6 Assessing the Potential Productivity by Means of Remote Sensing Variables and Physical Attributes of the Area.

In order to understand how satellite images can be employed to assess potential productivity of a certain area, it is important to look through the fundamental biophysical processes. The quantity of biomass a certain area is able to produce basically depends on the photosynthetic activity of the plants to capture radiation energy and to convert it into chemical energy (carbohydrate).

#### 5.3.6.1 Theoretical Background

Referring to the relevance of the laws of thermodynamics and interpreting it as 'the input of energy to an ecosystem is exactly equal to its total output of energy', Montheith (1972) was the first to indicate the direct linear relationship between NPP and the amount of photosynthetically active radiation (PAR). He demonstrated quantitatively how the physiological process of plants to capture solar energy and store it as chemical energy is dictated by atmospheric factors, leaf optical properties and other factors that influence photochemical efficiency. This early pioneer work continues to provide a basis for several remote sensing based studies in the area of plant determination of productivity in several ecosystems (Tucker 1977, Justice 1986, Ruimmy et al. 1994, Goetz et al. 1997, Gower et al. 1999, Running et al. 2004, Hill et al 2004, Richters 2005). Basically gross plant productivity (as expressed by Gross Primary Production –GPP) is given as:

$GPP = \varepsilon * APAR$ ……………………………………………………………………...……..**5.17**

Where:
GPP = the gross primary productivity
ε = the light conversion efficiency
APAR = Absorbed Photosynthetically Active Radiation

Determination of plant productivity through remote sensing is appealing because some of the factors which influence the photochemical process are readily quantified from the diverse spectral information. One of the most important facets in this case is quantifying the real amount of absorbed energy that is available for the plant (APAR) to use it in photosynthesis. The amount of APAR depends on the quantity of solar radiation reaching a surface of the earth and the ability of the vegetation to absorb the radiation. The portion of solar radiation that is absorbed for photosynthetic process has been estimated from spectral reflectance for theoretical explanations and practical operations in several instances of NPP determination (Ruimy et al. 1994, Myneni et al. 1994, Goetz et al. 1998, Reiner 2001, Still et al. 2004). The light absorption and conversion processes vary in time and space, however, and must be adequately modelled in order to use remote sensing to estimate GPP and eventually NPP (Goetz et al 1997). Remote sensing products with high temporal resolution should alleviate this problem provided that other necessary conditions are met. The amount of radiation intercepted by vegetation is directly related to the vegetative leaf area that can also be detected using remote sensing. This makes the logic of radiation conversion efficiency for predicting NPP from remotely sensed inputs an attractive approach (Goward 1995, Running et al 2004, Hill et al 2004, Richters 2005).

This approach is however sensitive to the several input parameters required to estimate vegetation productivity in a plausible precision. There are many sources of uncertainties and careful selection and preparation of input variables is therefore indispensable.

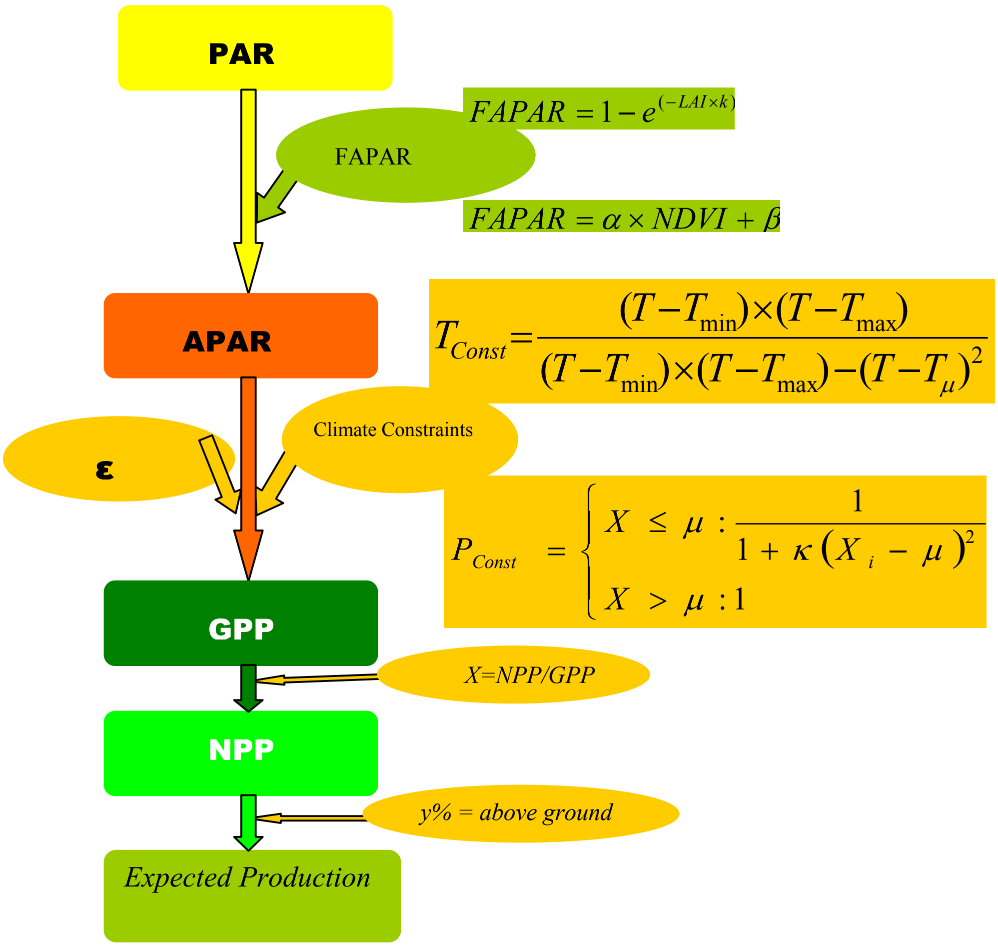


**Fig 5.13.Flow chart of climate and spectral information based productivity estimation**

### 5.3.6.2 Photosynthetically Active Radiation (PAR)

Solar radiation can be measured with pyranometers, radiometers or solarimeters. The instruments contain a sensor installed on a horizontal surface that measures the intensity of the total solar radiation, i.e., both direct and diffuse radiation from cloudy conditions. Where the instruments are not available, like in the case of this study, solar radiation is usually estimated mathematically through the duration of bright sunshine hours. PAR is 45- 48% of the daily incoming solar radiation (Reeves et al 2001, Richters 2005). It is measured in $MJ/m^2$.

### 5.3.6.3 Estimating the Fraction of PAR Available for the Plants (FAPAR)

The estimation of FAPAR theoretically entails observation of plant light utilisation over the visible spectral range (0.4-0.7 μm). The linear relationship of NDVI is extensively used to approximate this fraction (Tucker et al. 1983, Myneni et al. 1994, Gower et al. 1999, Ruimy et al. 1999). The slope of the linear curve and the constant factor differs from one environment setting to the other (Lind et al. 1999 cf. Olsson et al 2002). In the absence of adequate equipments to measure this phenomenon over long period of time, selecting available empirical formula for similar ecological set ups is still widely used (Hill et al 2004). When possible, using such determination method coupled with other method is recommended. For example, some authors stated the LAI could successfully estimate the fraction of PAR available for plants (Myneni et al. 1994, Sellers et al. 1996, Ruimy et al. 1999). Therefore, the two methods can be combined to find the best way to estimate FAPAR.

$$FAPAR = \alpha * NDVI + \beta \quad \ldots\ldots\ldots 5.18$$

Where α = the slope
and β = is the constant.

**Table. 5.7 Examples of α and β values used by different researchers**

| $A$ | $\beta$ | *Author* |
|---|---|---|
| 1.25 | -0.025 | Ruimy et al (1994) |
| 1.164 | -0.143 | Myneni et al (1994) |
| 1.67 | -0.08 | Prince et al (1995) |
| 1.62 | -0.04 | Lind et al (1999) cf. Olsson et al (2001) |
| 1.42 | -0.39 | |

The other alternative or supporting option is the LAI -FAPAR model (Sellers et al. 1996).

$$FAPAR = 1 - e^{(-LAI \times K)} \quad \ldots\ldots\ldots 5.19$$

Where:
LAI = leaf area index
K = light extinction constant (usually it is estimated to be 0.5 for medium stocked canopy)

### 5.3.6.4 Absorbed Photosynthetically Active Radiation (APAR)

APAR is the solar energy (400 - 700 nm) actually consumed by green canopy in the photosynthetic process. Remote sensing of APAR has been achieved through estimation of PAR (see 5.3.3.2) and the fraction of PAR intercepted by the canopy, FAPAR (see 5.3.3.3). The available photosynthetically active radiation is therefore simply the product of FAPAR and PAR (Gower et al. 1999). Since PAR does not fluctuate significantly around the tropics, more attention was directed in this study towards FAPAR. The unit of APAR is $MJ/m^2$ like PAR.

### 5.3.6.5 Environmental Constraints of Converting APAR to Carbohydrate

The amount of biomass produced for each MJ of APAR varies spatially and temporally across ecosystems. This topic has induced an intensive discussion in remote sensing of plant productivity and several researchers have been trying to find out a global efficiency index for different biomes and vegetation types. Given the vast heterogeneous nature of landscapes in their geologic and climatic traits even at local scale, such global index may be farfetched. Therefore, determining the efficiency of light conversion (ε) based on local environmental constraints is a viable alternative (Field et al. 1995, Gower et al 1999).

Research has shown that maximum LAI, which is a function of light conversion efficiency, is well correlated with available soil and water or long-term climatic variables such as annual mean temperature (Grier et al. 1977, Woodward 1987, Neilson 1995). In the Ethiopian Rift Valley, especially the water availability plays an important role in the development of plants. Vegetation status proxies like NDVI, NDVIc, and others tested in this research showed persistence coincidences of their maximums to periods of high monthly average rainfall. In accordance with the objective of this study, the light conversion efficiency of grasses, agricultural crops and other herbaceous plants was of due interest. Feoli et al. (2000), Zerihun et al. (1990) and Zemede (1998) describe that C4 type photosynthesis plants dominate the vegetation composition of the Ethiopian Rift Valley. Therefore, it is safe to adopt a general light conversion rate for C4 type of photosynthesis plants and latter refine it by actual environmental features of the specific location across the entire area. Accordingly, the average optimum value and ranges of cardinal wilting points for this plant category is used to determine the suitability of temperature and precipitation through out the year.

***i. Temperature***

The Rift Valley is known for its high temperature and high evapotranspiration. Thus the role of low temperature is merely theoretical. The general function to determine temperature stress as factor of suitability for photosynthesis is given as (Raich et al. 1991) :

$$f(T) = \frac{(T - T_{\min}) \times (T - T_{\max})}{(T - T_{\min}) \times (T - T_{\max}) - (T - T_{\mu})^2} \quad \text{..........................................5.20}$$

Where:
T = air temperature (°C)
$T_{min}$ = cardinal minimum temperature (°C) for photosynthesis

$T_{max}$ = cardinal maximum temperature (°C) for photosynthesis
$T_{\mu}$ = optimum temperature (°C) for photosynthesis

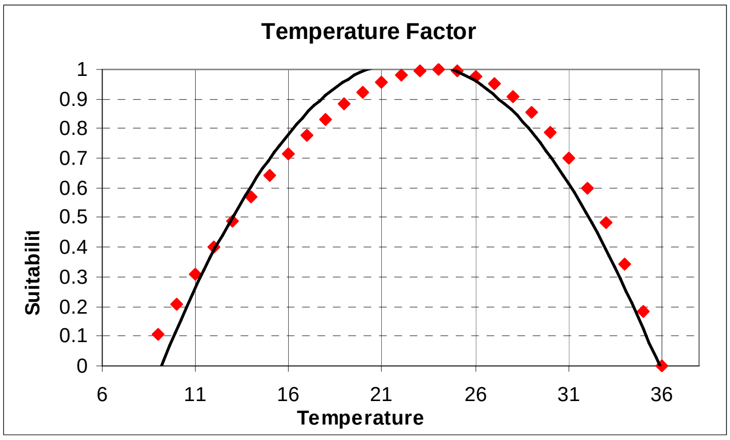


**Fig 5.14 Temperature suitability curve**

At optimum temperature the suitability for photosynthesis is 1 and the further it deviates from the optimum the suitability approaches towards minimum and maximum cardinal points.

***ii. Precipitation***

Unless there is flood inundation in some of the low-lying Awash River banks, the maximum precipitation available for plants seldom gets to a point where it may be considered a factor for stress. Generally, precipitation deficiency is considered a limiting factor especially in the core research area where the semi natural ecosystem has been serving as home to intercontinental and intra-Africa migrating birds. Suitability of this variable is estimated as:

$$\begin{cases} X \le \mu : \dfrac{1}{1+\kappa(X_i-\mu)^2} \\ X > \mu : 1 \end{cases} \quad \text{.......................................................5.21}$$

Where:
$X_i$ = average monthly rainfall
$\mu$ = the average optimum monthly precipitation requirement for the plant
$\kappa$ = calibration constant.

The direct outcome of the above described productivity estimation procedure was the above and blow ground gross primary production without accounting the respiration and maintenance costs by the plants themselves for self-perpetuation. Moreover, only dry matter was calculated without accounting the moisture content of the plants. To account for the latter, the samples harvested at the ASLNP and its surroundings were air-dried, weighed again and moisture content was calculated. The average moisture content from the samples was found to be 64.5 %. Relevant and available literatures were referred to determine the proportion of average above ground/below ground parts of a whole herbaceous plant in tropical conditions. Moreover, information on the amount of carbohydrate used by the plant itself for maintenance and respiration was collated. Hill (2004) considered a pseudo invariant ratio of 2/3 for above ground plant biomass as acceptable, though this ratio varies spatially and temporally. Nicolas (2005) modelled the above- and below-ground biomass for non-woody biomass vegetations that resulted in similar output like the one stated in Hill (2004). Waring et al. (1998) found the ratio of NPP/GPP to be 0.47 ± 0.04 SD in several sites that are distributed in three countries in both northern and southern hemisphere. Zhao et al (2005) calculated the Global Mean Total NPP/GPP ratio at 0.51. Therefore it is pertinent to conclude that the plants themselves use half the GPP either for respiration or maintenance.

#### 5.3.6.6 Result

The Abijjata sub catchment has the least productivity in all land cover classes. The core regions of the Abijjata-Shala Lakes National Park that is known as important feeding ground for migratory birds lies inside this sub catchment. In December and January the productivity rate is almost negligible in these areas. July to September the NNP increases in central and northern part of the study region, while the southern part exhibits a bimodal distribution where NPP attains the highest point in April and December. The average annual productivity of sub catchments in the Zeway-Awassa basin is given in table 5.8.

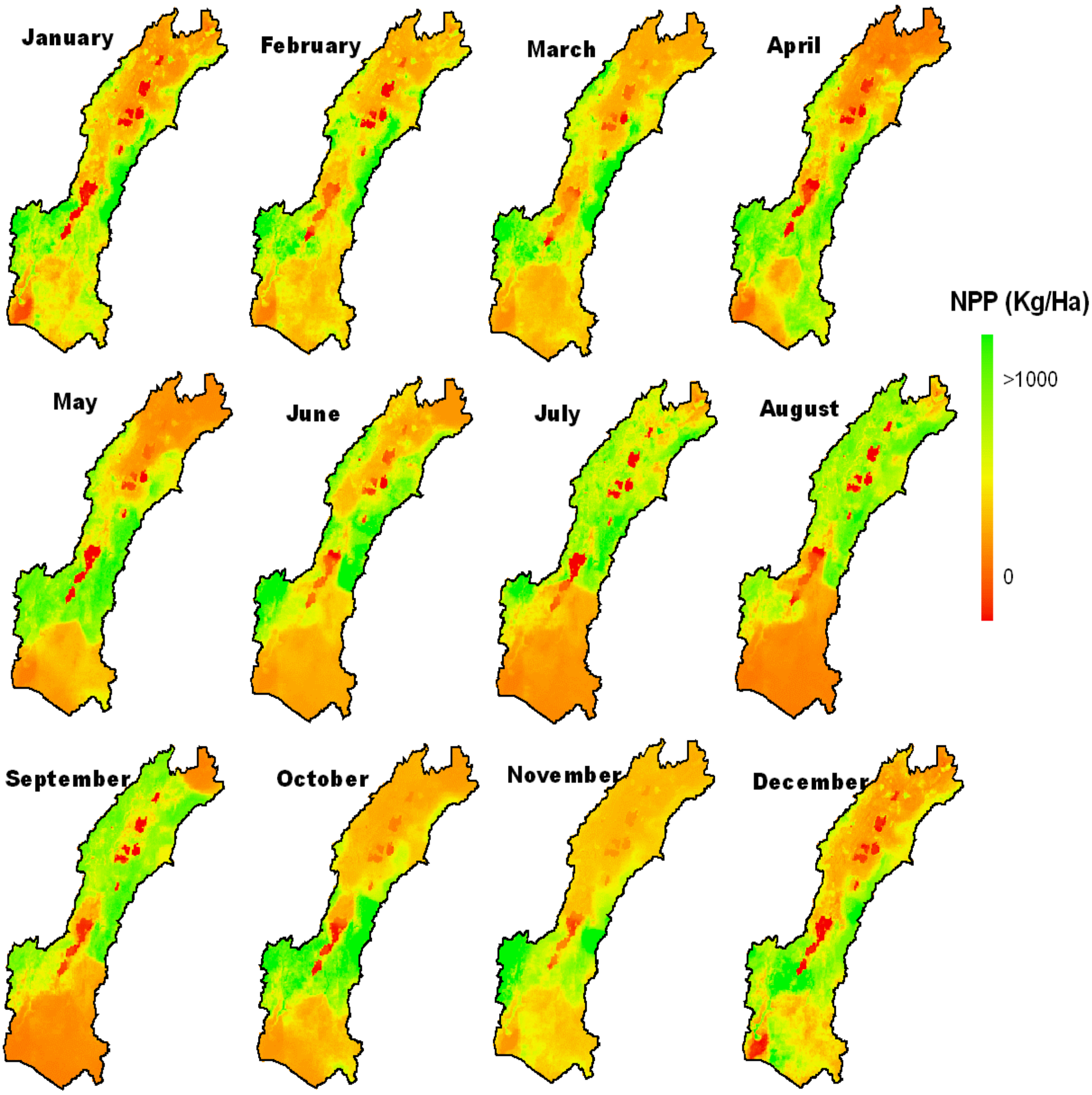


**Fig. 5.15. Estimated average monthly NPP in central and lower Ethiopian Rift Valley**

The distribution of productivity across time clearly follows rainfall patter. This is especially significant in the case of the Abijjata area where there is very little or no expected productivity except the three rainy months: July, August and September. Open woodlands and shrub lands hardly accumulate any biomass in other months in this specific area. Any human impacts during these months can easily bring about a profound negative consequence during the following dry period.

**Table 5.8. Average yearly productivity of selected land cover classes in the sub catchments of the Zeway-Awassa basin**

| *Land cover in the sub-catchment* | *Kg/M²/Year* |
|---|---|
| Abijjata >> BushLand/Shrubland | 0.407 |
| Abijjata >> Mosaic of Agric&Trees | 0.884 |
| Abijjata >> Open woodland | 0.497 |
| Abijjata >> Rainfed Agriculture | 0.630 |
| Awassa >> BushLand/Shrubland | 0.872 |
| Awassa >> Mosaic of Agric&Trees | 1.546 |
| Awassa >> Open woodland | 0.990 |
| Awassa >> Rainfed Agriculture | 1.106 |
| Langano >> BushLand/Shrubland | 0.475 |
| Langano >> Mosaic of Agric&Trees | 1.309 |
| Langano >> Open woodland | 0.724 |
| Langano >> Rainfed Agriculture | 1.026 |
| Shala >> BushLand/Shrubland | 0.698 |
| Shala >> Mosaic of Agric&Trees | 1.359 |
| Shala >> Open woodland | 0.776 |
| Shala >> Rainfed Agriculture | 0.900 |
| Zeway >> BushLand/Shrubland | 0.534 |
| Zeway >> Mosaic of Agric&Trees | 1.071 |
| Zeway >> Open woodland | 0.635 |
| Zeway >> Rainfed Agriculture | 0.882 |

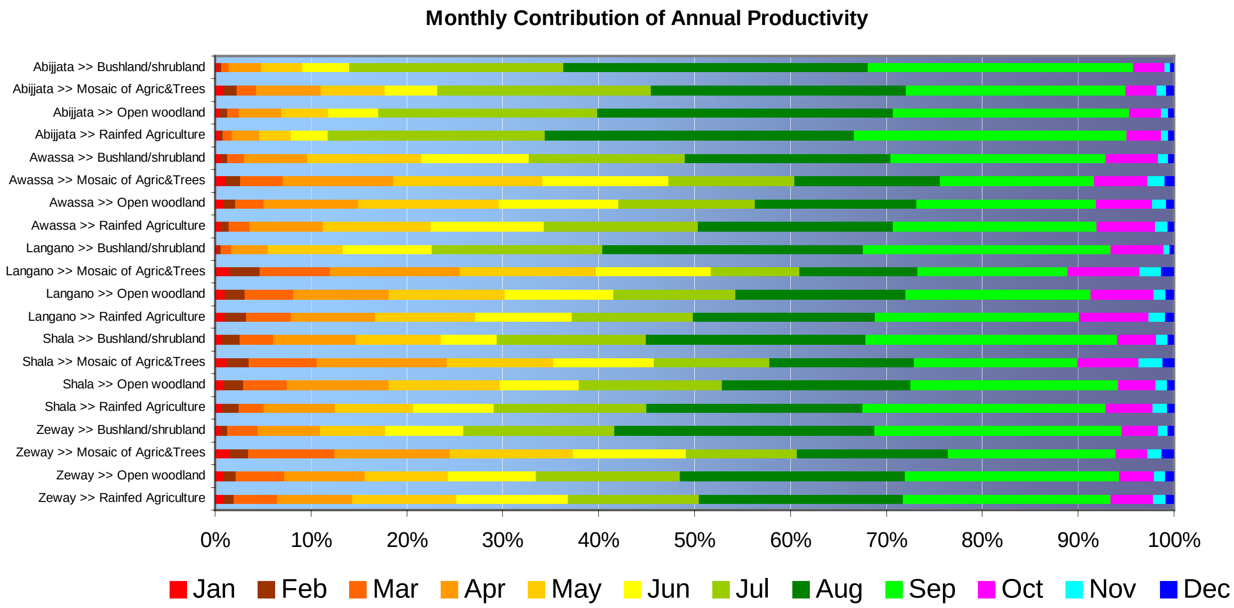


**Fig 5.16 Distribution of productivity across time and land cover type in the sub catchments.**

### 5.3.6.7 Limitations and Applicability in the Context of This Study

The strength of this approach lies in its incorporation of site specific climatic and vegetation conditions. However, spatially contingent climate data is hardly available in most countries without spatially interpolating variables from the limited number metrological stations. Application of interpolation in this study has undoubtedly brought in some errors. The inability to identify the source of errors and quantify them was one of the drawbacks of this method. The other source of uncertainty was the use of global Light Use Efficiency (LUE). Even though their effect on the productivity calculation was minimised by site-specific climate parameters, using a single coefficient of for all land cover classes exposed the model for further errors. On the other hand, determining the LUE for each and every land cover classes in each and every landscape is practically impossible at the moment.

In the essence of low cost remote sensing, this approach can be considered important as available data on climate along with low-resolution remote sensing products can be successfully utilised to provide facts and reliable overlook of the entire study/management area. The low-resolution images are usually free of charge and climate data are collected and made available for a wide variety of uses by national agencies.

## 5.4 Summary and Discussion

Biophysical information, especially on productivity of an area, is one of the most crucial factors for activities ranging from monitoring ecosystems to decision making (Reeves et al 2001). In areas where conflicts between the protection interest of the conservation community and the resource consumption necessity of the local inhabitants are prevalent, information on dynamics of productivity may be used to determine long-term regional and local land use options. Such information should be continually updated and should be easy to collect it. Readily available remote sensing products like MODIS provide an opportunity to attain this goal in reliable, fast, cheap and site specific way. Until recently the trend was either to use global models or make surveys. While repetitive surveying activities are prohibitively expensive, generalised models unfortunately result in imprecise result in several instances. Reliable model inputs must be largely dictated by sites and species specific factors. Grier et al. (1984) described an error magnitude in the range of -8% to +93% due to the application of generalised models from literature compared to site specific equations. Even though it may not be possible to include all the influencing factors in the estimation models due to logistical, technical and budgetary constraints, an effort to develop site-specific model is the only plausible choice left. Since the dynamics of biotic factors quickly shift from one state to the other due to natural and socio-economical facets, the information required for monitoring of nature conservation or management of protected areas should be not only site specific but also continuous, reliable and affordable. Simple site-specific models as demonstrated in this study are not only easily and efficiently built but also they are believed to serve for a long period by using updated remote sensing products.

Periodical assessment of vegetation conditions is important to understand the dynamism of a landscape where many ecosystems functions interdependently. Protected areas cannot survive in complete isolation even in areas of less population density. In fact what has been happening in the ASLNP is the cumulative effect of several small-scale degradation processes and deteriorations elsewhere in the landscape due to increase in population density. To feed the increasing population more land has been cleared instead of making effort to increase the productivity of already cultivated agricultural lands. As agriculture crops cover more land during the growing season, farmers are forced to find grazing place for their livestock. No wonder that park areas with very weak and vague legal structure immediately become a target during such periods. Low productivity and lower amount of standing biomass in these areas during specific period of the season is an indication of anthropogenic activities which may work against the ecological balance of protected area systems.

Some experts in rangeland management place more reliance on change in species composition than on site productivity to determine rangeland condition. Bush encroachment is used as indicator of range deterioration (Alemayehu 2001). However, several researchers showed productivity estimates based on remote sensing could identify trends of decreasing long-term productivity thereby indicating potential site degradation. The time interval in years required to show a decrease in productivity linked to some aspect of site degradation cannot be known without some level of uncertainty though (Reeves et al 2001). Satellite derived information not only provide estimates of productivity or standing biomass that may be available as livestock feed, but also give necessary input to identify locations where livestock density may be high. The traditional method to determine livestock density of an area is to count the total livestock and divide for the area. However, not the entire areas provide feed for livestock. Some land cover classes are impacted heavily while others are not used for livestock at all. It is only through remote sensing that proper identification of the distribution of areas prone to overgrazing is possible.

Therefore, the applicability of biomass and productivity estimation from low cost remote sensing (products) should be promoted in developing countries. It is usually in these countries that high biodiversity sites are situated while resources and know how for continuous surveying are lacking. By using MODIS data or comparable low cost remote sensing imagery, it is be possible to characterise seasonality of vegetation, estimate quantity of herbage that may be available for livestock and to monitor the rates and trends of change in primary production. Consistent, objective and frequent estimates of productivity will be available for even very inaccessible ecosystems.

# Chapter 6

# Livestock Centred Land Use and the Natural Ecosystem

## 6.1 Local and National Perspectives of Priorities of Land Use

The livelihood of more than 80% of the Ethiopian population is directly related to low input arable agriculture and poor yielding livestock production system that are highly dependent on natural environment (FDRE 1997). These types of production do not permit to keep a status quo on land use objectives and keep natural systems intact. The rural subsistence farmers want to expand their agriculture at the expense of grazing areas, woodlands and forestlands to ensure food security for the household, while development oriented government and non-government officials advocate the use of better inputs and introduction of irrigation to achieve the same goal without expansion. Ecologists and conservationists are wary of agricultural land expansion and settlement in natural ecosystem while being equally sceptical about excessive intervention in hydrological systems (EWNHS 1996, Fekadu et al. 2001). Others encourage a change in the livestock production system to increase the quality of products instead of increasing the quantity of livestock. Pastoralists or semi-pastoralists usually keep cattle for prestige and security that low livestock production is not a serious issue for them (FDRE 1997, Alemayehu 2002).

Decisions on land use at any level and the way the stake holders interact to each other and within each other have important impacts on the functioning of socio-economic and environmental systems with lasting implications to sustainable agriculture, household food security, continuity of ecosystems functioning, biodiversity and many more (Geist et al. 2002). In areas like the Abijjata-Shala, these decisions are highly influenced by the production priority of subsistence farmers, wood gatherers and charcoal makers for their livelihood on one side and the conservation priority of national or regional government for maintaining ecological integrity of the area or attraction of international tourists objectives on the other (EWNHS 1996, Zinabu 1998). Without alternative means, the local users will not simply agree to the national or regional land use priority as their very existence is in danger. Even though they acknowledge, the ecological or biodiversity service of the ecosystems, it is the production potential of the land that the local inhabitants find important for their own existence. Therefore, it is less likely that a rural household either as an individual member or collective society would give priority to land use objectives that solely address the issue of safe guarding the ecological integrity of the area. This has been demonstrated in high-level conflicts in Awash National Park, Abijjata Shala National Park and Nechsar National Park in recent years (Jacob et al 2001).

Apart from subsistent agricultural land use, there are other forms of newly emerging agricultural land use objectives in the area. Flower plantations are at the moment the national focus to earn foreign currency. They are booming around Lake Zeway. They are thought to create off farm jobs for locals that would reduce pressure from agriculture fields. However, the water abstraction from the lake and exposing the ecosystems to uncontrolled chemical usage poses an unknown danger. Given the alkaline nature of soils and water in the Rift Valley, Soda-ash industries have easily accessible raw materials. The one that is frequently blamed for the abstraction of water from the Lake Abijjata was located just a few hundred metres from lakeshore during establishment. Now the lake has retreated far away from the plant denying on the process several migratory and resident birds their age-old winter feeding grounds. Resort areas are largely limited to Lake Langano because it has extended beaches and the water is more suitable for swimming and water sports. A vast area of the lakeshore is already fenced off for this purpose. Further allocation of land for resorts along the Lake Langano means the locals loose their access to the lake and adjoining grazing area. As has been observed several times in the past, such blockages force the distributed livestock pressure to concentrate in certain areas like parks and few remaining communal lands.

Livestock production is not limited to subsistent agro-pastoralists in the region. There is a government owned cattle ranch - Abernossa Cattle Ranch -, which covers more than 800 hectares of land, located between Lake Zeway and Lake Abijjata. The ranch has managed to keep its vegetation cover sufficiently intact for years. In this landscape where small-scale agriculture plots are the fibre and threads of the landscape, the ranch looks like an isolated vegetation island during dry seasons. The success is attributed to the fact that the ranch has been entirely fenced by barbed wire and guarded for several years. Conservation targeted land use objectives would not afford the logistic resource such ranches have. The land cover change analysis from 1972-2000 proves that only fenced enclosures have survived the vegetation degradation process that has been rampant for the past three decades.

Inside Abijjata-Shala Lakes National Park there are breath taking panorama sites that attract tourists to view the full extent of both lakes at the same time. Moreover, there are several hot springs along the Lake Shala slopes. These natural wealth are attracting individuals who want to control only that part of the park for private business effectively paralysing the remaining diminished law enforcement power of the park administration. In the name of private investment any important public land can be set for grab in today's Ethiopia economic philosophy. So far few concerned politicians and the park administration resisted the pressure and temporarily warded off such a move. Considering allocating some part of the core park area to conflicting private business inside a National Park shows the level of doubt some decision makers are harbouring about the conservation priority of the area.

## 6.2 The Land Cover Dynamics in and around the ASLNP

### 6.2.1 Land Cover Change Process

The use of spatial analysis enhances the understanding of the processes and causal factors of LUCC (Nelson 2002, Vancker et al. 2003) that may be useful for decision making at different levels of administration. In this study, classified multi-temporal imagery (1972, 1986 and 2000) was further processed in a GIS environment to find out the spatial and temporal dynamics of vegetation cover in the core study area-the ASLNP, in 5km and 10km buffers around the park.

Firstly two consecutive layers (1973 & 1986, 1986 & 2000) were separately investigated to map the change process during this period.

**Table 6.1 Major land cover change processes in Zeway-Awassa Basin and the proportion area (in %) affected by these processes**

| Major Process | 1973-1986 | 1986-2000 |
|---|---|---|
| **No Change** | 51.36 | 65.84 |
| **Forest and Land Degradation** | 26.07 | 15.67 |
| **Rehabilitation** | 10.90 | 11.93 |
| **Deforestation** | 9.66 | 5.35 |
| **Slight Modification** | 1.38 | 0.84 |
| **Dry up** | 0.30 | 0.02 |
| **Unexplained** | 0.17 | 0.07 |
| **Urbanization** | 0.03 | 0.14 |

Secondly, the output of the first process, i.e. the two land cover change process maps, were again superimposed on each other. This second process revealed the spatial location of processes where some of the change processes are permanent and some are temporary. In this way some of the most important information required to allocate resources, if restoration is desired or if prevention of further degradation is attempted, are made available for natural resources managers or administrative bodies.

During attempting to depict long-term change processes in a single snapshot, each analysis or visualising unit (pixel, grid cell or vector polygon) represents the value of a function of one of the combination of land cover classes over time (Muzein et al. 2006). Usually the numbers of the combinations are very high when data from several periods are used. The amount of possible combinations or alternatives are given as:

$$C = \prod_{i=1}^{p} N p_i \quad \text{......} \mathbf{6.1}$$

where C = the possible number of land cover class trajectories,
Π = multiplication and
N = number of land cover classes in a given period ($p_i$).

If N is the same in all periods then,

$$C = N^p \quad \text{......} \mathbf{6.2}$$

With an increase in p, N grows exponentially. A subjective contextual editing (Expert-Context-Editing method), based on actual ground information and expert knowledge, brings C into manageable number of classes that can be reasonably visualized and interpreted.

There were 1584 combinations of classes in the first output of the change dynamics analysis. These were summarised to only 9 meaningful legends (Fig 6.1). The legends represent the change dynamics classes that show not only the process involved but also the nature of permanency of those classes. The spatial extent of this process was limited to ASLNP, the immediate areas outside the park boundary within a 5km distance and the immediate areas outside the park boundary within a 10km distance.

**Table 6.2 The gross extent and proportion of long-term dynamics in and around ASLNP**

| *Process* | *Park* | | *Park+5km* | | *Park+10km* | |
|---|---|---|---|---|---|---|
| | Area (ha) | % | Area (ha) | % | Area (ha) | % |
| Desiccation (water bodies dry up) | 2298.7 | 11.31 | 20.5 | 0.03 | 13.2 | 0.02 |
| Successful Rehabilitation | 2838.9 | 13.96 | 1689.2 | 2.42 | 1015.6 | 1.33 |
| Recent Degradation | 1524.9 | 7.50 | 13563.7 | 19.41 | 10311.1 | 13.51 |
| Permanent Degradation | 6126.2 | 30.13 | 20843.8 | 29.83 | 34653.4 | 45.39 |
| No Change | 3588.6 | 17.65 | 30015.0 | 42.95 | 25398.6 | 33.27 |
| Inundation (increase in water bodies) | 287.7 | 1.42 | 158.7 | 0.23 | 46.7 | 0.06 |
| Initial Rehabilitation | 2180.4 | 10.72 | 3396.8 | 4.86 | 4764.8 | 6.24 |
| Urban Settlement | 0 | 0 | 148.3 | 0.21 | 91.1 | 0.12 |
| Unknown | 1486.0 | 7.31 | 46.6 | 0.07 | 53.0 | 0.07 |

The likelihood of degradation is three times higher than the natural rehabilitation in the park. Areas outside the park suffer more damage than the park itself. However, this cannot be a consolation in the face of land and vegetation degradation that is raging in the whole landscape including the semi-natural ecosystems in the park. The general picture of land cover change process is tainted by degradation of land and vegetation in the park as well as outside of it. An inevitable vicious circle that involves land degradation, low agriculture productivity and further clearing of woody vegetation has already engrossed the land use system in the park as well as in the vicinity.

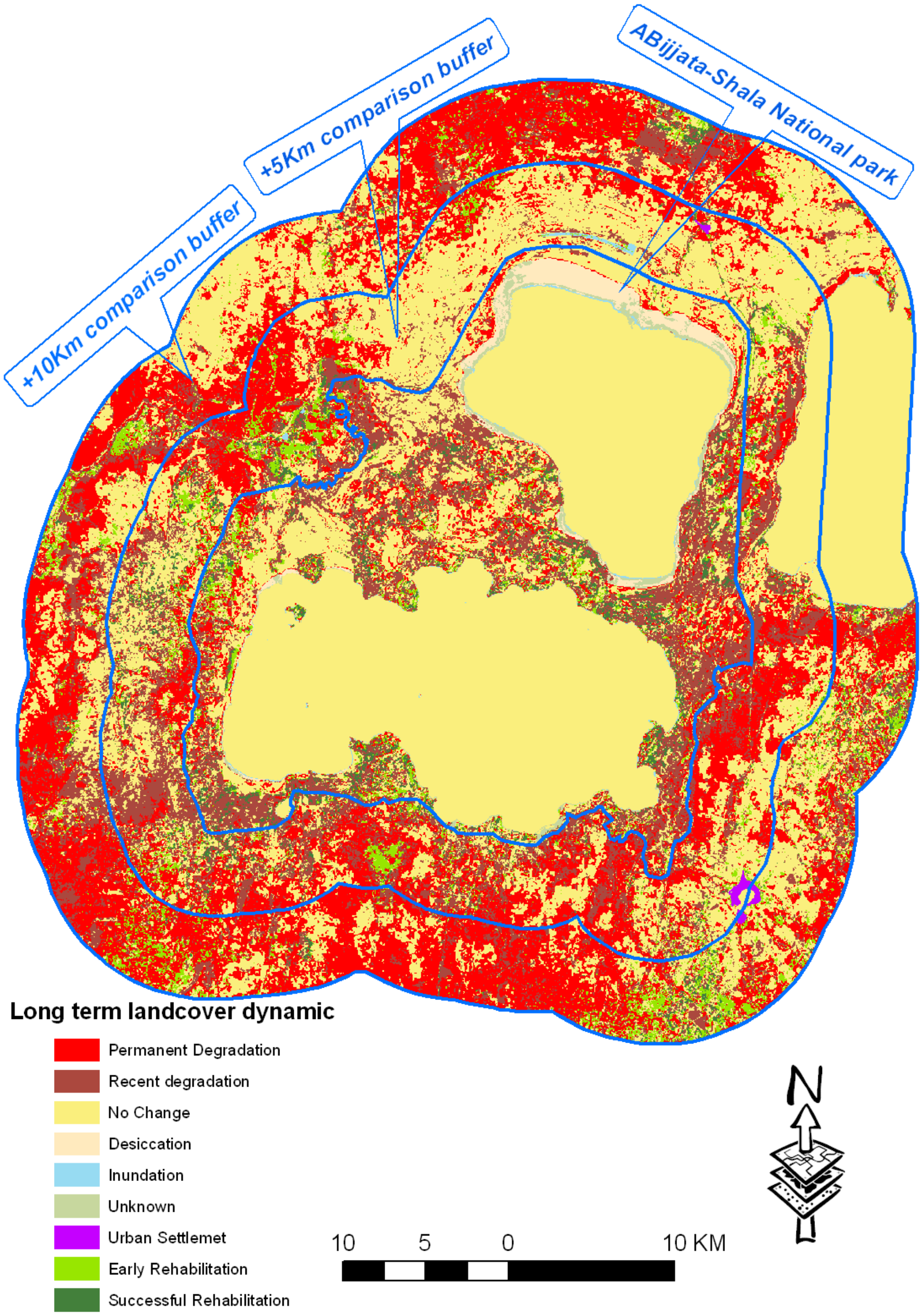


**Fig. 6.1 Spatial location of long-term land cover dynamics (1973-2000).**

### 6.2.2 Major Land Use/ Land Cover Change Driving Forces

Driving forces are generally subdivided into two broad categories: proximate causes and underlying causes. Proximate causes are the activities and actions which directly affect land use, e.g. wood extraction or clearing land for agriculture. Underlying causes are the 'fundamental forces' that trigger the proximate causes, including demographic pressure, economic policy, technological development, institutional and cultural factors (Geist et al. 2002, Vancker et al. 2003). The underlying factors have a multi scale sources. Global factors that influence local agricultural marketing or international tourism can be indirectly responsible. Regional factors like the presence of road, access to market, political turmoil and armed conflict may be a direct source of influence in the decision process of land use. Loss of productivity coupled with population boom may be considered local factors. Thus the proximate causes are only manifestations of the underlying causes. Any intervention, therefore, must be geared towards addressing the underlying causes.

As in most developing countries, the major cause of vegetation change is related to activities of cultivation agriculture in this research area. From 1973 to 2000, agriculture alone was the driving force for 83.4% and 70.1% of the natural vegetation loss in ASLNP and in Zeway-Awassa Basin respectively. The strong influence of agriculture in a National Park is unfortunate and concerning. From the 45 households interviewed in the ASLNP, a staggering 43 of them responded that their agricultural plot has been expanded significantly in the past 10-20 years. However, the drive to expand has been largely set off by the need to fulfil household food demand. Only 13.3% of the farmers expanded their agriculture to produce cereals for commercial purpose.

## 6.3 Identification of Critical Sites for Conservation around the Semi-natural Ecosystems in the Zeway-Awassa basin.

Ecological entities are all so interconnected that it is hardly possible for an isolated ecosystem to last long (Begon et al. 2000, Cox et al. 2001). Vegetation loss in upland areas exacerbates surface erosion and eventually sedimentation or eutrophication in lake systems. Such processes may benefit some organisms while harming others. As has been observed by Sharew (1996), a decreasing lake is a blessing for species like Flamingos while it is a disaster for fish eating birds like Pelicans.

To ensure the integrity of Abijjata Shala National Park the whole influencing sphere must be addresses if a sound solution is to be found. To this end some important and sensitive parts of the Zeway-Awassa basin are investigated in order to find out how the change process in the past three decades affected their equilibrium.

### 6.3.1 Geographic and Topographic Distribution of Important Changes in the Landscape

Geographic and topographic relationship of changes are analysed in relation to their proximity to areas that contain an IBA or their overlapping areas. Unfortunately the whole basin could not be assessed, as the TM and ETM+ images do not cover a small part of the northern Zeway sub basin. However, the most important IBA sites within the basin are included and the important land cover processes they passed through have been analysed. Accordingly, 750km², 2428km² and 3575km² terrestrial lands and water bodies covered by IBAs within a distance of 10, 20 and 30km respectively from the central location of the IBAs have been found to experience either land degradation or serious vegetation loss. Nearly half of the total degraded area within 10km is flat (< 2%), comprising mudflats along the shores and open woodlands. During the same period the size of rehabilitated land within the 10km radius amounts to only 1/5 of the land lost to degradation in flat lands. In steep slope areas, the rehabilitation ratio improved to 1/3 due to some commercial reforestation programmes on the eastern shoulder of the Langano catchment.

Within the Zeway-Awassa basin there are up to 85km², 1012km² and 2625km² of recently degraded areas where from 2 to 5 IBAs overlap in 10km, 20km and 30km radius respectively. All of these areas may not be necessarily important areas as some part of them are located in already developed areas like towns. However, some of the locations, for example between Chitu, Abijjata and Langano, are of immense ecological importance, as they could be potential natural corridors to link several IBAs physically. Even though birds are capable of bypassing small physical blockades and even fly long distances, the role of corridors in facilitating mobility of the entire organisms in the systems is of crucial importance to ensure integrity of ecosystems (van Langevelde 1999, Wascharlemann et al. 2004).

**Table 6.3 The number of IBAS that are located within 10km, 20km and 30 km to each other and their spatial extent in different topographic ranges and Land cover processes.**

| Land cover process | Slope classes | Number of Important Bird Areas | Total area (ha) within a distance of | | |
|---|---|---|---|---|---|
| | | | 10km | 20km | 30km |
| Rehabilitation | Steep (>25%) | 1 | 1229 | 1201.75 | 829.75 |
| | | 2 | 32.75 | 1093 | 1479.75 |
| | | 3 | 0 | 32.5 | 542.5 |
| | | 4 | 0 | 3.5 | 109.75 |
| | | 5 | 0 | 0 | 1.75 |
| | Flat (<2%) | 1 | 6637.75 | 7874.75 | 5572.75 |
| | | 2 | 860 | 7981.75 | 9765 |
| | | 3 | 0 | 234.75 | 4707.5 |
| | | 4 | 0 | 13.5 | 951 |
| | | 5 | 0 | 0 | 126.75 |
| | Undulating (2-25%) | 1 | 7649.25 | 12026.25 | 9665.5 |
| | | 2 | 286.25 | 7330 | 11916 |
| | | 3 | 0 | 297.75 | 5709 |
| | | 4 | 0 | 40.25 | 1563.5 |
| | | 5 | 0 | 0 | 96.5 |
| Degradation | Steep (>25%) | 1 | 3343.5 | 4550.75 | 2004.5 |
| | | 2 | 147 | 4469.25 | 7141.5 |
| | | 3 | 0 | 719.75 | 1637.75 |
| | | 4 | 0 | 80 | 1210.5 |
| | | 5 | 0 | 0 | 80.5 |
| | Flat (<2%) | 1 | 28585.75 | 62103 | 41649.75 |
| | | 2 | 5755.25 | 39815.75 | 55657 |
| | | 3 | 0 | 6916.5 | 37899.75 |
| | | 4 | 0 | 1397.5 | 17744 |
| | | 5 | 0 | 0 | 6449 |
| | Undulating (2-25%) | 1 | 34560 | 75036 | 51409.5 |
| | | 2 | 2587 | 37026 | 77187.25 |
| | | 3 | 0 | 8572.5 | 35578.5 |
| | | 4 | 0 | 2148 | 19084.5 |
| | | 5 | 0 | 0 | 2784.25 |
| | | Total | 91673.5 | 280964.75 | 410555.3 |

### 6.3.2 Multivariate Gradient Analysis

Species distribution is affected by alteration of their breeding or wintering ranges either through anthropogenic, antropozoic or environmental factors (Begon et al. 2000). These factors differ greatly in their impact, depending upon the timing of events and the biology of the species involved (Osborne et al. 2001).

In order to assess the relative roles of biotic and abiotic factors in dictating the distribution and abundance of some selected bird species in ASLNP and its immediate surroundings, an ordination technique was used. The technique was designed in such a way that the 5-year bird data were included there by temporal variability was preserved.

Ordination is a general term for different multivariate techniques, which adapt a multi-dimensional scattered data points in such a way that when it is projected onto a two-dimensional space any fundamental distribution of data becomes distinguishable during visual inspection (ter Braak 1995). It is basically used to summarise species abundance data that are spatially and temporally distributed by producing a low-dimensional ordination space in which similar species and samples are plotted close together, while dissimilar species and samples are placed far apart (ter Braak 1995, ter Braak et al. 1998). Generally, ordination techniques are used to describe relationships between patterns of species composition and the underlying environmental gradients, which influence these patterns.

There are several ordination options depending on the characteristics of the environmental input data. The most common are Canonical Correspondence Analysis (CCA) and Detrended Correspondence Analysis (DCA). Both are capable of producing species and environment scores (Leps et al. 1999). During preliminary testing, CCA result was found out to suffer the notorious arch effect[9] in the distribution diagram (Leps et al 1999). Consequently DCA has been chosen for this research. The inputs are largely organised from the remote sensing analysis as well as from metrological data. As environment data, mean annual precipitation data from meteorological stations which are located inside the basin and those just at outer periphery of the basin, yearly lake level of Abijjata and annual average biomass availability were considered. The abundance data on those bird species, which were consistently counted by EWNHS for the 5 years period, constituted the species data.

The result of the DCA analysis has shown that only very few bird species have direct correlation to the decrease in lake size and biomass availability. Such inconclusive distribution has been displayed because the exact location of species data was not collected during bird counting, the data was only for five years, and there may be a short term species response to some environmental or man made event within this 5 years. Green biomass availability and lake size show a fairly similar declining trend. The birds which have direct correlations with lake area (or shore size) are largely terrestrial shore and mud flat birds like Little Ringed Plover, Reed Cormorant, Greater and Lesser Flamingos. The only rainfall pattern that has correlation with biomass or lake size across time is recorded in Kulumsa station, situated at the north-eastern part of the Zeway sub catchment. According to this result the decrease in the size of Lake Abijjata appears to have its roots either in patterns of

[9] Arch effect is a distortion in an ordination diagram. It is caused by the unimodal distribution of species along gradients.

availability of annual vegetation cover (alias green biomass) or rainfall patterns of the Lake Zeway catchment areas.

The fluctuation of size of Lake Abijjata is a historically known fact, though it has never been so low and for such a long time. Ayenew (2004) investigated the relationship between lake levels and rainfall in the Zeway-Awassa basin from 1970s to mid 90s and found that terminal lakes like Abijjata had started showing less correlation to rainfall after the mid 80s due to water abstraction and change in land use.

The result of DCA further revealed the diversity of environmental factors in the Basin, the very strong environmental fluctuations across time and most importantly, the lesser influence of the environment on species distribution at the current level. The pattern of environmental and biotic factors (green biomass) observed in 2003 was found to be slightly more favourable than the other periods. Generally, except for few species, the pattern of species distribution shown by the DCA analysis does not permit conclusions with certainty. This is probably due to the short tem data (only 5 years) used as an input. Unfortunately species distribution data older than 5 years is not available. Moreover, the exact location of bird count was not registered except the crude information like the name of the nearest big lake or marsh. For examples it was not possible to know where in the park the count had been conducted. To partially compensate this spatial data deficit the nearby bird counts, i.e. from Chitu and Langano, have been incorporated in the ASLNP count. The other reason, which was not possible to include in the DCA analysis, was the number of people daily working around the lakeshore for salty 'soil' or sand extraction. The presence of people along with their domestic dogs and cats scares away some species permanently or temporarily. Some species like the Marabou Stork and Egrets are well accustomed to the presence of human beings. Such reasons made the explained variable through DCA lower. The total amount of explained variables by Axis 1 and Axis 2 is 51.5%, and 10.7%. The full result of the DCA operation is presented graphically in the form of a scatter gram in (fig. 6.2) and the key to species codes are given in the appendix section.


**Fig 6.2 Schematic representation of DCA scores of environment, species and temporal variability of environment**

## 6.4 Remote Sensing of Livestock Based Farming System: The Issue of Land Suitability and Carrying Capacity of Semi-Natural Ecosystem

Assuming the calculated green biomass as highlighted in the previous chapter is the maximum available amount of feed, the maximum potential livestock carrying capacity of the agricultural and semi-natural ecosystems was determined for the entire study area. Comparison of the number of livestock units (TLU)[10] and feed availability is made not based on the exact amount animal feed accessible for livestock but on the maximum potential biomass available in each mentioned land cover class. All calculated green biomass is not edible, there are others like humans and wildlife, which also use some of the edible biomass, and some of the biomass is not accessible for livestock. Therefore the feed availability calculated throughout this study contains an element of overestimation.

[10] 1TLU = 250 kg live weight in the tropics. The weight of a cow is assumed to be 1 TLU

Nevertheless, this comparison gives important clues about the influence of livestock based agriculture in modifying the natural ecosystem even under circumstances where competitions from others (human beings and wild animals) are assumed to be negligible.

### 6.4.1 Distribution of Livestock in the Study Area

In most reference literatures the density of livestock in landscapes is directly calculated by dividing the number of livestock units to the total area without considering the spatial heterogeneity of livestock pressure. In the absence of detail land cover /land use maps, this approach may be the only option. A new approach is attempted in this study to distribute the pressure in the landscape based on spatial distribution and the proportion of land cover classes. It is obvious that land cover classes like urban areas, lakes, bare lands and closed forests have no mentionable use for livestock feed. As irrigation is mostly dedicated to producing specific commercial output, residues are scares or they will not be accessible to livestock. Hence no importance for feed. Therefore the livestock density is concentrated within few classes like natural pastures, grasslands and agricultural fields (off season as well as cut and carry). Other semi-natural LULC classes also carry proportionally less amount of livestock. To this end, an importance weight (***w***) has been estimated to each land cover class.

***Weight calculation***

The first step is to find out the spatial proportion of land cover classes in the polygons (usually the administrative area, where the number of livestock are counted).

$$P_i = \frac{\sum_{i=1}^{n} LC_i}{A_p} \quad \text{.......................................................................6.3}$$

where:
$P_i$ is the proportion of the $i^{th}$ land cover class
$LC_i$ is the total size of the $i^{th}$ land cover class
$A_p$ is the size of the administrative region

Then the weight of each land cover class is calculated based on its suitability for livestock after adjusting the livestock count or TLU to $P_i$.

$$p_{ai} = d_i \times p_i \quad \text{.......................................................................6.4}$$

$P_{ai}$ is the adjusted proportion; ***d*** is the distribution of livestock in each land cover.

The distribution of livestock assumed to follow availability of grazing or browsing lands, availability of after-harvest recouping areas and crop residue opportunities. The Woody Biomass Inventory and Strategic Planning Project (WBISPP 2001) estimated the contribution of land cover classes for some land covers in the administrative zones where the Zeway-Awassa Basin lies.

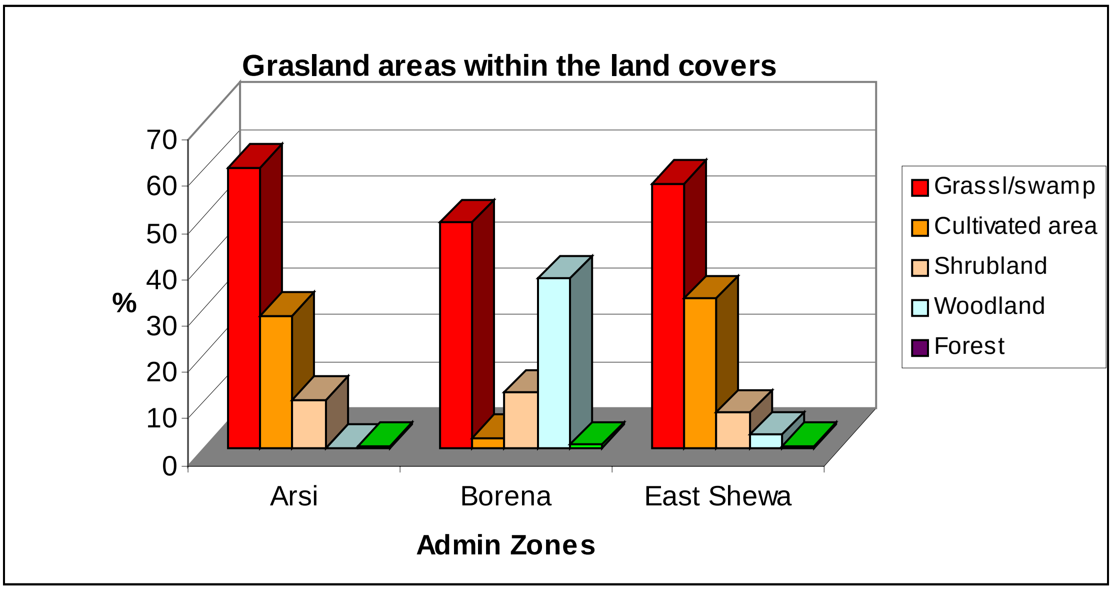


**Fig. 6.3 Proportion of grazing areas in land cover classes.. (WBISPP 2001)**

The above information and the information gathered during fieldwork led to the assumption that livestock distribution in different land cover situations follows the pattern given below.

**Table 6.4. Initial assessment of feed availability in diverse land cover classes**

| *Land cover classes* | *Availability for livestock* |
|---|---|
| Closed forest, Urban, Irrigation and Lakes | Unsuitable or 0 |
| Degraded/open forest, Closed woodlands | 25% of the area ~ 0.25 |
| Bush land Shrub land, Agriculture and tree patches | 100% of the area ~1 |
| Others | Attract more than their normal share: calculated as equation 6.5 |

$$P_{ai} = LC + \left( \frac{LC * \sum LC_u}{\sum LC} \right) \qquad \text{.......................................6.5}$$

where:
$P_{ai}$ is the adjusted proportion of Land cover class that supports the livestock
LC is the proportion the land cover class (>0)
$LC_u$ is the proportion of unsuitable land

Then:

$$W_i = \frac{P_{ai}}{LC} \quad \text{.......} \quad \mathbf{6.6}$$

where:
$W_i$ is the adjusted weight for land cover class i in the administration polygon.
$P_{ai}$ is the adjusted proportion of Land cover class that is assumed to support the livestock
LC is the proportion the land cover class (>0)

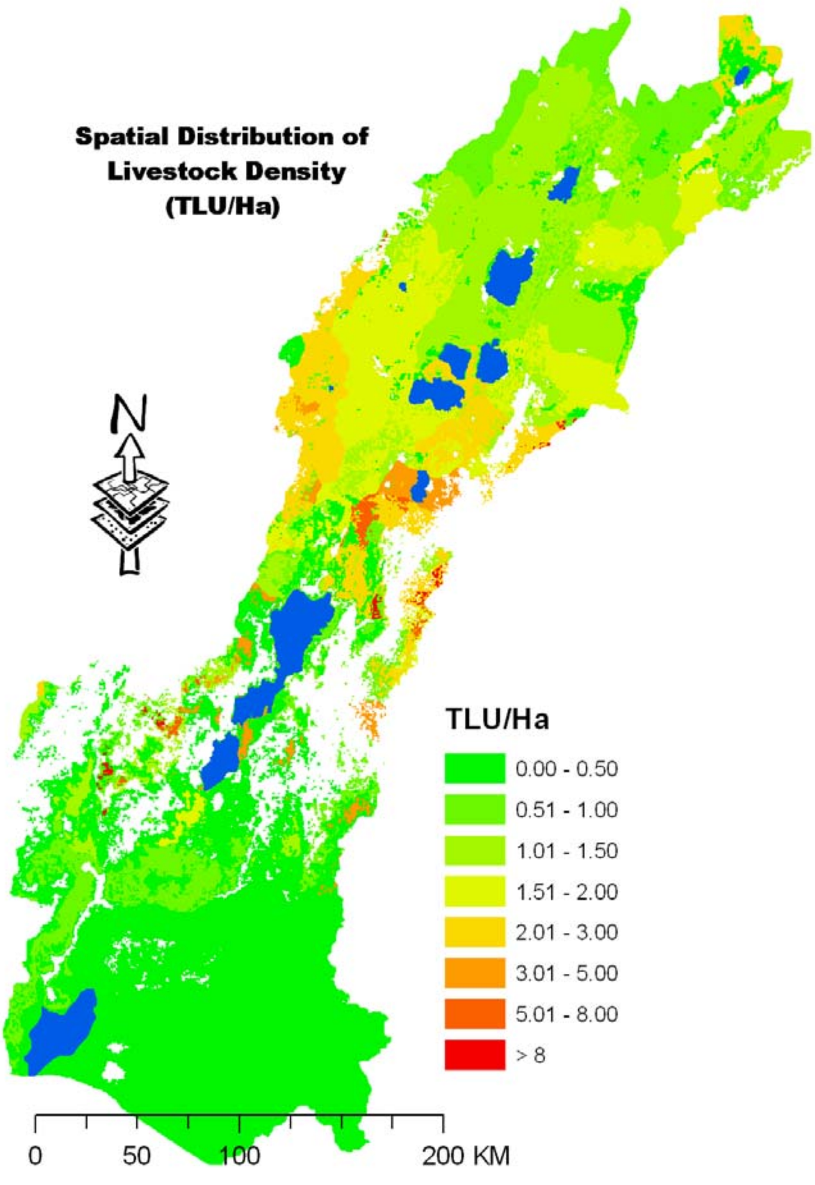


**Fig 6.4 Spatial distribution of livestock density after adjusting to land cover class suitability**

### 6.4.2 Daily Average Feed Requirement in the Rift Valley

A TLU intake[11] per day varies from one administrative region to the other as the herd composition and their intake behaviour is different. Le Hourérou (1989) described the daily proportional feed intake of cattle, camels, sheep and goats to be 1.5-2.5%, 2-2.25%, 3-4% and 5-6% of their live weight respectively. Given the high density of livestock located in the highlands where natural grazing is significantly diminished, it is unlikely that the maximum intake proportion suggested by Le Hourérou (1989) is reached in this study area. Under such condition its realistic to resort to the lower conservative figure. Accordingly, an intake proportion was calculated for each spatial unit after taking into account the fact that there is 64.5% moisture content of forages. The calculated value ranges from above 12kg green biomass per day in Hamer Benna to around 6.3kg in Northern Omo. The average intake is 8.9kg (SD 1.48) per day per tropical livestock unit. This appears to have a pattern of inverse relationship to human population density.

### 6.4.3 Land Suitability Assessment

The attempt to assess land suitability covers the whole basin. This assessment of suitability for livestock production is aimed at demonstrating whether livestock based agriculture is an appropriate land use option or not. In ideal nature protection schemes this information could have been used to gauge the suitability of land for herbivore wild animals (De Leeuw et al. 2002). The case in ASLNP and its surroundings is quite different as herbivore wild animals play an insignificant role.

Availability of food and water is one of the most important determining factors for land use decision for livestock development. Once the spatial distribution of TLU, the daily average intake pattern across the study area and the maximum possible feed availabilities throughout each month are known, the monthly feed status of the given area is easy to determine. The product of the first two variables was deducted from the maximum possible feed availability so as to come up with a spatially distributed result where possible feed deficits are clearly displayed. While negative values are set to demonstrate that the number of livestock is well above the carrying capacity of the area, positive values do not necessarily indicate a surplus in feed productivity. As discussed elsewhere, an unknown quantity of the green biomass is not accessible or not readily available for livestock consumption.

[11] intake refers to the amount of feed a TLU requires per day

In order to assess the suitability in an objective manner, certain simple criteria were set. As water is the most important factor, the distance from water sources (only natural ones are considered) must not exceed 4 km to qualify as 'Suitable'. Moreover, the maximum productivity of the area should not be less than the monthly feed requirements. Marginally suitable land is expected to fulfil at least 50% of the feed demand every month, 75% of the demand for at least 9 months or 100% of the feed demand for a minimum of 4 months per year. Water should also be available within a radius of 10km. In both cases areas with slope more than 50% are not considered. Areas that do not fall into one of the above categories are automatically assigned as 'not suitable'.

Out of the total area of the basin, 2.5% and 14.6% are suitable and marginally suitable respectively, the rest 72.9% being unsuitable. The picture dramatically changes for the Abijjata Shala Lakes National Park area where the whole park area fulfils the water availability criteria. Only 0.4% of the sub basin that comprises the bulk of the park area is suitable, only 3% is marginally suitable and the rest 96.6 % is not suitable at all. There is again no coincidence between marginal suitability of lands for livestock and importance of the area for ecosystem conservation due to the presence of IBAs. About 82.2% of the total area covered within the radius of 10km is not suitable while 16.6% is marginally suitable and the remaining 1.2% is suitable. Despite this fact the average household livestock holding is 9.91 for cattle and 91.1% of the interviewed households believe the park is a good area for livestock production. With an average family size of 8.53, i.e. livestock number to human population ratio of 1.16, the livestock density in the park is nearly the same as the environmentally better regions of highland Ethiopia.

**Table 6.5.Percentage of suitable, marginally suitable and not suitable areas in the whole basin and its sub-basins.**

| *Sub-Basin* | *Suitable* | *Marginally suitable* | *Not Suitable* |
|---|---|---|---|
| Zeway | 2.98 | 30.37 | 66.65 |
| Abijjata | 0.39 | 2.95 | 96.65 |
| Shalla | 1.41 | 17.84 | 80.75 |
| Langano | 5.40 | 32.11 | 62.48 |
| Awassa | 0.38 | 24.24 | 75.37 |
| Zeway-Awassa Basin | 2.48 | 24.61 | 72.91 |

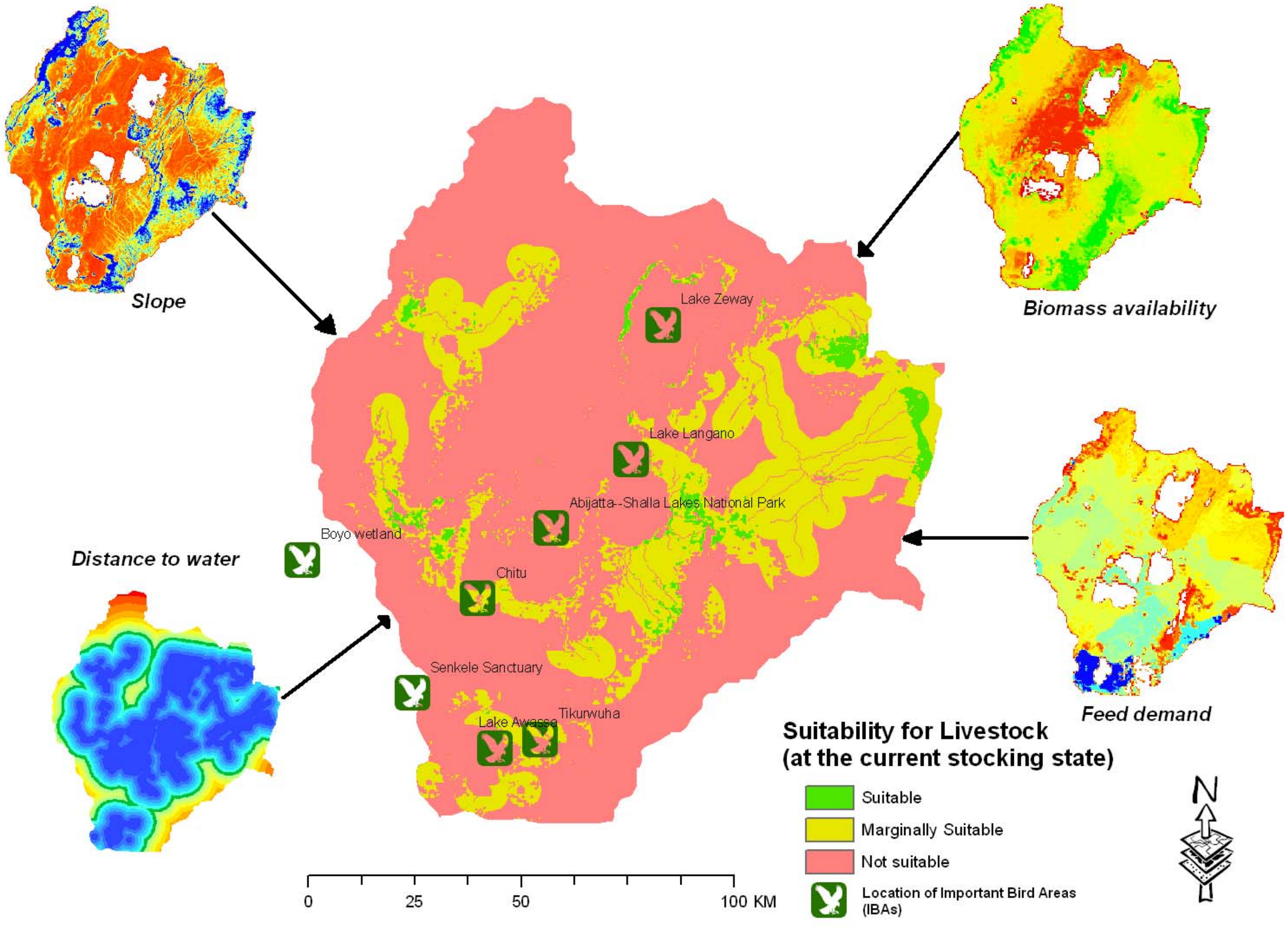


**Fig. 6.5 Land Suitability classes for livestock production and their relative geographical position to IBAs**

### 6.4.4 The State of Other Protected Area Networks

Since all designated protected areas are subjects to uncontrolled grazing, it is essential to understand the capability of the land to support livestock in addition to the herbivore wild animals. Even though performing suitability analysis for all parks, sanctuaries and wildlife reserves in the Rift Valley is not the prime aim of this study, vegetation-based estimations which may give a clue on the state of the protected areas are attempted for all of them.

Nechsar National Park is by far the protected area with richest standing biomass according to this study. During the wet season it has more standing biomass than the surrounding areas while it is also loosing much of it during dry period more than the surrounding. Even during its lowest point it preserves more biomass, which may be converted to herbivores feed (livestock or wildlife) than most of the other parks at their maximum. A maximum standing biomass of 5 tons per hectare has been observed in Nechsar Park, while the other maxima in Senkelle, Awash and ASLNP amounted only to 1.3, 0.33 and 0.42 tons per hectare respectively. However, the monthly biomass productivity of the areas was not as spectacularly different as the standing biomass estimates. For example, the maximum average productivity of Nechsar was 2.4 tons per hectare in May, while the maximum average productivity of ASLNP was 1.3 tons per hectare in August. While most part of the monthly productivities in Nechsar was apparently accumulated in the standing biomass of the succeeding month, a substantial amount of the monthly produced maximum biomass was utilised or removed from the other protected areas.

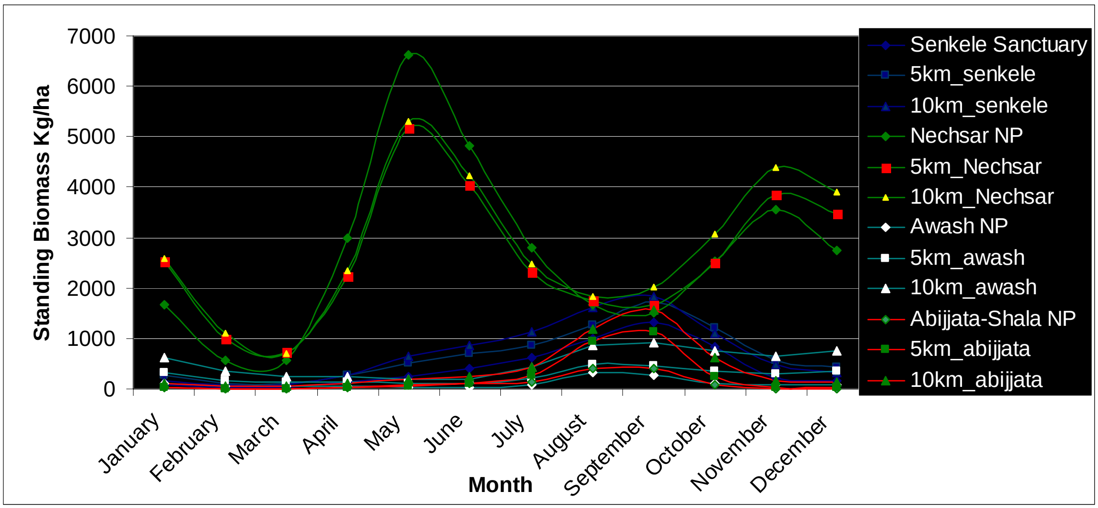


**Fig. 6.6 Monthly standing biomass around selected protected areas, 5 km and 10 km outside the protected areas.**

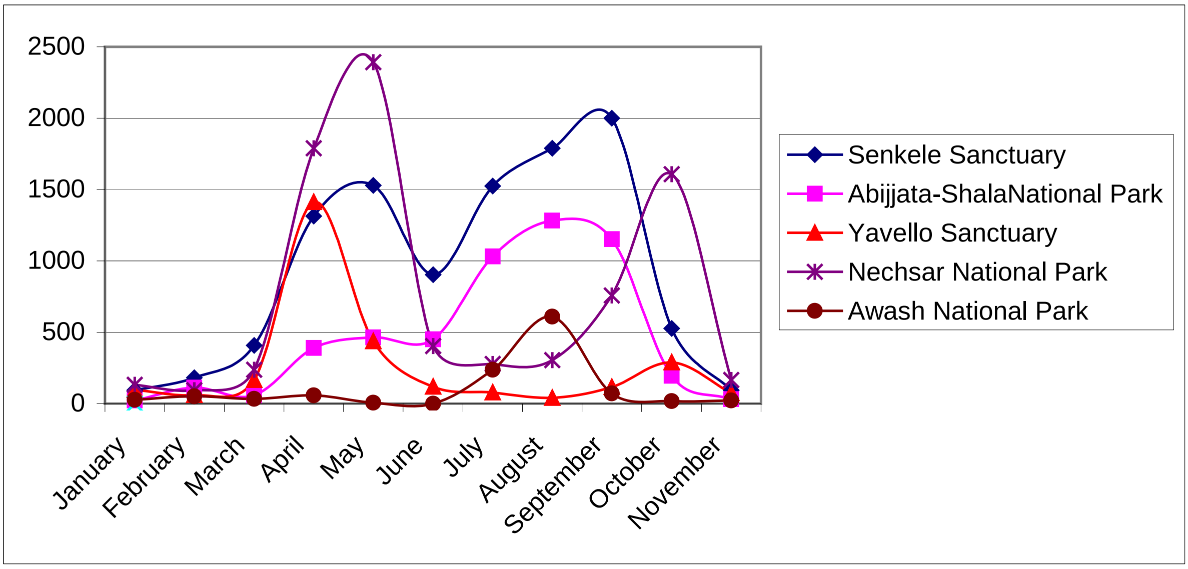


**Fig. 6.7 Monthly NPP around selected protected areas (Kg/ha).**

### 6.4.5 Carrying Capacity of Livestock in and around Protected Areas

The capacity of the investigated areas to support livestock was simply calculated by comparing the monthly available green biomass in the area and the monthly feed requirement in that specific area. The livestock carrying capacity follows a similar pattern of the biomass available in each month, even though the livestock density of each area widely differs. So as to magnify the importance of standing biomass for livestock production, it is assumed that all the green biomass present in the landscape is always accessible and usable for livestock. It is further assumed that it is the only source of livestock feed. Since the Nechsar National Park demonstrates a surplus throughout the year, it is not worth including in this discussion.

In ASLNP and its surroundings the monthly feed supply is inadequate throughout the year. The average deficit ranges from 89 kg/ha in July to 223 kg/ha in March. July is usually the start of the vegetation development phase. However, the density of livestock is so high that even in this month a deficit is unavoidable. Only in August and September is the vegetation level capable of supporting the livestock with natural biomass in the park. It is evident that livestock production cannot depend solely on natural biomass at this rate of stocking.

The area is known for its salty ‘soil’ that is widely used as cattle feed in many part of the country. A portion of the deficit is therefore compensated by such alternatives. This ‘soil’ is extracted from the shore of Lake Abijjata by digging vast tracts of land. These activities attract a large number of people to come to this area daily.

Other parks also have similar problems. For example, the Awash National Park is not sufficiently capable of supporting livestock feed fully even for a single month in the year.

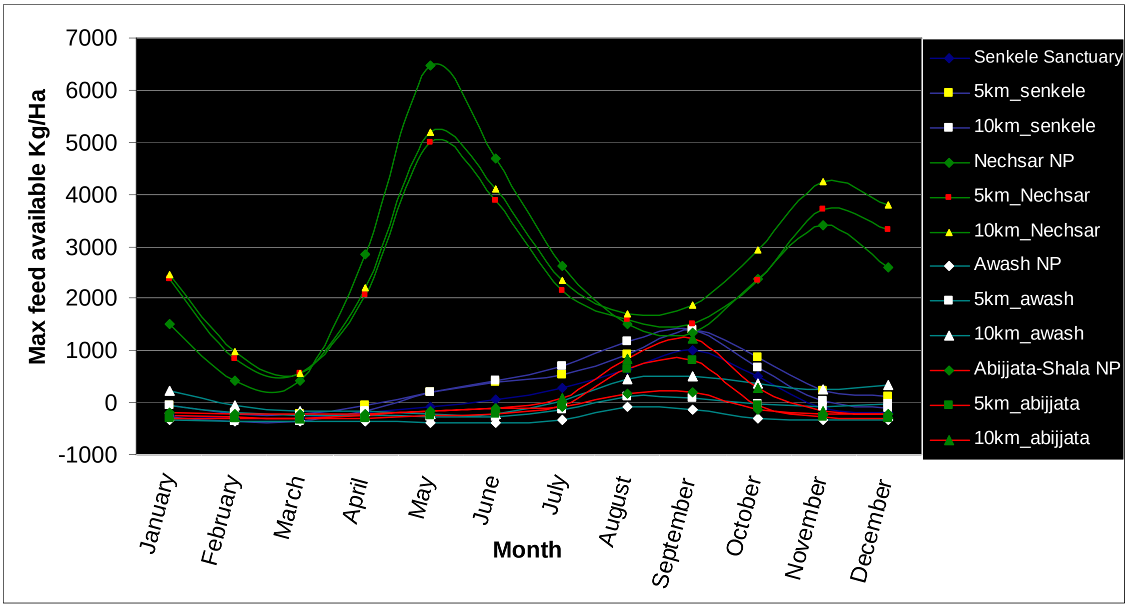


**Fig 6.8 the monthly feed situation in selected protected areas.**

### 6.4.6 Carrying Capacity of Land Cover Classes

It has been demonstrated that in finer spatial scale the dynamics of recent degradation in terms of loss in vegetation cover is lower inside the park than in the surrounding two circumscribing zones. A look at the livestock pressure inside the park throughout the year reveals that, contrary to the surrounding areas, the park is susceptible to high livestock impact especially during rainy seasons. It is not only the low productivity inside the park that creates such significantly lower net livestock feed during rainy seasons, but also due to the fact that a large amount of land outside the park is covered by agricultural crop thereby driving the livestock herders to graze in the park area.

The monthly feed balance inside the park and inside the two selected circumscribing circles has been broken down to each land cover level in order to investigate the susceptibility of specific land cover classes. In all the three spatial entities, open woodlands exhibited lower value of feed balance. As described in section 5.3.5.6, the productivity of open woodlands is not less than most of the other land cover classes. However, even during rainy season the amount of remaining green biomass (after deducting the amount of biomass livestock would consume) is significantly lower than the others. This is a manifestation of targeting this land cover class for grazing during peak agricultural periods. As the distance increases away from the park area, the strength of impact on this land cover class has been observed to decrease.

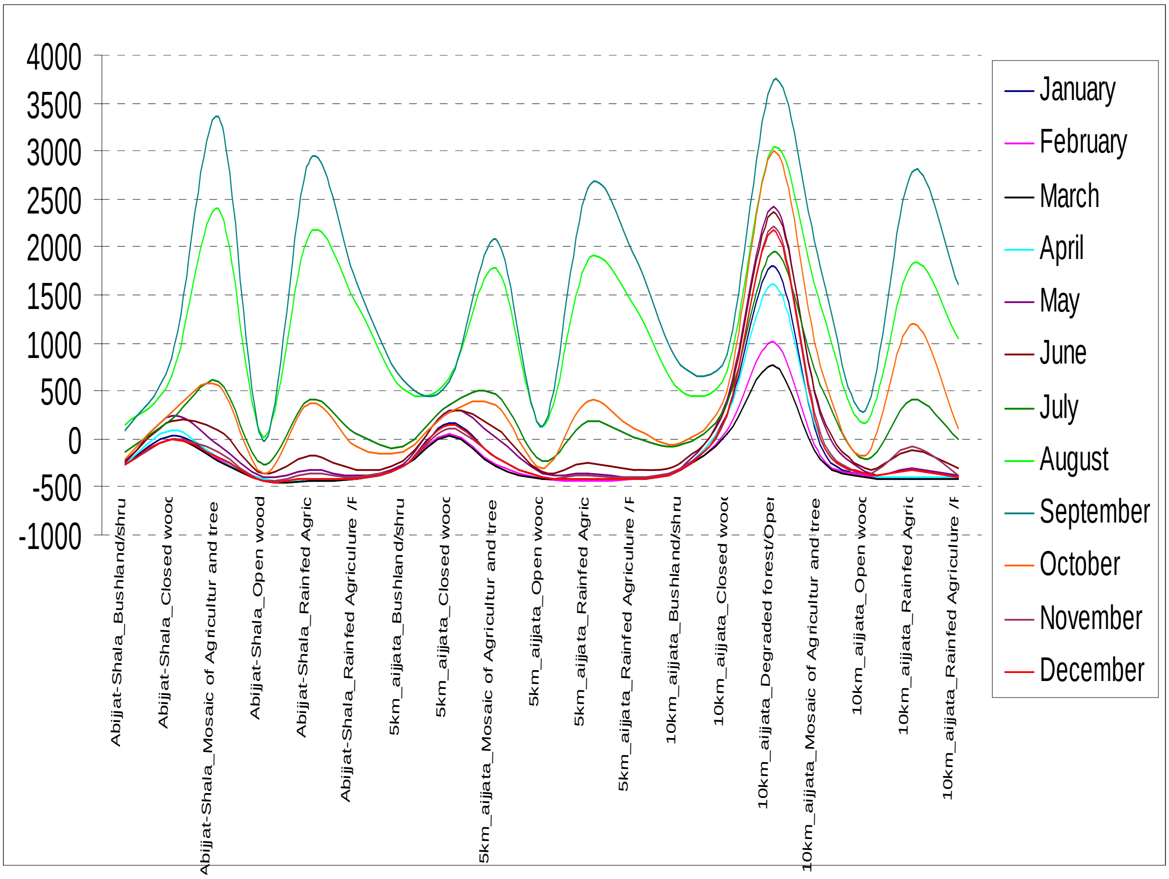


**Fig 6.9 The monthly feed situation within ASLNP in different land cover classes.**

### 6.5 Environmental Implications of Land Cover Changes and Livestock Impact.

Whether it is due to conversion of land to cultivation or due to overgrazing, the removal of vegetation cover reduces protection cover of soil and minimises the regrowth and restocking capacity of vegetation (Zerihun et al 1990). Dregne et al. (1991) believe that overgrazing contributes considerably to desertification and land degradation processes. Indirect effects of livestock density include trampling, which leads to soil compaction and, when excessive along cattle trails, around homesteads and water points, may cause run-off and gully erosion (de Leeuw et al. 2002). In ASLNP and its environs feeding crop residues to livestock, thus depriving the agriculture land of recycling nutrient. This makes the land quickly unproductive and forces farmers to convert more natural areas to agriculture. Zemede (1999) reported that animal feed, comprising chiefly dry crop residues, is traded in markets in the Zeway-Awassa basin. Due to lack of alternative off-farm income generation, cutting acacia trees and charcoal making is consequently practiced even inside the park itself. Such mode of farming practice results in a perpetuating vicious circle that cannot be broken without radical change in socio-economical structure, ecological, technological development or external intervention (Nori et al 1998).

The land cover change induced vicious circle also affects water regimes of an area in a number of ways. Inadequate vegetation cover speeds up sheet and gully erosion. During short and intense flash rains, the torrents carry sediments usually rich in nutrients end up in the lakes, thereby resulting in sedimentation and eutrophication. This phenomenon coupled with decrease in lake size in turn can lead to fish mortality caused by decreased oxygen concentrations, algal blooms and increased alkalinity (Zinabu 1998). Legesse et al (2003) implied that up to 8% increase in discharge could be expected at the outlet of Ketar, one of the two major feeding rivers of Lake Zeway, if the current woody vegetation or grassland were converted to cultivation. However, observations of multi temporal satellite imagery shows that the lake size has been in fact decreasing slightly in recent years even though such conversion is becoming more a norm than an exception. Abstraction of water for commercial agriculture, industries and recently for small-scale cooperatives farms is the main reason for the decrease. The tendency of small-scale irrigation is on the rise as small irrigation is nationally promoted to ensure household food security in rural Ethiopia. A loss in the volume of Lake Zeway means an exponential water recharge loss for Lake Abijjata. Though no significant drop in the overall bird distribution has been observed due to the decrease in lake size, some flagship bird species like Pelicans and much of the aquatic life are reported to disappear from the site (EWNHS 1996 and Fekadu et al. 2002). If an artificial revival of the Lake Abijjata is sought, then raising the water volume of Lake Zeway or compensating the amount of water yearly abstracted with fresh water will be the feasible strategy.

In between the IBA around Lake Zeway and those IBAs around Abijjata, Chitu and Langano stretches the Abernossa Cattle Ranch. Vegetation conditions in the ranch improved dramatically during the first period (1973-1986) and latter stabilized to semi-climax acacia woodland. The ranch is a living example of the potential of natural succession in the area through controlled grazing and reduced human intervention. This is purely human exclusion programme. The social, cultural and economic cost of such intervention would be beyond acceptable limit to the inhabitants and the socio-economic reality of the area, if protected areas followed this suit.

## 6.6 Summary and Discussion

The land use changes and the consequent changes in land cover characteristics in the basin as well as in the park area have left their traces in the form of extensive bare surfaces consisting of subsistence farms. Increasing sedentary agriculture, pushed by the rise in human population, in areas, which have been predominantly used by agro-pastoralists for extensive grazing, is causing land use induced conflicts. Environmental conflicts arise from putting land into uses that are not compatible with its characteristics and beyond the biophysical capability of the land. Cultivation of areas with little and unreliable rainfall and poor soil structure result in poor production that prompts further expansion or crop failures subjecting most of the cultivated land bare for long periods. For many years the communities that inhabit semi-arid areas have depended on semi-pastoralism as the main socio-economic activity. However, the demand for more food and money for purchasing non-food commodities forced these communities to increase their stocks, practice crop production and over harvest trees to produce charcoal for sell. The availability of major roads and nearby markets attracts the local inhabitants to practice charcoal making as an off farm money generation activity. The increasing settlement and the haphazard way of exploiting vegetation resources, which has virtually impacted the whole terrestrial area of the park directly and the aquatic life indirectly, is approaching to a level where reversing it without creating a deep social problem is impossible.

The change in agricultural system does not result in a reduction of livestock. While a general decline in per capita livestock holding is observed, the livestock density increased as the livestock number decrease per household has been offset by an increase in population. As a result the suitable land for livestock production (at the current stocking trend) is highly diminishing. Consequently, more natural and semi natural grasslands have been subjected to overgrazing, soil compaction, and gully erosions. Except for a handful of stranded individuals that occur inside the park administration compound, large mammalian wildlife is virtually missing since the habitat that can support such life was destroyed long ago. Domestic dogs and cats are also playing a role in the food chain of the park through directly taking prey on small rodents and birds as well as scaring away other animals particularly terrestrial birds from the area. This phenomenon holds true in areas considered as IBAs too.

# Chapter 7

# Overall Conclusions, Discussion and Recommendations

## 7.1 Conclusions and Discussion

The application of readily available remote sensing products and GIS analysis systematically demonstrated that the establishment of a park or designating an area as 'ecologically important' does not guarantee that the environmental or biodiversity features within it will be protected. Many critics have claimed that parks cannot continue to protect the biological resources within their borders and there is a widespread sense that these areas are not working (Bruner et al. 2001). The natural and semi-natural ecosystems of the ASLNP and the IBAs in the Zeway-Awassa Basin are subjected to LULC dynamics in the same way as the non-protected part of the landscape. The designation of a park or declaring areas as IBAs has not spared them from the negative impacts induced by land use changes. In the absence of readily usable, detailed and timely spatio-temporal information on the LULC, it is hardly possible to plan and implement mitigation measures at any administration level.

It is a common fact that remote sensing and GIS have been extensively used for LULC information generation for years. However, the technical complexity and associated costs hindered the adoption of this technology and tools in Ethiopia as in many developing countries. The use of low cost remote sensing products for monitoring the vegetation status of the central and southern part of the entire Rift Valley has been demonstrated in this study to emphasize the relevance of low-resolution images for fine scale temporal analysis. In such large areas, it is usually politically appointed administrators that decide the fate of natural ecosystems. More tangible and less complicated remote sensing end products can be one of the tools managers of protected areas might use to win the support of such decision makers. The strategy and method used to extract wide range information ranging from land cover map production to analysis of monthly biomass productivity from the freely available MODIS image can be readily adopted at local and regional level for use in decision making. The models that are presented in section five to successfully estimate standing biomass and monthly NPP in the Rift Valley may be directly used in local condition and even at the country level. The same way, livestock density can be accurately mapped in spatially contiguous raster using these low cost remote sensing products as vital input.

Each of the sub objectives have been dealt with as stipulated by using different optical remote sensing products, active remote sensing data (SRTM), a variety of image enhancement methods and several GIS techniques. The sub objectives are elucidated by the research findings of this study.

***Sub Objective 1***

***Testing efficient satellite image enhancement methods for land cover classification in minimum external input and low cost conditions.***

Understanding the change in natural or semi-natural ecosystems induced by humans, the source of dynamism and the consequence of it on functionality and sustainability are prerequisites for protected area management at local level. The number of people and their livestock number may be counted occasionally. However, their impact in space and time should be adequately known if viable mitigation measures are sought. Long-term information is required to establish these facts. Since 1972 Landsat series data coupled with GIS analysis have been in use by those who have the resource and technical know how. Thanks to concerned organisations and communities, both images and required image data management programmes are becoming increasingly available to the general community. However, image enhancement methods are still time consuming, expensive and sometimes dependant on external inputs. It has been shown in this research that sophisticated and computational intensive radiometric, atmospheric and topographic enhancements are not always necessary or they can reasonably be replaced by fast and manageable techniques. The applicability of image based atmospheric correction without much additional external information (Chavez 1996) has been proved to be better than those of the time consuming and external data dependent techniques such as ELC and MFF. It has been further proved that atmospheric correction can be skipped in this specific research area if the thermal layer is properly used. An easy method to calculate the radiant-temperature-at-sensor (in Celsius) by using only the DN values of the thermal band that is applicable for the entire country has also been developed. It is believed that such simplifications will encourage satellite image users to utilise the entire variability captured in the image. The current practice is to discard the thermal band all together. It is also demonstrated in this research that topographic corrections improve the classification of rugged topographies like the Lake Shala cliffs. However this enhancement should be limited to steep slope areas, as there is the problem of 'overcorrecting' in gentle slope areas. The freely available SRTM data proved to be a valuable input to this effect.

***Sub Objective 2***

***Identifying the land cover/land use change and examining the change dynamics at different scales.***

There was more active land cover change process in the first study period (1973 to 1986) than during the second study period (1986-2000) in the entire Zeway-Awassa basin. In the first period nearly half of the landscape underwent land cover change processes with more than 26% of the entire landscape experiencing forest or land degradation. In the second period the extent of the change process was limited to only 1/3 of the total area with reduced amount of degradation processes than before. This reduction in the degradation process was simply because there was not much left to degrade. The agriculture expansion in fact increased during the second period. However, much of this agricultural expansion took place in areas that had been already degraded from higher vegetation classes in the first analysis period.

One of the strongest attributes of satellite remote sensing is its repeated coverage of the same area at given period. This attribute is however not fully utilized to analyse long-term dynamics of land cover. A new approach that facilitates analysis of the long-term land cover dynamics has been elucidated in this study. Since land cover continuously changes, one-period observation may not be enough to make a sound conclusion. The deforestation process observed in some area will not continue that way because there is no forest for the process to continue. The land will naturally start new process of land cover change. The Expert- Context- Edition suggested and explained in this study could be adopted for multitemporal analysis of land cover changes. The exercise of long-term land cover change analysis was limited to the ASLNP and its immediate surroundings within 10km radius due to data handling limitations. However, the result described in that section is believed to apply comparatively to a wider area with similar environmental and socio-economic backgrounds.

***Sub Objective 3***

***Assessing the status of Livestock feed demand and supply by means of remote sensing and GIS in a fine temporal scale covering the central and southern Ethiopian Rift Valley.***

A change in primary production relates to the food available for humans and other species. Years of low NPP (including agricultural) may lead to extraction of more wood to compensate the agriculture loss by purchasing food and animal feed. Therefore, this information is important for natural resources management and other purposes. The MODIS image-derived parameters coupled with available climate data provided an important means for linking changes in ecosystem condition with implications for spatial and temporal productivity situations. In order to make the metrological data (point data) fit remotely sensed raster data, they must be converted into spatially contiguous surface data. The calendar system of the original data was difficult to understand. A resampling procedure was developed so that the data should fit the normal Gregorian calendar system. Once the monthly raster maps were created, it was possible to prepare site-specific calibration coefficients for use in the productivity estimation. This was also part of the effort to generate information from the usually available climate data and low cost remote sensing products.

As it was described in the fifth chapter, the monthly NPP of the Central Rift Valley was successfully estimated. Remote sensing derived variables were also successfully applied to estimate LAI and standing green biomass. The models may work for other areas too. For example a monthly LAI raster map has been prepared using the models developed in this study for the Nile Basin for use as an input in runoff modelling. The research has not yet been completed, but the LAI input is still being used as an input to represent the temporal vegetation distribution of the area.

The conventional way of monitoring livestock density in GIS entails equal distribution of density per area. However, this is not always the case in landscapes where there are several kinds of land cover classes. This study demonstrated a new way of GIS based livestock density calculation that takes the suitability of land cover classes into account. Together with spatially distributed TLU intake variable, the new way of density calculation resulted in spatially accurate information of feed demand. Finally, the livestock supporting capability of each land cover or ecosystem was determined with better locational accuracy.

***Sub Objective 4***

***Finding out the integrity of terrestrial ecosystems spatially and temporally in Abijjata-Shala Lakes National Park, and the Important Bird Areas in the Zeway-Awassa Basin.***

Migratory and resident birds richness map was made in this study for the first time in order to assess areas of importance. Areas that are rich both in intercontinental migratory birds and resident birds coincide largely with IBAs and designated protected areas in the Rift Valley. However, the role of national parks or reserves as a method of biodiversity conservation begs for a closer look. As the parks and reserves are not single ecological entities or isolated ecosystems by themselves, they pose a series of management problems. The increasing intervention in these already multiple and complex socio-economic problems, makes ill equipped conservation strategies and methods that revolve around the imaginary boundaries of parks useless. This study revealed the rate of degradation processes in the ASLNP is almost three times more than the rate at which the ecosystems replenish themselves naturally. According to de Leeuw (2002) and others, the ecosystem approach is the best way of promoting biological diversity outside the traditional protected areas system. In addition to the strategies described in sections 7.3.1 and 7.3.2, targeting specific ecosystems and designing a program to preserve or restore them is deemed imperative to alleviate the problems in the park and the IBAs.

Since the entire population believes that the future of their livelihood hangs on livestock, it is important to know the suitability of designated protected areas and IBAs for livestock development. Despite the belief of the inhabitants that the area is good for livestock, the Abijjata sub catchment is almost entirely not suitable for productive livestock development at the current productivity and animals stocking rate. Stocking more livestock than the productivity of the area can support is one of the reasons for widespread degradation. Investigation of the impact of livestock further showed that open woodlands, especially in the park, are vulnerable for over grazing throughout the year. It is no wonder that the open woodland land cover along with its ecological system is dwindling through time.

The environmental condition of the Rift Valley does not permit the development of full climax vegetation. The alkalinity of the soil, the erratic pattern of the rainfall and high evapotranspiration are not suitable for such vegetation. The vegetation structure of open or dense woodland, mainly with semi-climax species is well suited. The complete loss of this land cover means the loss of an important natural ecosystem, which may be difficult to replace. Therefore, preserving this ecosystem with the participation of the local inhabitants is one of the key strategies to ensure biodiversity conservation. The park is almost overrun by population. This ecosystem can be saved or restored if and only if the number of people depending on it for charcoal wood is reduced. This is clearly beyond the capability of the park administration. A far fetched solution would be sufficient monitory compensation for those people willing to be relocated elsewhere outside the designated park area.

***Sub Objective 5***

***Identify the underlying and proximate causes of land cover/land use changes, which have been leading to undesirable side effects for nature and biodiversity conservation.***

Loss of the productive ecosystem (natural vegetation) and the growing dehydration of the aquatic ecosystem in the ASLNP are considered the immediate detrimental and observable facts. These phenomena are manifestations of drivers of land use change in a broader scale. Agricultural activities have been found to be the major proximate causes of vegetation cover loss. During the entire study period, agriculture was responsible for the loss of more than 4/5 of the total terrestrial productive ecosystem. More than 37.6% of the total park area has been experiencing this loss for the past 3 decades. The cause of the aquatic ecosystem disturbance (loss of water bodies, increasing alkalinity and loss of fish in Lake Abijjata) is directly related to the water abstraction from the feeding rivers. Low agricultural productivity and loss of harvest due to erratic rain are the main reasons, which are leading to small-scale irrigation in the Lake Zeway sub catchment. The hydrological connection of the two lakes means reduction in the water level of the Lake Zeway has a direct repercussion on the stability of the aquatic system in the other lake.

## 7.2 Limitation of the Study

- ***Insufficient bird data:*** It has been only five years since the bird counting in the IBAs has been commenced by the EWNHS. Long-term data would have given a clear pattern of avian abundance and distribution in relation to the changing environmental and anthropogenic influences. Moreover, the count has been targeting only water birds excluding some of the key land birds that would have explained the impact of changes in terrestrial ecosystems. The exact location of the counting site is not documented. For example the bird count data for Langano does not specifically mention where in Langano area the count has actually been conducted. Langano is a very wide area. The personal opinion of the experts was involved in determining the representative point.
- ***Absence of adequate spatial data on ecologically important areas:*** Most of the designated protected areas and all of the IBAs do not have proper spatial information. The only spatial information about IBAs is the latitude and longitude of the point that is believed to represent the area. This study tried to use some fixed radius to convert the point data into polygon. This kind of polygon fails to represent actual boundaries.

- ***Inventories of ecosystem services could not be done:*** A complete ecosystem inventory was out of the realm of this study. However, it is believed an inventory of ecosystem services would permit a better generalization of the underlying cause for ecosystem changes.
- ***No recent population data*:** The last time Ethiopia had a population census was in 1994. It was not possible to know how many people indeed moved into the park area after that. The frequent change of administration boundaries also affected the use of previous census reports. With authenticated and recent census population data, this research would have benefited more. The same analogy goes to livestock count. It was not possible to find historical livestock data made by a relevant institution.

## 7.3 Recommendations and Outlook for Future Studies

### 7.3.1 Remarks on Strategic Approaches to Save ASLNP

The park has not only been hugely paralysed to function properly for the past three to four decades, but also its own existence is in the verge of peril due to excessive human settlement. Nowadays there is a concerted debate about the role of protected areas for biodiversity conservation and human welfare. The pro human welfare camp advocates that conservation of biodiversities would come automatically from the local inhabitants themselves provided that their living condition is improving (Brockington et al. 2006). They go further to accuse the conservation pro group of disrespecting the humanity of locals in the name of protecting nature. The other groups argue that proper conservation measures would enhance the livelihood of locals without endangering the functioning ecosystems. They assert that national and international protected areas would increase local income if the service these areas are providing to humanity in general were considered and the direct and indirect users were ready to pay (Terborgh et al. 2002). Local inhabitants around and inside designated ‘protected areas’ cannot be asked to scarify their existence so that important ecosystems for biodiversity may be saved for the entire humanity. The people in and around the ASLNP must produce food for themselves and their dependents, they must find a way to get instant cash to pay their non-food needs like education, health and land tax. If the government and international community indeed agree that these places are of national and international importance for biodiversity, then they should be ready to cover the costs of preserving it without deriving the very community who preserved the ecosystem for generations to destitution.

The rural households believe the ASLNP is a suitable place because livestock constitutes the chief principal savings mechanism, power for ploughing, and security for crop failure or emergency cash needs. As long as this perception persists, and it will be there so long as there is household food insecurity and lack of income for non-food expenditure, increase in livestock density per unit of area will be a likely scenario.

Therefore, schemes that boost agriculture productivity and increase household income should be designed and implemented urgently. The ASLNP is a roadside park very near to major markets. There is a comparative advantage for the inhabitants to produce agriculture commodities that are transported only short distances like diary products. If a sustainable programme to boost livestock productivity were initiated, the income would offset the need to cut more wood for charcoal making. Commercial ranching or cooperative dairy systems may be a good beginning. Resort areas surrounding the lakes are prohibiting easy movement for the locals while making huge profits for individuals. Such resorts may have a positive impact from the national tourism point of view. However, the local inhabitants should also benefit from the windfall income that is going elsewhere. It should always be remembered that the geographic source of most of the physical pressures (like water abstraction) and economic pressures (forcing people for more expansion of land and charcoaling) are far from the park itself.

### 7.3.2 Suggestions to Preserve the IBAs

The aquatic ecosystems systems support the bulk of intercontinental migratory species. In the face of a dwindling Lake Abijjata, a possible new water source should be explored. In the past several rainy seasons, the Awash River threatened the Koka Dam and floods the low lying fields causing a major damage and took the lives of several people. If this excess water could be diverted before it reaches Koka Dam into the Lake Zeway sub basin that ultimately finds its way into Lake Abijjata, the huge economic damage and loss of human lives would be avoided at the same time saving the fragile ecosystems in the Zeway-Awassa Basin. The fresh water from the northern highlands would dilute the high alkaline content of the lake and pave the way for more fish development. The increasing water need for irrigation in the basin could also be partially fulfilled along the way. The technical, economical and social aspect of this activity needs deeper investigation, though at the outset it appears feasible.

Integrated watershed management should also be encouraged. Sometimes the local inhabitants are forced to cut trees and make charcoal to generate cash to pay not only their non-food basic needs but also government levied land tax. Instead of pushing the local community that far, the administrators should find a balancing point where the local people may be pardoned from such levies if they demonstrate that they are practicing sustainable land management without harming the general ecosystem of the area. Livelihood improvements undoubtedly encourage the inhabitants to protect the environment their existence hangs on. If there is a political will to practice such encouragement, low cost remote sensing and GIS may be employed to set priority and select targets for special consideration.

### 7.3.3 Institutional Coordination

Agriculture development workers have the duty of ensuring sufficient agricultural production at any cost. The small-scale irrigation projects they are pursuing undoubtedly benefit the poor. However, irrigation should be a complementary activity to natural resources conservation rather than a liability. Increased yield through irrigation (3 to 7 fold in some parts of the country) will alleviate the rapid expansion of cultivation lands. The natural resources conservation community should try to adapt itself to such reality. Finding synergetic solutions that alleviate negative environmental consequences or that encourage positive outcomes for the wider natural environment which at the same time support the national effort to address food security problems of the country should be on the top of natural resources conservationists task list. However, this is a multidisciplinary task that involves several ministerial offices at different administration hierarchy.

### 7.3.4 Limits of Spatial Technology Adoption for Nature Conservation

With increasing availability and access to remotely sensed data and spatial data management software, the limit to adopting the application of low cost remote sensing and GIS appears to be highly technical and institutional. Low level of national capacities to use information and technology transfer currently limits the possible applications of local, regional and international cooperation in nature conservation. Today high-speed communication, reduced legal barriers to geospatial data exchange, reduced data access barriers and frequent updating of spatial data by several providers are making spatial data exchange and cooperation easier. In order to make use of this opportunity by the natural resource conservation community two major activities are suggested:

1. ***Assigning a representative from the environment and biodiversity fields in the national spatial data management agencies:*** The Ethiopian mapping agency is the only capable institute concerning national spatial data management. However, their focus does not transcend much from topographic data production. Therefore, either assigning a person or establishing a unit that oversees the collection, analysis and availability of timely data for natural resources conservation community should be explored.
2. ***Internal capacity building on spatial data collection and management:*** This involves strengthening a spatial data management unit inside the organizations themselves and arranging training for the staffs.

## 7.4 Indications for Further Studies

- ***Strategic plan for biodiversity monitoring in different administrative levels as well as for NGOs**:* The ecosystem and biodiversity service of ASLNP at local, national and international level is known to some extent. A multidisciplinary and full-scale study is required to establish the value of the area firmly. To aid this, a study pertaining periodic inventory and regular monitoring schemes by different actors is urgently required.
- ***Platform for networking parks, reserves, sanctuary management at local and regional officers:*** Due to the federal administrational structure of the country, managements of protected areas are scattered without a sound communication platform. A functioning communication media for experience and data exchange should be encouraged.
- ***Assessing the possible means of diverting water to the Zeway sub catchment:*** The neighbouring Awash River basin is always suffering flooding during rainy seasons. There may be a way to divert this extra water from the River Awash during peak periods into the Zeway sub catchment. This would have a two-pronged benefit, namely: avoiding catastrophic damage from the Awash Basin and alleviating the growing water problem in the other basin. The technical, economic, social and environmental feasibility of this measure needs a detailed study to ensure a sustainable and synergetic solution.

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# Appendices

**Appendix 1 Characteristics of the Satellite Images used**

**a) Characteristics of the Landsat MSS**

| | *Landsats 1-3* | *Wavelength (µm)* | *Nominal Spectral Location* | *Resolution (meters)* |
|---|---|---|---|---|
| *Multispectral Scanner (MSS)* | Band 4 | 0.5-0.6 | Red | 57[12] |
| | Band 5 | 0.6-0.7 | Green | 57 |
| | Band 6 | 0.7-0.8 | IR | 57 |
| | Band 7 | 0.8-1.1 | IR | 57 |

**b) Characteristics of the Landsat Tm and ETM+**

| | *Landsat 5 and 7* | *Wavelength (µm)* | *Nominal Spectral Location* | *Resolution (meters)* |
|---|---|---|---|---|
| *Enhanced Thematic Mapper Plus (ETM+)* | Band 1 | 0.45-0.52 | Blue | 30 |
| | Band 2 | 0.53-0.61 | Red | 30 |
| | Band 3 | 0.63-0.69 | Green | 30 |
| | Band 4 | 0.78-0.90 | IR | 30 |
| | Band 5 | 1.55-1.75 | MIR | 30 |
| | Band 6 | 10.40-12.50 | Thermal-IR | 60 |
| | Band 7 | 2.09-2.35 | MIR | 30 |
| | Band 8 | .52-.90 | Panchromatic | 15 |

**c) Spectral attributes of the MODIS**

| | *Bands* | *Wavelength (µm )* | *Description* |
|---|---|---|---|
| *MODIS Terra* | Band 1 | 0.62-0.67 | Red |
| | Band 2 | 0.841-0.876 | Near-infrared |
| | Band 3 | 0.459-0.479 | Blue |
| | Band 4 | 0.545-0.565 | Green |
| | Band 5 | 1.23-1.25 | Short wave infrared |
| | Band 6 | 1.628-1.652 | Short wave infrared:(similar to Landsat band 5) |
| | Band 7 | 2.105-2.155 | Short wave infrared:(similar to Landsat band 7) |

[12] Resampled to 57 meters by the provider

**Appendix 2 Coefficients for exoatmospheric irradiance for MSS, TM and ETM**

Coefficients of the exoatmospheric irradiance for Landsat ETM+

| Band | 1 | 2 | 3 | 4 | 5 | 7 | 8 |
|---|---|---|---|---|---|---|---|
| Value W/m² SR | 1969 | 1840 | 1551 | 1044 | 225 | 82.07 | |

Coefficients of the exoatmospheric irradiance for Landsat TM

| Band | 1 | 2 | 3 | 4 | 5 | 7 |
|---|---|---|---|---|---|---|
| Value W/m² SR | 1957 | 1829 | 1557 | 1047 | 219.3 | 74.5 |

Coefficients of the exoatmospheric irradiance for Landsat MSS

| MSS on board | Band | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| Landsat1,2 | Value W/m² SR | 1856 | 1559 | 1269 | 906 |
| Landsat 3,4,5 | Value W/m² SR | 1849 | 1595 | 1253 | 870.3 |

**Appendix 3 Field collected LAI and Biomass data**

| sample_ID | Center of the MODIS pixel | | LAI | Standing Biomass (g/m²) | NDVI | NDVI_C | PVC | RSR | SAVI | SR | GREENESS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | X | Y | | | | | | | | | |
| 1 | 462723 | 833636 | 0.75 | 44.00 | 0.50 | 0.29 | 0.49 | 1.76 | 0.33 | 2.97 | 1580.30 |
| 2 | 462723 | 832136 | 0.90 | 72.00 | 0.58 | 0.34 | 0.56 | 2.22 | 0.35 | 3.71 | 1653.21 |
| 3 | 463223 | 832136 | 1.16 | 97.00 | 0.60 | 0.36 | 0.58 | 2.41 | 0.37 | 3.95 | 1790.43 |
| 4 | 463223 | 832636 | 1.19 | 67.00 | 0.57 | 0.34 | 0.56 | 2.20 | 0.36 | 3.66 | 1652.83 |
| 5 | 461723 | 829136 | 0.02 | 0.10 | 0.46 | 0.20 | 0.46 | 1.17 | 0.33 | 2.69 | 1687.74 |
| 6 | 464223 | 841636 | 0.02 | 12.50 | 0.44 | 0.21 | 0.45 | 1.24 | 0.29 | 2.57 | 1273.74 |
| 7 | 464223 | 847136 | 0.41 | 34.00 | 0.50 | 0.26 | 0.50 | 1.56 | 0.35 | 3.02 | 1674.05 |
| 8 | 464223 | 864136 | 0.26 | 12.50 | 0.50 | 0.24 | 0.50 | 1.41 | 0.35 | 3.00 | 1649.12 |
| 9 | 463223 | 834636 | 0.47 | 39.50 | 0.49 | 0.27 | 0.49 | 1.63 | 0.32 | 2.92 | 1432.57 |
| 10 | 463223 | 848636 | 0.60 | 46.00 | 0.57 | 0.34 | 0.56 | 2.19 | 0.36 | 3.68 | 1626.02 |
| 11 | 444223 | 786636 | 0.80 | 90.10 | 0.60 | 0.33 | 0.59 | 2.20 | 0.38 | 4.02 | 1768.38 |
| 12 | 446723 | 791136 | 0.88 | 64.00 | 0.52 | 0.28 | 0.52 | 1.69 | 0.33 | 3.17 | 1439.83 |
| 13 | 463723 | 832136 | 0.88 | 152.00 | 0.51 | 0.30 | 0.51 | 1.80 | 0.35 | 3.11 | 1675.29 |
| 14 | 444723 | 786636 | 0.89 | 111.00 | 0.63 | 0.30 | 0.61 | 2.08 | 0.44 | 4.37 | 2316.54 |
| 15 | 466723 | 867636 | 0.91 | 105.00 | 0.52 | 0.29 | 0.51 | 1.73 | 0.33 | 3.15 | 1477.25 |
| 16 | 461223 | 862636 | 0.98 | 135.00 | 0.55 | 0.35 | 0.54 | 2.19 | 0.31 | 3.47 | 1458.07 |
| 17 | 444723 | 788136 | 0.88 | 98.00 | 0.55 | 0.29 | 0.54 | 1.79 | 0.32 | 3.40 | 1258.04 |
| 18 | 471223 | 890636 | 1.01 | 126.00 | 0.59 | 0.31 | 0.57 | 2.00 | 0.43 | 3.86 | 2186.91 |
| 19 | 461723 | 824636 | 1.02 | 98.00 | 0.54 | 0.33 | 0.53 | 2.03 | 0.32 | 3.31 | 1255.82 |
| 20 | 463223 | 836636 | 1.07 | 167.67 | 0.52 | 0.32 | 0.51 | 1.95 | 0.34 | 3.17 | 1643.04 |
| 21 | 443723 | 785136 | 0.80 | 54.67 | 0.65 | 0.30 | 0.63 | 2.21 | 0.47 | 4.77 | 2486.17 |
| 23 | 445223 | 788636 | 1.42 | 175.00 | 0.61 | 0.35 | 0.60 | 2.35 | 0.38 | 4.17 | 1575.61 |
| 25 | 443223 | 785136 | 1.04 | 126.00 | 0.62 | 0.36 | 0.60 | 2.45 | 0.40 | 4.23 | 1868.70 |
| 26 | 445723 | 789636 | 0.98 | 198.00 | 0.61 | 0.35 | 0.59 | 2.37 | 0.36 | 4.10 | 1533.02 |
| 27 | 461223 | 805136 | 1.88 | 225.00 | 0.63 | 0.39 | 0.61 | 2.72 | 0.39 | 4.33 | 1680.32 |
| 28 | 459723 | 861136 | 1.22 | 255.00 | 0.64 | 0.39 | 0.62 | 2.79 | 0.38 | 4.51 | 1804.49 |
| 29 | 460223 | 856136 | 3.26 | 607.00 | 0.71 | 0.45 | 0.69 | 3.74 | 0.46 | 5.96 | 2224.77 |
| 30 | 463723 | 815636 | 2.55 | 628.00 | 0.67 | 0.41 | 0.65 | 3.12 | 0.43 | 5.03 | 1975.30 |
| 31 | 463223 | 862136 | 1.73 | 531.50 | 0.70 | 0.42 | 0.68 | 3.39 | 0.44 | 5.63 | 2183.64 |
| 32 | 462223 | 850136 | 1.54 | 510.00 | 0.61 | 0.40 | 0.60 | 2.70 | 0.37 | 4.17 | 1635.42 |
| 34 | 461223 | 806136 | 2.78 | 522.00 | 0.69 | 0.43 | 0.67 | 3.38 | 0.47 | 5.44 | 2396.65 |
| 35 | 461723 | 860136 | 2.81 | 636.00 | 0.70 | 0.43 | 0.68 | 3.52 | 0.44 | 5.74 | 2182.48 |
| 37 | 445223 | 788136 | 0.98 | 132.00 | 0.65 | 0.38 | 0.63 | 2.79 | 0.42 | 4.78 | 1978.52 |
| 38 | 446223 | 790136 | 2.40 | 220.00 | 0.67 | 0.41 | 0.65 | 3.13 | 0.43 | 5.05 | 2110.64 |
| 39 | 464223 | 816636 | 2.89 | 428.00 | 0.74 | 0.44 | 0.72 | 4.05 | 0.51 | 6.80 | 3230.15 |
| 41 | 459723 | 856636 | 2.88 | 500.00 | 0.71 | 0.43 | 0.69 | 3.63 | 0.46 | 5.98 | 2950.48 |
| 42 | 460723 | 858136 | 2.02 | 520.00 | 0.73 | 0.45 | 0.71 | 4.04 | 0.47 | 6.52 | 2247.82 |
| 43 | 462723 | 861636 | 2.04 | 490.00 | 0.71 | 0.41 | 0.68 | 3.38 | 0.46 | 5.81 | 2692.14 |
| 44 | 459723 | 860136 | 2.30 | 570.00 | 0.71 | 0.41 | 0.68 | 3.35 | 0.46 | 5.83 | 2309.37 |
| 45 | 460223 | 857136 | 1.32 | 160.00 | 0.71 | 0.45 | 0.68 | 3.71 | 0.44 | 5.83 | 2038.82 |
| 46 | 461223 | 860636 | 2.10 | 690.00 | 0.72 | 0.45 | 0.69 | 3.79 | 0.44 | 6.05 | 2156.71 |
| 47 | 460223 | 855136 | 2.34 | 590.00 | 0.78 | 0.49 | 0.75 | 4.97 | 0.51 | 7.94 | 2597.97 |
| 48 | 446223 | 789136 | 2.84 | 440.00 | 0.76 | 0.50 | 0.74 | 4.84 | 0.52 | 7.46 | 2698.39 |
| 49 | 443723 | 786136 | 3.02 | 745.00 | 0.74 | 0.49 | 0.72 | 4.43 | 0.47 | 6.75 | 2285.96 |

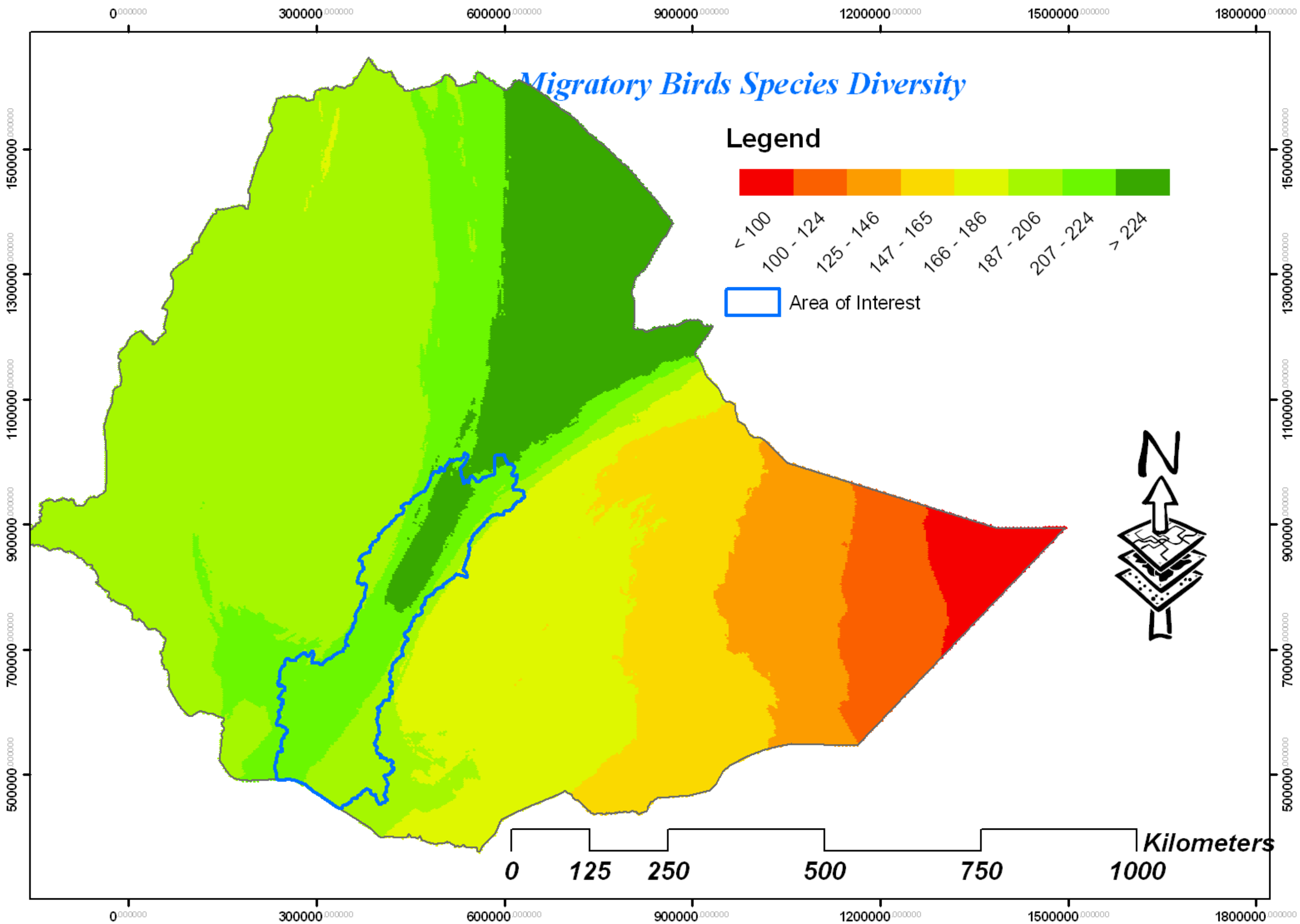
## Appendix 4. Standing biomass in selected land cover classes for each sub basin

| *Standing Biomass* | *kg/ha* | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Land cover clases in sub basins** | **JAN** | **FEB** | **MAR** | **APR** | **MAY** | **JUNE** | **JULY** | **AUG** | **SEPT** | **OCT** | **NOV** | **DEC** | **area(ha)** |
| Abijjata @ Barelands | 86.0 | 50.5 | 55.4 | 149.3 | 276.7 | 443.5 | 821.7 | 1467.7 | 1339.4 | 370.9 | 73.8 | 61.0 | 5756.7 |
| Abijjata @ Bushland/ | 231.4 | 140.9 | 204.9 | 457.0 | 937.6 | 1675.9 | 4517.9 | 14648.2 | 18171.3 | 4217.5 | 465.8 | 333.6 | 33737.7 |
| Abijjata @ Closed wo | 5272.6 | 2721.8 | 2940.0 | 3316.4 | 5780.1 | 8589.9 | 11474.6 | 15725.5 | 15621.4 | 11436.3 | 6508.7 | 6554.1 | 598.8 |
| Abijjata @ Irrigatio | 2362.3 | 1808.4 | 2195.8 | 3918.1 | 4424.0 | 6465.8 | 15880.7 | 32193.9 | 40642.6 | 14190.0 | 3634.9 | 2911.7 | 1033.6 |
| Abijjata @ Mosaic of | 2953.4 | 1918.1 | 1656.1 | 4051.8 | 9074.1 | 12008.5 | 23713.3 | 49277.3 | 47590.0 | 13466.6 | 3374.1 | 3068.8 | 836.1 |
| Abijjata @ Open wood | 380.0 | 240.9 | 314.8 | 759.7 | 1557.3 | 2239.6 | 4934.1 | 12673.7 | 12551.4 | 2967.2 | 471.1 | 428.5 | 62949.0 |
| Abijjata @ Rainfed A | 315.1 | 187.6 | 257.2 | 576.6 | 1251.2 | 2728.8 | 10142.3 | 33007.1 | 37105.6 | 8123.7 | 852.2 | 536.5 | 14667.3 |
| Abijjata @ Urban Are | 127.4 | 85.1 | 148.8 | 385.3 | 617.6 | 1018.5 | 3530.0 | 14029.0 | 13289.7 | 1550.4 | 153.6 | 149.3 | 40.7 |
| Awassa @ Barelands/s | 1.0 | 14.8 | 94.5 | 1048.8 | 1383.0 | 2153.8 | 1422.2 | 14726.9 | 13440.9 | 80.1 | 190.1 | 29.1 | 225.0 |
| Awassa @ Bushland/sh | 542.4 | 387.7 | 671.8 | 1755.5 | 4146.5 | 7464.2 | 11681.6 | 17470.5 | 24070.6 | 12640.8 | 2166.5 | 986.6 | 1621.5 |
| Awassa @ Closed wood | 6132.6 | 3820.8 | 4195.2 | 8799.3 | 15032.1 | 17398.0 | 15877.0 | 18052.1 | 22698.7 | 19056.6 | 10326.5 | 8470.7 | 5545.6 |
| Awassa @ Mosaic of A | 11134.0 | 5862.3 | 7795.2 | 23364.5 | 42629.8 | 46315.9 | 42648.6 | 57672.9 | 70034.0 | 55089.1 | 28926.6 | 19939.0 | 33743.4 |
| Awassa @ Open woodla | 1941.3 | 1112.8 | 1372.6 | 4470.3 | 8853.2 | 11192.5 | 12854.2 | 17156.5 | 24064.9 | 15663.4 | 4797.3 | 3149.0 | 8580.7 |
| Awassa @ Rainfed Agr | 1103.5 | 764.0 | 1085.8 | 3312.3 | 6959.7 | 13631.8 | 29052.8 | 53211.0 | 58904.8 | 28167.2 | 6048.3 | 2501.4 | 16567.9 |
| Awassa @ Urban Areas | 1435.2 | 1179.0 | 1684.3 | 5071.8 | 8005.7 | 8111.2 | 11686.1 | 17912.0 | 19298.1 | 10270.9 | 3423.7 | 1910.6 | 1575.0 |
| Langano @ Barelands/ | 62.9 | 38.5 | 35.4 | 80.2 | 254.2 | 364.3 | 977.1 | 3163.0 | 2975.9 | 635.3 | 105.9 | 112.8 | 2325.0 |
| Langano @ Bushland/s | 327.6 | 201.7 | 261.2 | 632.5 | 1427.0 | 1932.6 | 5051.3 | 17167.6 | 20982.3 | 7037.9 | 1076.1 | 631.0 | 11605.2 |
| Langano @ Closed woo | 5704.3 | 3494.0 | 4241.8 | 7883.2 | 13246.2 | 9898.5 | 8327.9 | 14946.5 | 24406.7 | 22345.8 | 13621.8 | 9895.0 | 9482.8 |
| Langano @ Mosaic of | 8886.7 | 4017.2 | 5476.9 | 15204.2 | 33664.4 | 20268.2 | 16739.4 | 35558.2 | 63234.1 | 80487.3 | 56507.1 | 30814.6 | 49960.2 |
| Langano @ Open woodl | 1026.7 | 588.2 | 820.7 | 1962.4 | 3673.6 | 3788.2 | 5612.7 | 13413.5 | 17961.2 | 10208.6 | 3391.5 | 2104.2 | 29034.7 |
| Langano @ Rainfed Ag | 3088.3 | 1730.5 | 1926.5 | 4050.6 | 8628.7 | 7242.3 | 13473.6 | 45501.6 | 68442.1 | 47128.8 | 17774.6 | 8599.9 | 46387.6 |
| Shala @ Barelands/sa | 140.0 | 112.5 | 123.0 | 195.3 | 302.7 | 413.3 | 585.2 | 688.9 | 550.1 | 197.6 | 71.6 | 89.2 | 2369.1 |
| Shala @ Bushland/shr | 582.0 | 391.9 | 520.6 | 1076.3 | 1894.6 | 3119.9 | 6419.4 | 20464.3 | 37633.6 | 14807.2 | 1972.3 | 970.5 | 52867.2 |
| Shala @ Closed woodl | 5241.1 | 3608.8 | 4707.8 | 9025.0 | 16094.4 | 11191.6 | 11787.2 | 24280.4 | 32692.1 | 21197.3 | 7943.6 | 6095.2 | 14423.1 |
| Shala @ Mosaic of Ag | 9307.2 | 4607.0 | 6597.1 | 17339.6 | 38003.8 | 31776.7 | 29693.1 | 49132.0 | 66371.4 | 62770.6 | 41249.6 | 25779.0 | 59596.2 |
| Shala @ Open woodlan | 1059.3 | 766.4 | 948.9 | 1971.6 | 4414.2 | 5223.9 | 6944.2 | 14723.8 | 22032.7 | 10687.3 | 2279.2 | 1372.9 | 103039.6 |
| Shala @ Rainfed Agri | 942.2 | 539.5 | 722.9 | 1928.3 | 5767.3 | 9422.4 | 15453.4 | 36161.7 | 56425.5 | 29830.4 | 7767.0 | 3236.1 | 99326.5 |
| Shala @ Urban Areas | 957.9 | 701.6 | 1237.3 | 3081.4 | 10253.8 | 10027.4 | 6731.6 | 12239.5 | 23031.7 | 12925.3 | 2754.8 | 1435.9 | 937.5 |
| Zeway @ Barelands/sa | 261.9 | 153.9 | 161.2 | 270.8 | 344.2 | 448.5 | 675.8 | 1608.6 | 1644.2 | 648.6 | 312.8 | 294.9 | 3721.7 |
| Zeway @ Bushland/shr | 388.6 | 221.7 | 384.6 | 880.4 | 1542.0 | 1836.6 | 4104.0 | 19272.6 | 34626.1 | 14828.2 | 3818.8 | 1468.5 | 74648.9 |
| Zeway @ Closed woodl | 7251.1 | 4802.9 | 5488.8 | 8846.8 | 14201.7 | 8382.8 | 5932.4 | 13377.6 | 27138.1 | 24657.4 | 16176.1 | 11942.1 | 56801.3 |
| Zeway @ Mosaic of Ag | 7726.4 | 5047.8 | 6146.0 | 11883.6 | 19448.3 | 14025.0 | 14807.6 | 36563.9 | 62431.8 | 47338.4 | 22051.2 | 14241.0 | 109705.2 |
| Zeway @ Open woodlan | 1016.5 | 611.4 | 851.8 | 1767.4 | 2820.0 | 2604.9 | 4270.9 | 15004.4 | 25416.1 | 13930.2 | 4814.5 | 2435.2 | 135789.9 |
| Zeway @ Rainfed Agri | 1626.8 | 933.5 | 1356.4 | 3750.1 | 8030.6 | 9535.4 | 17936.6 | 55696.1 | 81353.1 | 43338.2 | 11645.4 | 4816.0 | 265556.4 |

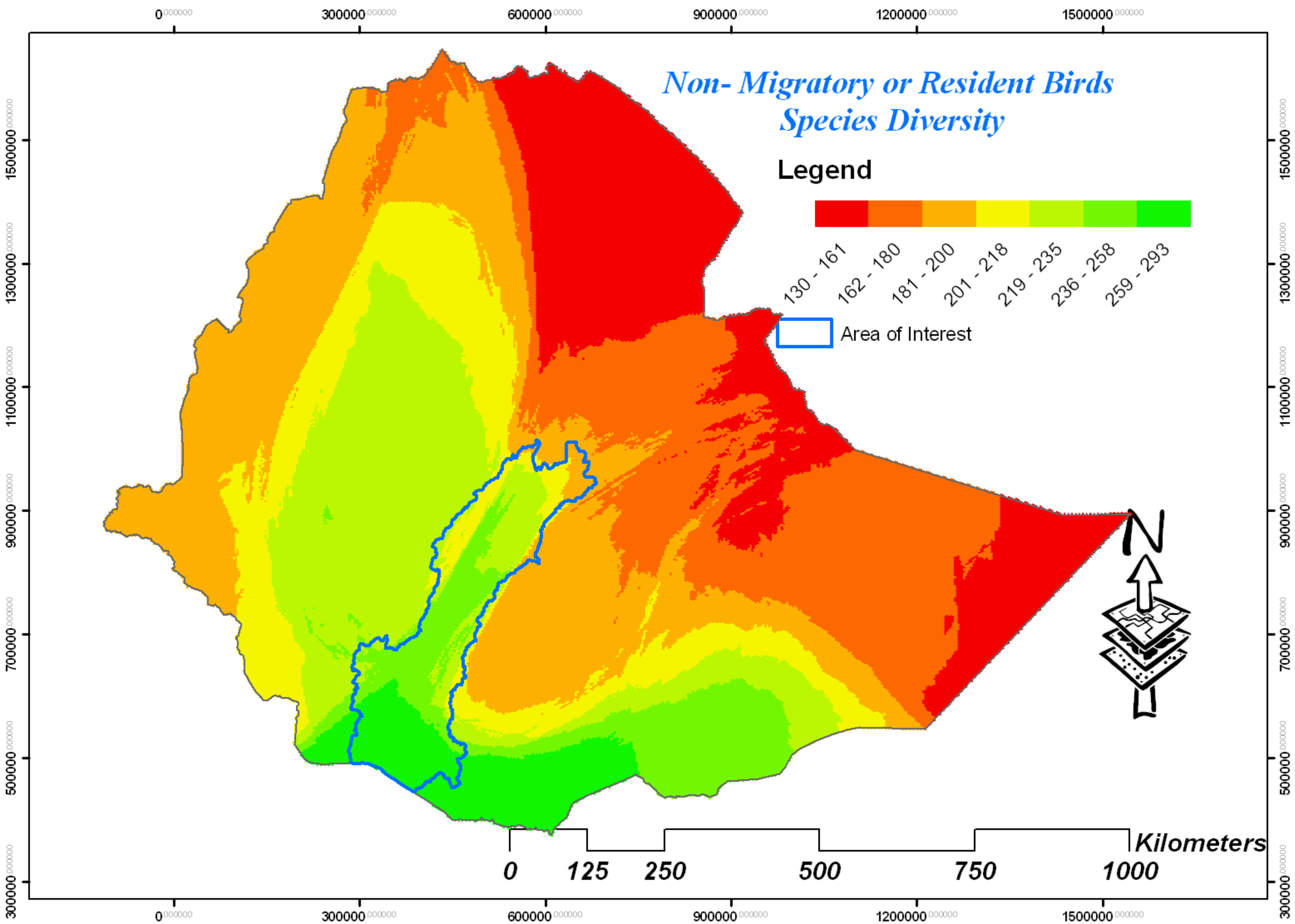
## Appendix 5 Estimated average NPP in selected LULC in each sub catchments (Kg/ha)

| *sublandcov* | *JAN* | *FEB* | *MAR* | *APR* | *MAY* | *JUNE* | *JULY* | *AUG* | *SEPT* | *OCT* | *NOV* | *DEC* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Abijjata @ Barelands | 0.0 | 0.0 | 0.0 | 69.0 | 96.9 | 120.0 | 531.9 | 645.6 | 561.6 | 51.6 | 0.0 | 0.0 |
| Abijjata @ Bushland/ | 15.0 | 12.0 | 29.5 | 140.2 | 172.5 | 201.6 | 908.8 | 1294.0 | 1125.5 | 133.7 | 23.0 | 17.0 |
| Abijjata @ Closed wo | 100.1 | 110.7 | 157.6 | 314.1 | 306.1 | 282.4 | 1630.8 | 1750.4 | 1424.9 | 299.3 | 141.6 | 117.6 |
| Abijjata @ Irrigatio | 79.5 | 155.2 | 211.7 | 459.9 | 309.9 | 398.3 | 1827.6 | 2170.5 | 1169.3 | 273.6 | 97.7 | 85.0 |
| Abijjata @ Lakes | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Abijjata @ Mosaic of | 78.4 | 124.1 | 172.7 | 598.6 | 591.4 | 483.0 | 1968.9 | 2352.0 | 2022.7 | 288.7 | 87.8 | 70.0 |
| Abijjata @ Open wood | 27.9 | 34.5 | 60.6 | 217.6 | 246.1 | 259.9 | 1133.6 | 1530.9 | 1225.0 | 165.7 | 36.7 | 29.9 |
| Abijjata @ Rainfed A | 25.4 | 26.9 | 56.8 | 183.0 | 203.1 | 245.1 | 1423.8 | 2034.3 | 1791.3 | 225.4 | 49.5 | 35.8 |
| Abijjata @ Urban Are | 13.2 | 22.3 | 45.9 | 223.0 | 142.0 | 239.4 | 998.1 | 1578.2 | 729.8 | 112.7 | 19.8 | 17.9 |
| Awassa @ Barelands/s | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Awassa @ Bushland/sh | 51.1 | 60.2 | 152.2 | 573.4 | 1037.6 | 978.6 | 1418.4 | 1873.5 | 1955.5 | 476.7 | 92.0 | 53.5 |
| Awassa @ Closed Fore | 279.5 | 489.6 | 1710.9 | 2795.4 | 2445.5 | 2082.3 | 2071.6 | 2493.4 | 2715.9 | 1447.1 | 500.8 | 256.2 |
| Awassa @ Closed wood | 131.8 | 181.8 | 369.4 | 1160.5 | 1668.2 | 1309.7 | 1419.0 | 1613.3 | 1760.2 | 561.3 | 170.4 | 114.2 |
| Awassa @ Degraded fo | 241.3 | 410.3 | 1419.2 | 2537.7 | 2655.8 | 2126.9 | 1966.0 | 2396.9 | 2674.5 | 1212.8 | 423.8 | 220.3 |
| Awassa @ Mosaic of A | 161.2 | 242.8 | 693.4 | 1787.8 | 2389.2 | 2031.5 | 2033.8 | 2345.6 | 2486.7 | 869.3 | 270.9 | 152.4 |
| Awassa @ Open woodla | 84.9 | 119.4 | 298.5 | 977.2 | 1445.6 | 1238.7 | 1407.2 | 1671.5 | 1853.9 | 578.7 | 145.2 | 82.2 |
| Awassa @ Rainfed Agr | 64.3 | 91.5 | 246.4 | 837.4 | 1245.4 | 1309.2 | 1772.4 | 2249.9 | 2350.8 | 670.1 | 150.5 | 72.0 |
| Awassa @ Urban Areas | 65.5 | 95.0 | 190.9 | 847.1 | 1414.1 | 1063.5 | 1408.8 | 1742.1 | 1777.0 | 456.0 | 107.4 | 62.1 |
| Langano @ Bushland/s | 14.0 | 15.9 | 49.7 | 180.2 | 370.6 | 444.9 | 844.3 | 1291.2 | 1228.0 | 263.1 | 30.5 | 21.5 |
| Langano @ Closed For | 417.8 | 1188.1 | 1943.2 | 2804.8 | 2517.6 | 1655.3 | 1317.2 | 1696.8 | 2016.5 | 1029.0 | 390.5 | 252.9 |
| Langano @ Closed woo | 150.7 | 269.8 | 619.5 | 977.3 | 1181.1 | 1007.1 | 912.5 | 1172.1 | 1417.6 | 482.1 | 153.3 | 114.3 |
| Langano @ Degraded f | 325.4 | 839.1 | 1543.4 | 2461.3 | 2246.7 | 1643.2 | 1284.6 | 1652.3 | 1965.6 | 1008.8 | 365.6 | 221.8 |
| Langano @ Mosaic of | 198.7 | 409.2 | 959.9 | 1773.8 | 1857.7 | 1561.2 | 1214.6 | 1613.7 | 2048.5 | 979.5 | 298.3 | 173.2 |
| Langano @ Open woodl | 72.8 | 147.7 | 368.3 | 720.1 | 879.8 | 817.6 | 925.1 | 1282.5 | 1400.8 | 474.4 | 93.4 | 61.0 |
| Langano @ Rainfed Ag | 104.6 | 231.2 | 473.6 | 899.7 | 1082.0 | 1024.4 | 1295.2 | 1948.8 | 2184.2 | 743.7 | 179.6 | 93.8 |
| Langano @ Urban Area | 189.5 | 494.8 | 1239.2 | 1871.7 | 2098.3 | 1557.6 | 1161.4 | 1488.6 | 1843.4 | 1029.7 | 223.2 | 137.9 |
| Shala @ Barelands/sa | 14.0 | 18.9 | 20.8 | 99.3 | 145.7 | 134.1 | 386.9 | 418.8 | 325.1 | 34.2 | -1.8 | 0.7 |
| Shala @ Bushland/shr | 51.6 | 123.5 | 250.8 | 598.1 | 619.6 | 406.2 | 1086.3 | 1596.8 | 1829.1 | 282.8 | 86.5 | 45.9 |
| Shala @ Closed Fores | 268.0 | 524.8 | 1981.4 | 2644.6 | 1567.9 | 1965.0 | 1892.3 | 2203.3 | 2405.5 | 1636.6 | 604.2 | 261.2 |
| Shala @ Closed woodl | 152.4 | 292.9 | 834.9 | 1598.1 | 1467.7 | 902.2 | 1367.5 | 1760.9 | 1891.4 | 305.8 | 140.4 | 118.6 |
| Shala @ Degraded for | 240.7 | 491.6 | 1415.8 | 2381.4 | 1469.8 | 1528.0 | 1504.7 | 1921.2 | 2154.7 | 1254.3 | 512.3 | 234.3 |
| Shala @ Mosaic of Ag | 166.6 | 303.9 | 976.3 | 1837.2 | 1505.0 | 1428.0 | 1638.9 | 2052.8 | 2308.0 | 875.6 | 328.1 | 167.4 |
| Shala @ Open woodland | 71.0 | 159.2 | 350.7 | 825.1 | 897.8 | 640.2 | 1162.6 | 1524.2 | 1681.6 | 301.8 | 91.9 | 57.3 |
| Shala @ Rainfed Agri | 66.7 | 155.3 | 237.4 | 664.1 | 737.1 | 755.2 | 1436.4 | 2026.9 | 2281.6 | 444.4 | 135.2 | 63.9 |
| Shala @ Urban Areas | 76.1 | 218.9 | 237.4 | 756.1 | 833.1 | 920.0 | 1154.6 | 1460.3 | 1752.6 | 386.6 | 121.1 | 55.6 |
| Zeway @ Barelands/sa | 8.4 | 10.0 | 19.2 | 132.1 | 121.4 | 191.1 | 451.0 | 634.0 | 478.8 | 44.7 | 10.0 | 9.3 |
| Zeway @ Bushland/shr | 30.5 | 38.7 | 171.0 | 345.0 | 362.9 | 434.2 | 839.4 | 1447.7 | 1376.1 | 203.8 | 52.1 | 35.8 |
| Zeway @ Closed Fores | 267.3 | 411.9 | 647.7 | 1143.5 | 1083.3 | 1369.0 | 2003.0 | 2296.7 | 1636.2 | 447.1 | 245.9 | 211.5 |
| Zeway @ Closed woodl | 166.1 | 285.7 | 976.0 | 1189.3 | 1305.3 | 1065.2 | 902.2 | 1230.2 | 1486.0 | 479.4 | 173.7 | 128.3 |
| Zeway @ Degraded for | 255.6 | 299.3 | 1626.4 | 2215.4 | 1928.1 | 1610.4 | 1559.3 | 1943.0 | 2268.2 | 336.1 | 202.9 | 218.5 |
| Zeway @ Irrigation | 98.4 | 181.0 | 234.8 | 721.6 | 306.5 | 656.9 | 1584.6 | 2158.9 | 1589.7 | 274.8 | 118.3 | 95.8 |
| Zeway @ Mosaic of Ag | 158.5 | 211.8 | 959.4 | 1293.8 | 1372.6 | 1255.4 | 1248.0 | 1685.2 | 1872.0 | 357.2 | 157.8 | 137.1 |
| Zeway @ Open woodlan | 57.1 | 78.9 | 320.8 | 534.1 | 550.5 | 580.2 | 953.4 | 1493.5 | 1414.8 | 233.2 | 74.9 | 57.4 |
| Zeway @ Rainfed Agri | 74.9 | 94.5 | 402.2 | 691.0 | 955.5 | 1025.6 | 1207.4 | 1872.0 | 1911.8 | 391.7 | 117.2 | 76.5 |
| Zeway @ Urban Areas | 77.6 | 143.3 | 426.2 | 803.0 | 794.8 | 742.6 | 1178.1 | 1495.8 | 1117.2 | 255.4 | 87.7 | 65.9 |

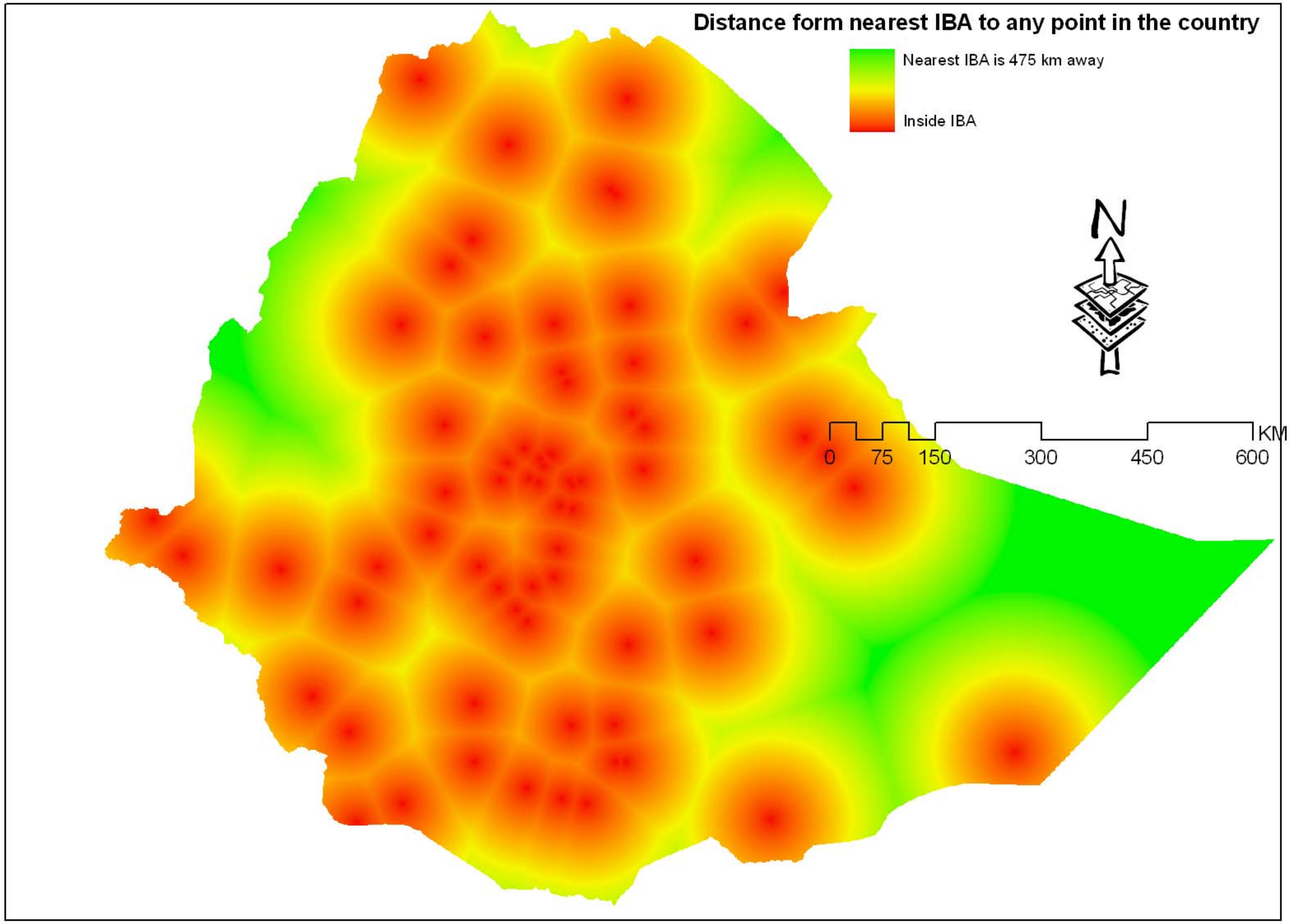
**Appendix 6 Map of Migratory bird species diversity in Ethiopia**



**Appendix 7 Map of Non-Migratory bird species diversity in Ethiopia**



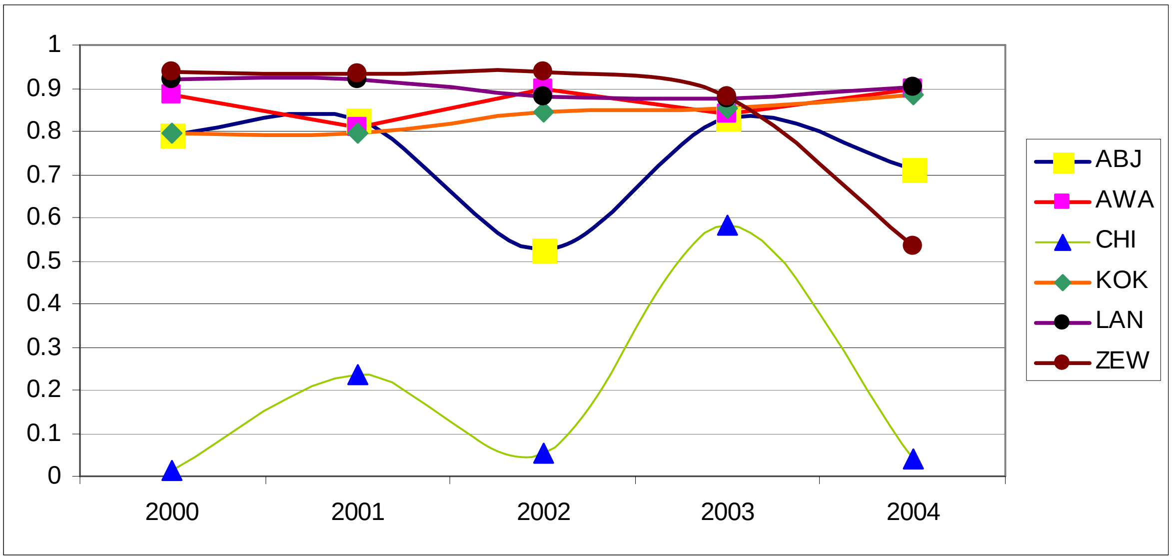
**Appendix 8 Map of Distance from IBAs**



## Appendix 9 Consistently counted species in ASNP, Chitu and Langano

| *Code* | *Common Name* | *Code* | *Common Name* |
|---|---|---|---|
| 1 | Wattled Ibis | 29 | Pink-backed Pelican |
| 2 | Three-banded Plover | 30 | Common Sandpiper |
| 3 | Yellow-billed Duck | 31 | Tufted Duck |
| 4 | Crowned Plover | 32 | Greenshank |
| 5 | Green Sandpiper | 33 | Grey Heron |
| 6 | Hamerkop | 34 | Marsh Sandpiper |
| 7 | Common Snipe | 35 | Black-tailed Godwit |
| 8 | Hottentot Teal | 36 | Marabou Stork |
| 9 | Glossy Ibis | 37 | Ringed Plover |
| 10 | Saddle-billed Stork | 38 | Black-headed Gull |
| 11 | Goliath Heron | 39 | Sacred Ibis |
| 12 | Pintail | 40 | Grey-headed Gull |
| 13 | European Marsh Harrier | 41 | Egyptian Goose |
| 14 | Yellow-billed Egret | 42 | Cape Teal |
| 15 | Little Ringed Plover | 43 | Gull-billed Tern |
| 16 | Spur-winged Goose | 44 | White Pelican |
| 17 | Black-headed Heron | 45 | Spur-winged Plover |
| 18 | Common Pratincole | 46 | Great Cormorant |
| 19 | Yellow-billed stork | 47 | Black-winged Stilt |
| 20 | Great White Egret | 48 | Kittlitz's Plover |
| 21 | Dunlin | 49 | Northern Shoveler |
| 22 | Wood Sandpiper | 50 | Avocet |
| 23 | Squacco Heron | 51 | Little Grebe |
| 24 | Reed Cormorant | 52 | Greater Flamingo |
| 25 | Red-billed Teal | 53 | Little Stint |
| 26 | Red-knobbed Coot | 54 | Ruff |
| 27 | Little Egret | 55 | Whiskered Tern |
| 28 | Cattle Egret | 56 | Lesser Flamingo |

**Appendix 10 Simpsons diversity : Probability of finding two individuals belonging to different species in space and time.**




| | |
|---|---|
| ABJ | Abijjata Shala |
| AWA | Awassa |
| CHI | Chitu |
| KOK | Koka |
| LAN | Langano |
| ZEW | Zeway |

**Appendix 11 Soil Unit in the study area**

| SOIL UNIT | *Central and Southern Rift Valley* | | *Zeway_Awassa Basin* | | *Abijjata-Shala Lakes NP plus 10 km surrounding* | |
|---|---|---|---|---|---|---|
| | Area ($KM^2$) | % of Total | Area ($KM^2$) | % of Total | Area ($KM^2$) | % of Total |
| Calcaric Cambisols | 505.0 | 0.7 | | | | |
| Calcaric fluvisols | 12.3 | 0.0 | | | | |
| Calcaric Regosols | 40.8 | 0.1 | | | | |
| Chromic Cambisols | 3952.9 | 5.2 | | | | |
| Chromic Luvisols | 9218.5 | 12.0 | 1745.1 | 11.2 | 294.7 | 11.8 |
| Dystric Leptosols | 407.4 | 0.5 | | | | |
| Eutric Cambisols | 4788.8 | 6.2 | 1668.9 | 10.7 | 239.5 | 9.6 |
| Eutric fluvisols | 7498.0 | 9.8 | 564.9 | 3.6 | | |
| Eutric Leptosols | 4652.9 | 6.1 | | | | |
| Eutric Vertisols | 14101.5 | 18.4 | 3504.6 | 22.5 | 113.6 | 4.6 |
| Haplic Calcisols | 970.6 | 1.3 | | | | |
| Haplic Luvisols | 2023.3 | 2.6 | 1022.3 | 6.5 | | |
| Haplic Phaeozems | 115.9 | 0.2 | | | | |
| Haplic Solonchaks | 206.6 | 0.3 | 206.6 | 1.3 | 206.6 | 8.3 |
| Humic Alisols | 1981.7 | 2.6 | | | | |
| Humic Nitosols | 2952.5 | 3.8 | 440.8 | 2.8 | | |
| Lithic Leptosols | 9051.2 | 11.8 | 735.3 | 4.7 | 3.7 | 0.1 |
| Luvic Phaeozems | 1588.9 | 2.1 | 670.7 | 4.3 | | |
| Mollic Andosols | 2904.1 | 3.8 | 1175.9 | 7.5 | 193.7 | 7.8 |
| Petric Gypsisols | 429.8 | 0.6 | | | | |
| Solonetz | 51.6 | 0.1 | | | | |
| Covered by Swamp | 555.6 | 0.7 | 155.9 | 1.0 | | |
| Vertic Cambisols | 1680.7 | 2.2 | 235.1 | 1.5 | | |
| Vitric Andosols | 3855.6 | 5.0 | 2263.8 | 14.5 | 843.8 | 33.9 |
| Covered by Water | 3155.3 | 4.1 | 1218.1 | 7.8 | 596.3 | 23.9 |

**Appendix 12 Soil Type in the study area**

| SOIL TYPE | *Central and Southern Rift Valley* | | *Zeway-Awassa Basin* | | *Abijjata-Shala Lakes NP plus 10 km surrounding* | |
|---|---|---|---|---|---|---|
| | Area(km²) | % of Total | Area(km²) | % of Total | Area(km²) | % of Total |
| Alisols | 1981.7 | 2.6 | | | | |
| Andosols | 6759.7 | 8.8 | 3439.7 | 22.0 | 1037.5 | 41.6 |
| Calcisols | 970.6 | 1.3 | | | | |
| Cambisols | 10927.4 | 14.2 | 1904.1 | 12.2 | 239.5 | 9.6 |
| fluvisols | 7510.3 | 9.8 | 564.9 | 3.6 | | |
| Gypsisols | 429.8 | 0.6 | | | | |
| Leptosols | 14111.6 | 18.4 | 735.3 | 4.7 | 3.7 | 0.1 |
| Luvisols | 11241.8 | 14.7 | 2767.4 | 17.7 | 294.7 | 11.8 |
| Nitosols | 2952.5 | 3.8 | 440.8 | 2.8 | | |
| Phaeozems | 1704.9 | 2.2 | 670.7 | 4.3 | | |
| Regosols | 40.8 | 0.1 | | | | |
| Solonchaks | 206.6 | 0.3 | 206.6 | 1.3 | 206.6 | 8.3 |
| Solonetz | 51.6 | 0.1 | | | | |
| Swamp | 555.6 | 0.7 | 155.9 | 1.0 | | |
| Vertisols | 14101.5 | 18.4 | 3504.6 | 22.5 | 113.6 | 4.6 |
| Covered by Water | 3155.3 | 4.1 | 1218.1 | 7.8 | 596.3 | 23.9 |